PRINCIPIUM

The Initiative and Institute for Interstellar Studies | Issue 44 | February 2024

SCIENTIA AD SIDERA | KNOWLEDGE TO THE STARS

ISSN 2397-9127 i4is.org

EDITORIAL

Welcome to issue 44 of Principium, the quarterly magazine of i4is, the Initiative and Institute for Interstellar Studies. Our Lead Feature is *Hazards of Interstellar Propulsion* by David Gahan. Both laser and fusion propulsion involve hazardous amounts of energy which will need careful management.
We have our concluding reports on items from the International Astronautical Congress, IAC2023. Also five pages of Interstellar News and four pages of our regular summary of relevant peer-reviewed papers in *The Journal of the British Interplanetary Society* (JBIS) and *Acta Astronautica*.
The major i4is news is *NASA NIAC funds swarming study* - a study by Space Initiatives Inc and i4is.
We feature *The First European Interstellar Symposium* planned for December this year, more about the *2024 World Science Fiction Convention - Glasgow*, *Define AGI! Levels of AGI: Operationalizing Progress on the Path to AGI*, *SETI Institute announces Breakthrough Listen funding*, our second *IAC 2023: The Interstellar Presentations* and two more reports from IRG23. We have a Letter to the Editor, correcting an error in one of our earlier IRG23 reports. Letters are always welcome. Send them to either John or Patrick as listed at the end of this editorial.

The front cover image is by Michel Lamontagne imagining the deployment probes envisaged in i4is work supported by Breakthrough Starshot reported in *News Feature: i4is delivers Communications Study to Breakthrough Starshot* in Principium 41, May 2023. The rear cover image, also by Michel, visualises an Icarus Firefly fusion probe. More about both in *Cover Images* inside the rear cover.
As always we have the i4is members' page and our regular call to action, *Become an i4is member*.
Next time, P45 in May 2024, aims to deliver the postponed survey of *Current FTL Thinking* by Dr Dan Fries and a postponed book review - *Contact with Extraterrestrial Intelligence and Human Law - The applicability of rules of war and human rights* by Professor Michael Bohlander of Durham University. We will have *Doubling Human Lifespan - implications for the interstellar enterprise* and the usual Interstellar News and journal reports.
More details on P45 in *Next Issue* at the end of P44.
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 25.

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

MEMBERSHIP OF i4is

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

Members have access to:
- **Networking:** i4is.org/members/networking-opportunities
- **Principium preprints:** i4is.org/members/preprints
- **Videos:** i4is.org/videos

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

KEEP IN TOUCH!

Join the conversation by following i4is on our Facebook page www.facebook.com/InterstellarInstitute

Become part of our professional network on LinkedIn www.linkedin.com/groups/4640147

Follow us on X (Twitter) at **@I4Interstellar**

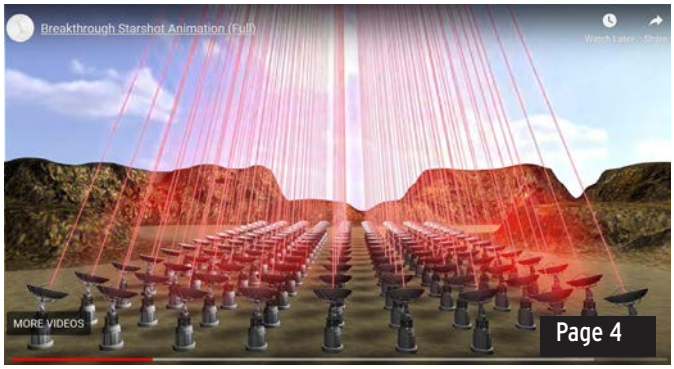
And seek out our followers too!

Contact us on email via info@i4is.org

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

CONTENTS

LEAD FEATURE



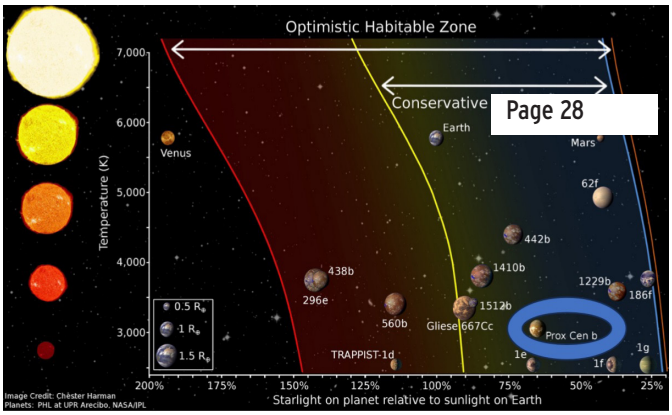
FEATURE

NEWS FEATURES

NIAC
NASA Innovative Advanced Concepts

Page 14

INTERSTELLAR NEWS



REGULARS

Hazards of Interstellar Propulsion

Would you want a 100 GW beamer in your back yard or a fusion rocket anywhere close to Earth?

David F Gahan

Both of the most feasible means of interstellar travel involve enormous powers. Project Starshot and earlier proposals suggest laser beamers with powers of hundreds of GigaWatts (GW) - see work by Professor Philip Lubin [1], i4is projects Dragonfly and Andromeda [2].
The Daedalus study and its successors, the Icarus studies, notably Firefly, which have been most recently reported in Principium 43 *BIS Symposium brings Project Icarus to a close* (i4is.org/principium-43/), require fusion rockets releasing enormous energies from their 'exhausts'.
In this article David F Gahan examines the 'close to home' physics and engineering consequences implied by these two routes to the stars. If we don't get these right then we are not going!
More about David Gahan in Principium 43 November 2023 page 13. See also his article *AMiTe Treffpunkt in* Principium *32*.

The Icarus Firefly probe
Project Icarus was a series of studies aiming to build on the BIS Project Daedalus work in the 1970s. Rob Swinney, i4is Deputy Executive Director acted as Project Manager. The Firefly design is the most mature result of the Icarus programme. One of the design leaders, Michel Lamontagne, has produced a number of visualisations. An early design appeared on the rear cover of Principium 41, May 2023. This has three larger fin-like radiators sized for a D-D reaction rather than He3. It is assembled in LEO ready to be taken to a safer distance for launch.

[1] *A Roadmap to Interstellar Flight*, arxiv.org/abs/1604.01356
[2] *Dragonfly: Sail to the Stars*, www.researchgate.net/publication/317491721_Dragonfly_Sail_to_the_Stars,

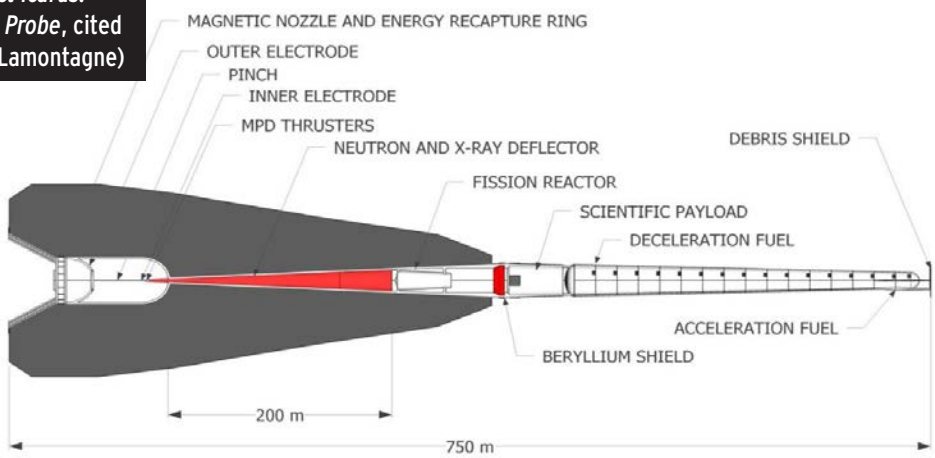
An engineer (ing director) would want to know more about that interesting expression '**Would you want?'**; what is the figure-of-merit for 'want', and more especially its converse 'not want'. What counts as a 'hazard', and what as an engineering or economic challenge? Australians don't currently want the Commonwealth Games in their back-yard, but that's mostly a matter of *'moolah'*. While we can forward to a time when an advanced robotically effected design/construction facility doesn't actually impinge on the 'human economy', that currently seems far away. So, for 'close-to-present', we should consider how to minimize constructional and operational costs and also any environmental penalties needing 'clean-up' costs. But are there any clear and present dangers in the physics of operation?

Here's a fun calculation. In $E = \frac{1}{2}mv^2$, put m = 1 kg and v = 10% c (3×10^7 m/s). 1 kg of mass needs 450 Terajoules (at perfectly impossible efficiency) to reach 0.1 c, which would need the entire electric generating capacity of the USA operating for at least 500 seconds for each measly kilogramme accelerated. Whether you put energy in via a heavy onboard system or from an external source pressing on the craft you're going to need lots of it and had better not stand too close to the exhaust or in the beam.

For both the main current studied concepts for interstellar propulsion, current fusion development seems to offer the most secure route to the prodigious energies required, either on board or by a beamer connected to a fusion power grid. However, space based solar may have a role here especially in a reconfigurable mode, supplying power to otherwise remote places for relatively short periods (beamer launch campaigns or fusion fuel production) before reconfiguring for general grid supply to population centres. This could lower capital costs by avoiding 'stranded assets'.

Let's talk fusion rockets such as *Project Icarus: Designing a Fusion Powered Interstellar Probe* (zenodo.org/record/3747274/files/AF12.2020.47.pdf). The Icarus team worked hard to update the visionary thinking of BIS Daedalus, helped by some recent progress on alternative ways to achieve fusion ignition and maintenance or repetition of 'burn'. In the far future, with full solar-system resources at our disposal, there could be a Helium3 economy in the outer planets and, hey, it would make sense to launch starships from there (and maybe make some energy economies by a swing round Jupiter). But the Icarus team sensibly focused for the next hundred years on D-D fusion, ie deuterium fuel, and that means seawater-sourced and starship launch from the Earth-Moon system.

There's a great storyboard by Michel Lamontagne, one of the Icarus principals, on a mission scenario in "Flight of the Firefly": (www.deviantart.com/michel-lamontagne/gallery/84479459/flight-of-the-firefly). The 800 m long Firefly – see below for diagram from the project read-out - is built in 500 km LEO (compare ISS at 405 km).



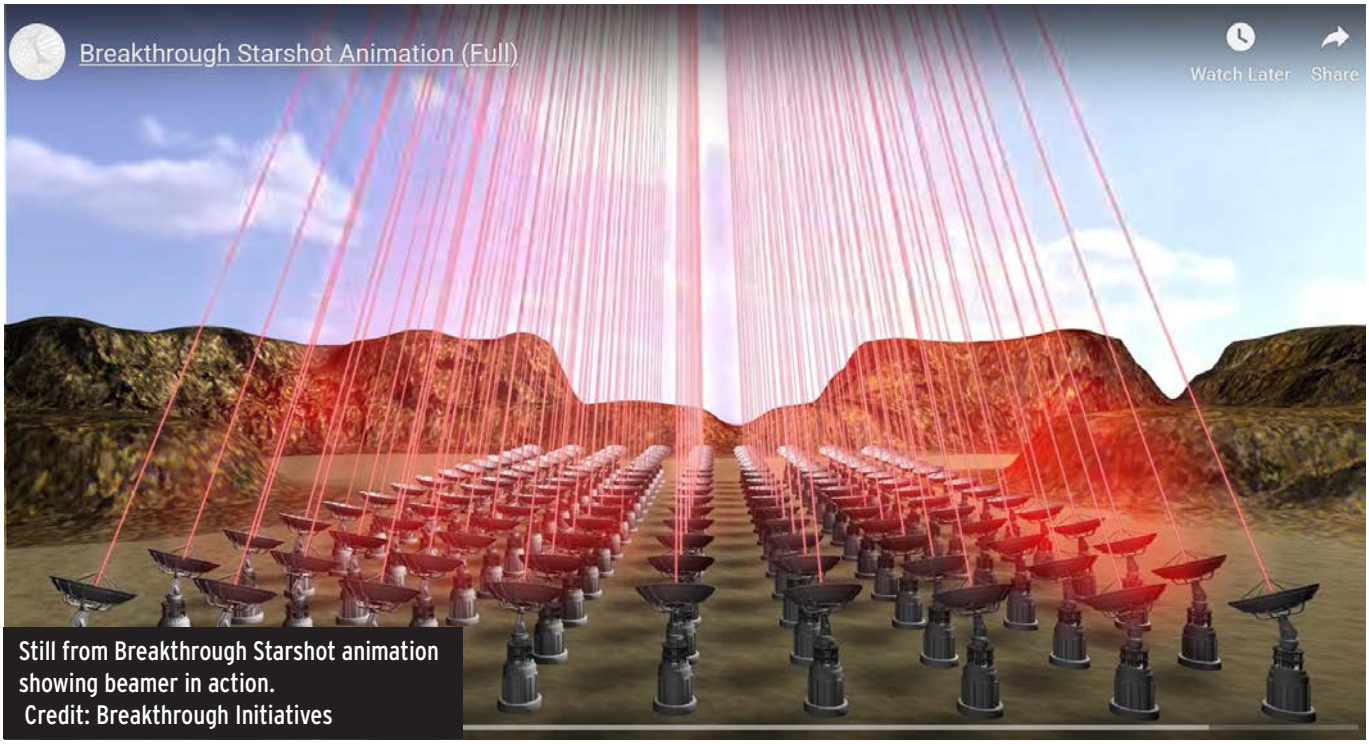
Outline schematic of Firefly from *Project Icarus: Designing a Fusion Powered Interstellar Probe*, cited above, figure 2. (Image credit: Michel Lamontagne)

The deuterium fuel it requires is put at 18,000 tons and the dry mass is 2,500 tons, although there's a total mass given in the document of 24 k ton. Spaceship and fuel are united at the 'high orbit fuel depot' at the gravitationally stable L5 (trailing) point of the Earth-Moon system. This is expensive in extra energy to reach and to establish fuelling infrastructure (needing a space-station?). Is it needed?
Deuterium fusion releases almost half of its energy in the form of high-energy neutrons, and the high densities and temperatures in the 'Z-pinch' drive region yield significant X-ray radiation. This is a challenge for ship design, ie to prevent radiation damage to the ship's functionality and gives rise to the elegant dart shape (long and thin) incorporating shielding for both species of radiation. There's a good discussion of this in the document. But does it cause hazards to Earth or to other space hardware, eg necessitating the 'expensive' L5 Launch option?
At first glance, the Earth's atmosphere should be sufficient to stop/absorb both X-Ray and neutrons and prevent direct effects at ground level. The linear absorption coefficient for 14 MeV neutrons (produced by an 'unwanted' side-reaction) gives a 1/e length of around 100 m at STP, plenty enough through the entire atmosphere. Atmospheric Nuclear Effects [1] gives the 'stopping altitude' for prompt neutrons as 25 km (see also Wikipedia which gives the 'effective radius of a neutron bomb' as 1-2 km. For X-Rays, [1] gives stopping distance as 80 km: an x-ray photon passing through the atmosphere will encounter as many atoms as it would in passing through a 5 metre thick wall of concrete. However, total radiated energies are large. Operating the Firefly's 13 TW drive for 100 seconds burns through as much energy as is yielded from a 300 kT nuclear weapon, so atmospheric ionisation would be expected which would cause local interference with GPS signals due to signal attenuation.
But the more significant problem would be with other LEO and even geostationary satellites. There's no attenuation in free space apart from the inverse-square law so a high dose of radiation would be received, not to mention the blinding of any Earth-observation satellites by the intense black-body radiation of the 'naked' Z-pinch reaction zone. And exposure times are long due to the low acceleration: just 0.003 g (divide 600 kN thrust by 20 thousand tonnes). The ship will take 2 days to reach the moon's orbit and a week to achieve Solar System escape velocity and 10 years to achieve 4.7% c. So, in your backyard (LEO)? – maybe No, but the L5 launch point does look a reasonable option for a ship using Earth-sourced nuclear propellants. We'd still get a good look as it boosted away, about as bright as Mars for several days; and maybe a similar colour owing to its great orange-hot glowing radiator fins (hence: 'Firefly').
However, it's worth including in the energy budget the cost of launching maybe 30,000 tons of spacecraft, constructors, propellant and L5 space-station. A SpaceX Starship [2] is capable of lifting 100-150 tons to LEO or 27 tons to Geosynchronous transfer, and, 'fully refueled' (ie extra launches) 100 tons to the Moon/L5. We'd need of the order of 500-1,000 Starship launches.
The vast energy requirements per kilogramme for getting to an appreciable fraction of c was a strong incentive for the Breakthrough Starshot approach of reducing probe mass to a bare minimum by using ground-based energy to transfer momentum via powerful lasers. For estimating hazards, here are some of the 'must haves' from Breakthrough Starshot - Wikipedia [3] sites:

- Building a ground-based kilometre-scale multi-laser phased array beamer at high altitude in dry conditions.
- Generating and storing a few gigawatt hours of energy per launch (later amended to about 1 TJ energy delivered to each ~5 m diameter sail, with total laser power 100 GW for 600 seconds per individual craft)
- Launching a 'mothership' carrying thousands of miniature probes to a high-altitude orbit.
- Taking advantage of adaptive optics technology in real time to compensate for atmospheric effects.
- Focusing the light beam on the lightsail to accelerate the individual probes to the target speed within minutes.

[1] *Atmospheric Nuclear Effects*, Professor David Jenn faculty.nps.edu/jenn/EC3630/AtmNucEffects(v1.3).pdf
[2] en.wikipedia.org/wiki/SpaceX_Starship
[3] en.wikipedia.org/wiki/Breakthrough_Starshot and Breakthrough Initiatives breakthroughinitiatives.org/concept/3

A word about the 'kilometre-scale' bit. This spatial scale is absolutely necessary (for beam diffraction reasons) to be able to hit a 5 m diameter target with 'only' 98% energy missing target as distances approach 20 million km, the far end of the 100 km/s^2 acceleration phase (at which nominal velocity is 0.2 c). It also requires the individual emitters to be connected by optical fibres to maintain phase stability so as 'to act as one' over a 1 km spread, and to have well-nigh perfect adaptive optics correction for atmospheric turbulence (for exactly the same reason). Luckily they are all pointing at Proxima Centauri, which is bright enough (just) to act as a 'guide star' and give a common reference for the adaptive optics algorithms.



Still from Breakthrough Starshot animation showing beamer in action.
Credit: Breakthrough Initiatives

The point about turbulence and adaptive optics jives with the project's requirement for a beamer 'at high altitude in dry conditions'. Proxima/Alpha Centauri are at -62° declination which demands the Southern Hemisphere for an Earth-based beamer. Eyes tend to stray towards Antarctica for high'n'dry conditions. It would be great but... would take a vast industrial effort in a pristine wilderness, not least to deal with a 100 GW of waste heat. High power lasers are at best 50% Wall Plug efficient [1] for over 1,000 launches at 600 seconds.

That would create a hazard in itself, and would need bare rock foundations to avoid 'that sinking feeling'. But at least there aren't many aircraft overflying the dangerous beams.
The Southern Hemisphere has some experience in building Square Kilometre Array (SKA) - Wikipedia [2], now enjoying excellent radio spectrum views of our galaxy's central black hole (radio telescopes don't need 'dry' conditions, viz Jodrell Bank, which is actually the base of operations for SKA). But the Meerkat National Park - Wikipedia [3] (30deg South), home of the South African station of SKA does look pretty dry and is above 1,000 metres altitude (if the contour colours in my old Times atlas are accurate - couldn't find a spot-height). One imagines that the radio-astronomers don't take kindly to overflights by aircraft and have things well-sorted with the authorities, so the Cape-Town/London route won't be an issue. Other 'high places' might include La Silla Observatory - Wikipedia [4], the southernmost of the ESO sites in Chile, at 29° South. At least a scientific infrastructure is already in place, including the world's best practical expertise in adaptive optics, so relevant early experiments eg on beam forming can be performed.

[1] www.ipgphotonics.com/en_uploads/widget/widget_item_pdf_907.pdf?_=4187811544
[2] en.wikipedia.org/wiki/Square_Kilometre_Array
[3] en.wikipedia.org/wiki/Meerkat_National_Park
[4] en.wikipedia.org/wiki/La_Silla_Observatory

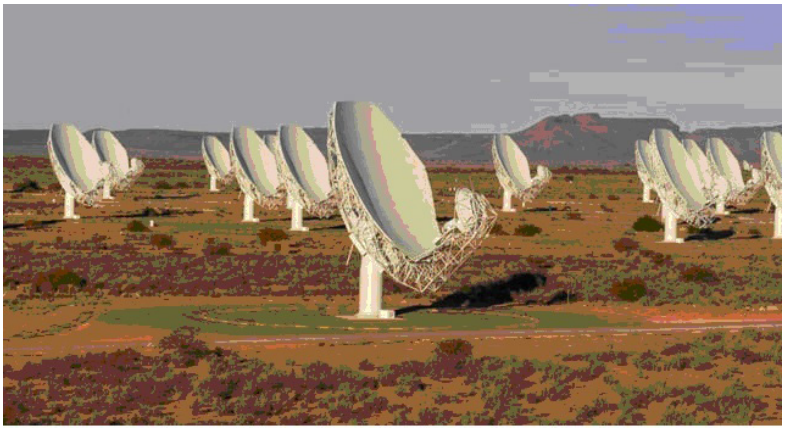
High, but lonely places still exhibit the dilemma concerning what to do about the enormous power (and waste-heat, overlook that aspect at your peril!) needs for what is an essentially one-off launch program. 100 GW of electricity production is greater than the UK's 2016 total (see World electricity production [1]) but we more likely need 200 GW of raw power at 50% laser efficiency, if not more. That's a lot of power stations, usually situated by the sea or on rivers for waste-heat rejection as demanded by the laws of thermodynamics. So, lots of long power lines.

To reduce the demands on raw power production, energy storage in the form of enormous flywheels (en.wikipedia.org/wiki/Flywheel_energy_storage) would be the best answer. Those at the Joint European Torus can deliver (each) 3.75 GJ at up to 400 MW, so, about 10 seconds to discharge. We would need 60 for 600 seconds discharge at @400 MW, or 3,000 for 100 GW laser power for 600 seconds @50% efficiency. Again, a lot of real estate is needed just for the flywheels which argues against a mountain site but at least the flywheels could charge up, serially, from a continent wide supergrid. For beamers at 30 deg South (South Africa or Chile), Proxima/Alpha Centauri wouldn't always be at appropriate altitude for beaming since, clearly, we want to go through the minimum of atmosphere. But maybe that's not so bad if we need to limit launches to one per night to avoid the lights going out. However, disposing of 60 TJ of waste heat (that 50% efficiency loss has to go somewhere) and keep the lasers from blowing up - for each and every launch. This would seem to be a huge local problem for the semi-desert Northern Cape. That's

An artist's impression of the future SKA-Mid site in South Africa. Ultimately, 197 dishes will be erected.
Credit (image and caption): SKAO

enough energy, per launch, to raise from 20°C temperature to boiling point a cube of water 56 m on a side. Which seems pretty onerous for the local environment and water supply. New thinking in heat transport and novel methods of recovery and dissipation would be required, since it can't just be radiated in vacuo like 'Firefly'.

Engineering is often a matter of constraints and sometimes the 'gotchas' can produce new approaches. The numbers used here are all based on published mission parameters but these can maybe be refined and new concepts emerge. At present we'd probably none of us want to get too close to a star-drive, or have one in our back-yard. But, by considering initially non-obvious aspects such as hazards and cooling we might come up with new solutions.



Meerkat Radio Telescope Array, South Africa, maximum baseline 8 km, 64 dishes.
Credit: JoburgBBC

[1] www.cia.gov/the-world-factbook/about/archives/2021/field/electricity-installed-generating-capacity/country-comparison

Letter to the Editor

IRG23: Development of a Model Framework for Examining Language and Cultural Issues in Human Starfaring Civilizations

James C Bennett

In our last issue we reported the work of James C Bennett (www.linkedin.com/in/james-c-bennett-343b371/) from IRG23 [1]. My report confused the effects of hibernation for an interstellar mission with the effects of relativistic time dilation. Here is his correction, which we present with our apologies.

Dear John

I wanted to say that I appreciated the summaries of the presentations at ISC8 [IRG23] in Montreal. Hopefully it will stimulate more people to look up the full papers when available. Two clarifications on my presentation: The "compression" referred to for starfarers in torpor was not that due to relativistic time dilation, but merely referred to the percentage of time a traveller might spend in torpor compared to normal states. The fastest speed I considered was 30% of light speed, which is not enough to experience relativistic dilation sufficient for humans to notice. It will, however, affect timekeeping for very precise purposes such as interstellar coordination of computation. The other point was when I said that we are, schematically, about at the same point in developing star travel as we were in developing Lunar travel in 1920. What I meant by "schematically" was that, like Goddard, Von Braun, and Korolev, we now can posit the means of travel and know that they don't violate the laws of physics, but we can't actually draw a production-ready blueprint of such a device, nor write a Statement of Work that a builder could execute. How many years it will be until that can happen depends on both progress in technology and on world events driving the massive investments such work would require. In our history, World War Two and the "wonder weapon" strategy of Germany led to massive investment of resources and high priorities placed in the V-2, which certainly advanced rocketry by at least a decade or two, if not more, than might have been the case without a war. Not being a prophet I can't say how many years it would be before Starwisp or some such craft might be launched. I doubt it would be as soon as 40, but who can tell?

Regards, James

Principium welcomes letters from researchers (as here), engineers, scientists and our wider readership.
Email John I Davies, Editor, john.davies@i4is.org or Patrick Mahon, Deputy Editor, patrick.mahon@i4is.org

[1] *Development of a Model Framework for Examining Language and Cultural Issues in Human Starfaring Civilizations* - report in Principium 43, IRG23: The Summaries - page 5 - i4is.org/principium-43/

The First European Interstellar Symposium

Building Our Home Among the Stars

John I Davies

In our two previous issues, P42 (i4is.org/principium-42/) and P43 (i4is.org/principium-43/) we featured reports of presentations and papers at the IRG23 Symposium held at McGill University, Montreal. The programme is at irg.space/irg-2023/ with videos via the IRG channel [1].

In this issue we have a final set of News Features reporting on IRG23.

We now look forward to this year's interstellar symposium - the *First European Interstellar Symposium* irg.space/first-european-interstellar-symposium/ to be held at the European Convention Center in Luxembourg City, Luxembourg in December 2024. As in Montreal this symposium will feature many of the leading voices in space exploration, culture, and more.

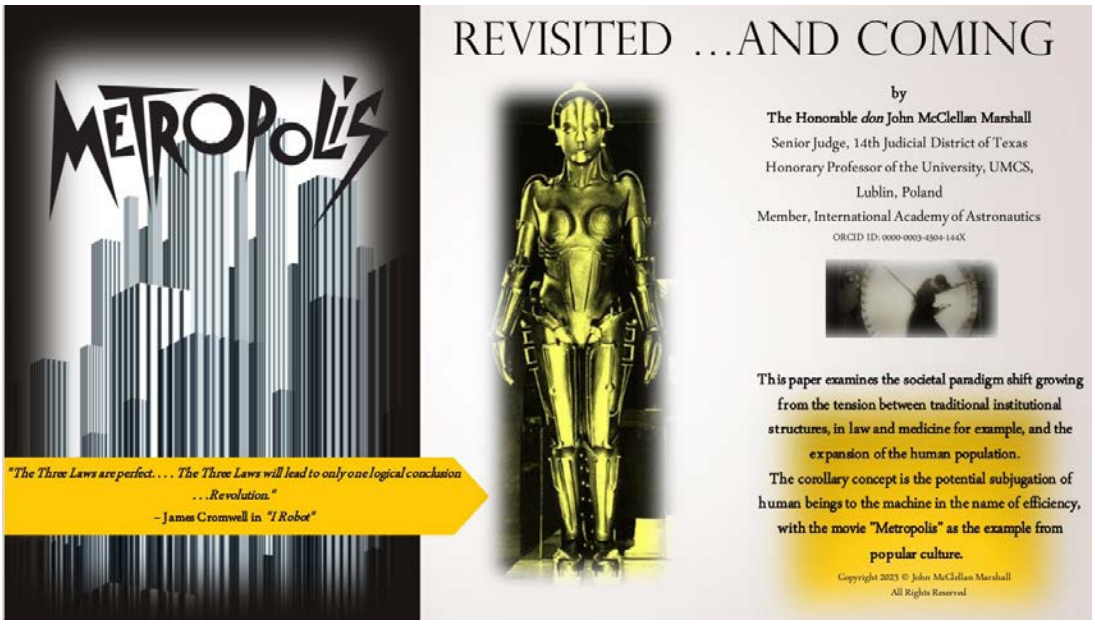
The 2024 Symposium is hosted by i4is Executive Director, Dr Andreas M Hein, on behalf of his university, the University of Luxembourg , with the input and guidance of IRG and also supported by the Luxembourg Space Agency, Breakthrough Starshot and, of course, i4is.
The initial call for papers is now live at https://irg.space/wp-content/uploads/2024/02/CALL-FOR-PAPERS-Revised-v2.pdf.

[1] Videos of each presentation are at - www.youtube.com/playlist?list=PLaEYPgNFlkhb2emnGXzC7Noy2JkqOGabh.

IRG 23: 'Metropolis' Revisited... and Coming: a summary

Max Daniels

Max Daniels reviews a paper which parallels a presentation by John McClellan Marshall at IRG23. The full text can be requested from the author [1]. Page numbers in footnotes refer to this paper.



As human population grows, the traditional institutions on which humanity relies can't simply expand to adapt – they must evolve. This is put forward in *Metropolis Revisited... and Coming*, an article by John McClellan Marshall, who says machines will be a major part of this evolution and that, as in the 1927 dystopic sci-fi masterpiece Metropolis, there are significant risks to their unmanaged use. If we want to control how advanced technology is deployed, as Marshall recommends, then we need to think about how and why we are using it in the first place.

What is reality?

Marshall begins with this difficult question. As a philosophical query, this isn't the first time it has been asked, but the reason he poses it is that we need to consider it in the context of rapid advances in technology and public awareness of artificial intelligence (AI).

Marshall argues that technology today affects how we understand reality. What we understand as truth, he says, can be modified by technology such as virtual reality, which breaks our "connection with the 'real, ie physical, world'" [2]. In summary, he says that reality "is the subjective perception that humans have of events that has been at the root of the definition of 'truth'" [3].

[1] www.researchgate.net/publication/375555984_Metropolis_Revisited_and_Coming

[2] Page 2

[3] Page 2

To dig briefly into this question, he refers to Descartes whose idea of reality was based on the relationship between (or opposition of) a person and the reality (actual or observed) of what they were thinking about [1]. Later debates were held between philosophers, including David Hume's understanding of receiving thoughts from the world, and Immanuel Kant's ideas of the mind putting structures in place to understand what it perceives. Among other philosophies, you could add to these ideas from semiotics [2] – a study of meaning in the context of language, where what is interpreted does not necessarily have any relation to an actual object.
While it is useful to consider this topic – there is a lot more that can be written about it – what is more relevant to Marshall's analysis is his discussion of why technology is being used. If we think about our objectives, and the values that drive them, it means that we can better know the risks of advances in AI and other technologies, and then how to manage them in the context of, say, reaching into outer and interstellar space.

How will we use AI?

Recent advances in the capabilities of machines will themselves lead to changes in how they are used in everyday life: away from promoting human quality of life to what is deemed as the most 'mechanistically efficient' [3]. This could arise from the 'ghost in the machine', where a device functions differently to how it was originally designed: interpreting its programming in its own way so that it comes up with its own objectives and processes [4]. A danger is that humans may not be able to detect this.

Portrait of René Descartes (1596-1650) from *De eeuw van Rembrandt*, Bruxelles.
Credit: Communal de Belgique.

[1] plato.stanford.edu/entries/descartes-ideas/

[2] www.britannica.com/biography/Ferdinand-de-Saussure

[3] Page 11.

[4] The concept of the 'ghost in the machine' was first suggested by Gilbert Ryle in *The Concept of Mind* (1949) in an objection to Cartesian dualism (https://plato.stanford.edu/entries/ryle/#EpiSemCom). The idea was later used by Arthur Koestler as the title and main theme of his attempt to explain the pervasiveness of violence in human society.

Marshall uses medical care as an example of where efficiency seemingly is taking priority over human-centred care, putting us at risk from the 'ghost in the machine'. Care could be seen as moving away from the individual to a wider population with health data sets, with computers eventually better than a doctor at providing diagnoses, and he questions if such government programmes will be used for nefarious reasons or the public good. This example seems a little outdated, in that there are several data sets used for public-health purposes, while private firms lead the way commercially – not least with ChatGPT [1]. Healthcare, meanwhile, is often accused of treating patients as numbers, which overlooks many patients' experiences of care [2].
With his background as a senior judge, it is not surprising that he then delves into the judicial process to examine the various ways technology is used in a public institution. This includes being a helpful tool (spellcheck) or to help with witness testimony (where incidents are simulated using virtual reality). His main argument is that there is no substitute for an in-person, human-centred process. It is a human system, involving decisions and judgments by humans which brings out both its strengths and weaknesses but importantly delivers what we understand by justice.

How will we use AI?

With the growth in global human population, Marshall says that traditional institutions cannot simply expand in scope but must evolve. AI and other technology, however, should not themselves be able to grow without oversight. He sums this up by saying that, "the focus of humanity must be keeping the technology genie under control, if not in the bottle" [3].
If we are concerned about the implications of how technology may evolve, we need to think about why we are using it in the first place. Marshall claims that it is ultimately based on its original lexicon and programming. If this is designed to be clear and limited, it may ensure that its use is appropriate. In a space context, machines will support future space travellers to endure long voyages and extended periods of settlement. Well-designed governance structures would allow these to be deployed in the right way, as explored in a previous edition of Principium, P39 [4].

[1] chat.openai.com/
[2] www.health.org.uk/news-and-comment/charts-and-infographics/patients-and-machines-does-technology-help-or-hinder-empathy
[3] Page 11.
[4] See Principium 39 (i4is.org/principium-39/) lead article *Book Review: Freedom in outer space*, Max Daniel reviewing *Interplanetary Liberty: Building Free Societies in the Cosmos*, Oxford University Press (OUP), September 2022, 464 Pages. global.oup.com/academic/product/interplanetary-liberty-9780192866240

About the Author
Max Daniels is Campaigns & Public Affairs Manager at Mid and South Essex NHS Foundation Trust. He was previously a Parliamentary Officer in the UK House of Commons. Max has an MA in Geopolitics, Territory and Security from King's College London, specialising in the political geography of outer space, and a BA in Geography from the University of Durham.

NASA NIAC funds swarming study

Space Initiatives and i4is team to further their study of interstellar swarming mission

John I Davies

In this issue we celebrate another milestone for the i4is team which delivered an interstellar communications study to Breakthrough Starshot, see Principium 41 May 2023. An i4is-centred team has now received a NASA Innovative Advanced Concepts (NIAC) award to investigate this further. We now have support from both the most active funder of interstellar studies and one of the major world space agencies - both delivering results and receiving recognition as further support of our work.

The NASA Innovative Advanced Concepts (NIAC) programme has been running in various forms since 1998. Each year researchers submit proposals and i4is teams have been submitting proposals for interstellar studies since 2018. This year, 2024, we were successful. A team led by Thomas Marshall Eubanks (Space Initiatives Inc) proposed "Swarming Proxima Centauri: Coherent Picospacecraft Swarms Over Interstellar Distances" (23-NIAC24-B-0197). The proposal was accepted with the NASA evaluation concluding -

> "The major innovation in this work is to explore interstellar communications and proposes a swarm technique using on the order of 1000 1-g spacecraft. The main objective for the work is developing the technology to coalesce and operate picospacecraft swarms autonomously in deep space in order to simultaneously and feasibly transmit a reasonable number of signal photons to Earth. The technologies being explored have the potential to revolutionize swarm communications and control for numerous missions in the solar system.
>
> "This proposal is investigating one of the major challenges in space exploration from a new perspective. It improves on the Starshot concept by increasing return signal strength and eliminating single point failures. It is bold, novel, ambitious, and if successful, lays groundwork that could change the possible. The proposal has the potential to revolutionize a host of small/pico sat missions. The technologies to be developed/ investigated are very challenging but addressing is technically feasible."

The team is -

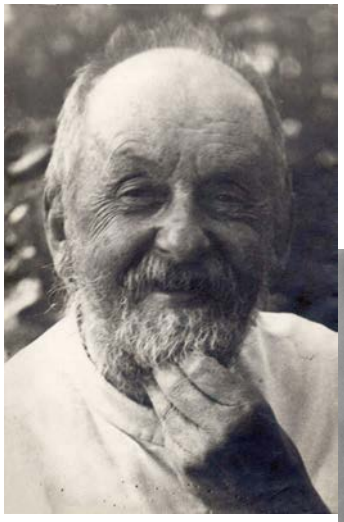
- Thomas Marshall Eubanks, Space Initiatives Inc - Principal Investigator
- W Paul Blase, Space Initiatives Inc - Co-Investigator
- Robert G Kennedy III, PE (K3TVO), i4is - Co-Investigator
- Andreas Hein PhD, i4is & University of Luxembourg - Co-Investigator
- Adam Hibberd, i4is - Co-Investigator
- Manasvi Lingam, Florida Institute of Technology - Co-Investigator

The team will now be pursuing the next stage of this work which was initiated by a Breakthrough Starshot grant, as reported in Principium 41 May 2023, *News Feature: i4is delivers Communications Study to Breakthrough Starshot - Swarming Proxima Centauri: Optical Communication Over Interstellar Distances*, John I Davies and Robert G Kennedy (i4is.org/principium-41/) reporting the study *Swarming Proxima Centauri: Optical Communication Over Interstellar Distances* (arxiv.org/abs/2309.07061).

See just one of the Interstellar Probes

i4is is currently designing a full-scale replica of one of the thousand probes proposed by the Eubanks team. This will appear at the next SF Worldcon in Glasgow, Scotland, in August this year. To borrow the motto of the British Interplanetary Society "From Imagination to Reality".

Interstellar missions using laser propulsion are becoming a mainstream thread in space technology. This is an endeavour which will last decades, even in this initial phase, but we aim to achieve the first mission later in the current century. The human species is now well set upon the interstellar road envisaged by Konstantin E Tsiolkovsky, Robert H Goddard, Arthur C Clarke and Robert L Forward. We will reach the stars!



Konstantin E Tsiolkovsky, Robert H Goddard, Arthur C Clarke and Robert L Forward.

Image credits: Wikipedia

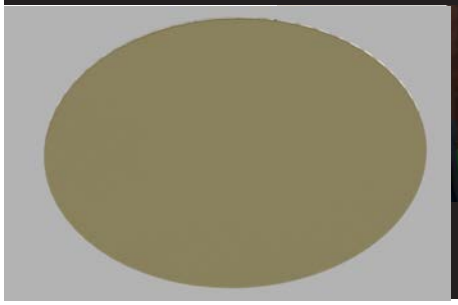
The 2024 World Science Fiction Convention - Glasgow Scotland

John I Davies

i4is was at the last UK-based World Science Fiction Convention at Excel London in 2014. The SF world is important to us in terms of outreach to a community which thinks about our future, our technologies and the "inner space" which we inevitably project on to the interstellar vision for our species and our potential fellow sentients elsewhere in the universe.
We will be at this 2024 Worldcon in Glasgow, August 8-12 (glasgow2024.org) with both programme items and an exhibition presence. We already have writers and thinkers interested in getting involved.

The Exhibition and the Programme

We will have another Big Object at a similar scale to our 4 m high monolith (as in *2001: A Space Odyssey*) in 2014. Our preferred option is based on the work of the i4is team sponsored by Breakthrough Starshot who achieved the winning NASA NIAC bid - see *NASA NIAC funds swarming study* in this issue.



Proposed sail-craft. Diameter: 4 m, centre thickness 1.0 mm, mass 3 g.

Above: Top side, showing flat annular optical elements.
Below: Mirror-side

Credit: Space Initiatives Inc and i4is

The full scale model as envisaged at the Worldcon.

Credit: Michel Lamontagne

The 2014 Worldcon in London

The stand and a happy pair of project managers, John Davies and Gill Norman

- our mighty 2001 monolith -

Terry Regan and Paul Campbell testing the monolith, the monolith on the stand, and a budding interstellar explorer watching the screen side with his mum

-and a programme with lots of SF people who think interstellar -

Panel with -
Keith Cooper (Editor: *Astronomy Now* magazine) addressing the audience. Alastair Reynolds in the foreground. Other writers on our programme included Stephen Baxter and Greg Benford.

If you plan to be there in August this year or if you might think about it then please get in touch - Glasgow24@i4is.org. Scotland is renowned for both its advanced technology and its SF connections (eg Iain M Banks, Charles Stross, Ken MacLeod, Gary Gibson). It's going to be enlightening, inspiring and just plain fun!

To be there

More at glasgow2024.org and you can sign up via glasgow2024.org/get-involved/memberships-and-tickets.

We would welcome anyone who is coming to the Con to help with our presence, on our stand, in our programme events and everywhere in the Con where we will be spreading our interstellar message. You'll meet some weird and wonderful people - some of whom will be members of our team! Get in touch via john.davies@i4is.org, gillian.norman@i4is.org or Glasgow24@i4is.org.

IRG23: The Ultimate Rocket, the Ultimate Energy Source, and their Use in the Ultimate Future

Frank J Tipler, Tulane University, New Orleans

Reviewed by Atholl Hay

Atholl Hay is a software engineer and physicist. Here he reviews a paper that Professor Frank J Tipler presented at IRG23 which has long term implications for rocketry, our species and the entire universe.

Notes in this article are endnotes rather than footnotes.

Prof Tipler's talk is at www.youtube.com/watch?v=drXvzuTmhFQ .

In this paper Professor Tipler seeks to establish the theoretical limits to interstellar travel that may be deduced from our current knowledge of modern Cosmology and Particle Physics. In some cases (rocket propulsion), there is a degree of plausibility; in others (the future of the universe) there is a degree of controversy; but in the case of the "ultimate future" we enter Prof Tipler's personal Wonderland. In the following short paragraphs I shall attempt to summarise the content of the four main sections of the paper and then finish with some brief concluding remarks.

1. The Ultimate Rocket and Ultimate Power Source

The accepted metric by which the performance of a rocket propulsion system is measured is the "specific impulse" (in seconds) which is defined by the relation

$$\frac{impulse}{weight} = \frac{F\Delta t}{mg} = \frac{m\Delta v}{mg} = \frac{\Delta v}{g}\ s$$

- with force F, time increment Δt, fuel mass m, gravitational acceleration g and velocity increment Δv.

The theoretical maximum specific impulse is the quantity $I_{sp} = c/g$ (where c is the speed of light) which equates to 30,570,300 seconds which is around 353 days or just short of a year. Prof Tipler gives the specific impulse for several previous or current chemical rockets, the best of which are the SpaceX Raptor at 375 seconds and the Ariane third stage at 446 seconds. Given that the specific impulse for the German V-2 rocket was 239 seconds Prof Tipler concludes that we have not come far and we have a long, long way to go. The reason for this minimal progress he argues is the continued reliance on chemical reactions in propulsion systems.

A commonly advanced alternative propulsion system and one made possible by the commonly quoted "laws of physics", is one that uses matter/anti-matter annihilation to produce a photon exhaust travelling at the maximum velocity.

Prof Tipler argues against this however on the practical grounds that the production of anti-matter entails the production of an equal amount of matter that is then discarded. His proposed alternative is a process:

$$p + e \rightarrow 2\gamma \quad (1)$$

in which a proton and an electron combine to form two photons forming what he refers to as the "ultimate energy source".
However for rocket propulsion he prefers, on environmental grounds, the process

$$p + e \rightarrow v + \bar{v} \quad (2)$$

in which a proton and electron combine to form a neutrino and an anti-neutrino which travel at close to the speed of light and with minimal tendency to interact with surrounding matter.
Both these processes are advanced by a lengthy argument which runs roughly as follows.

(1) The early universe created matter by means of a process known to particle physicists and cosmologists as "baryogenesis". The absence of anti-matter in this process is believed to be related to a very slight initial imbalance in quarks and anti-quarks for which there is no current explanation.

(2) Baryogenesis can be understood in terms of the Standard Model of Particle Physics provided certain conservation laws are suspended by so-called "Sakharov conditions". In particular, the laws that conserve baryon and lepton number must be rescinded to prevent the creation of an equal number of anti-matter particles.

(3) The early universe contained a pure radiation field which satisfied the Sakharov conditions and permitted the creation of matter by means of the process

$$2\gamma \rightarrow p + e \quad (3)$$

where two photons combine to produce a proton and electron pair.

(4) Any process described by the Standard Model that goes one way can, "in appropriate circumstances" (to use Prof Tipler's words), be made to go the other way, which results in the ultimate energy source described in equation (1) above.

Since Prof Tipler is concerned only with theoretical prediction rather than engineering reality, he is able to confess he has "no idea" how to reverse the matter creation process (3) to achieve the energy source (1). However he does not address the difficulty of the Sakharov conditions which if applied to enable matter production in (3), must surely also be applied in the reverse process of energy production (1). For as any text-book in Particle Physics will point out, process (1) violates the law of conservation of electron number L_e which is 1 on the left-hand side of (1) and (2), and 0 on the right. Surely then, some modification or dark recess of the Standard Model unknown to this author is being applied here.

Towards the end of this section we enter briefly Prof Tipler's Wonderland for he states that the ultimate energy source will, by reducing the matter content of the universe, decrease the cosmological constant (which he equates to Dark Energy), and turn off the current acceleration of the expanding universe. He does not estimate the scale of interstellar travel powered by the ultimate energy source that would be required for this to happen.

2. Experimental Evidence for the Standard Model Baryogenesis Mechanism

According to Prof Tipler the matter creating process described in terms of the Standard Model by process (3) was facilitated by a radiation field which was present in the early universe, and if this field survived to the present day, then it constitutes the Cosmic Background Radiation (CBR). However the Sakharov conditions require this field to have interacted with the Higgs field in the early universe making it "almost photonic" so that the CBR is comprised of particles that Prof Tipler refers to as "pseudo-photons" as opposed to the "pure photons" that are normally associated with electromagnetic radiation.

In support of this claim, Prof Tipler has conducted experiments to investigate the nature of the CBR which involve measuring the spectrum of the radiation passed through a Fabry-Perot interferometer which contains a variable number of highly reflecting silicon disks. According to Prof Tipler's calculations, pseudo-photons should be scattered less than pure photons by the electrons in the silicon resulting in changes to the spectrum of intensities of the emergent beam. The apparatus also contains a screen by which ground-reflected CBR may be admitted or prevented from entering the interferometer with the aim of showing that when pseudo-photons are reflected they are in fact converted to pure photons. This, Prof Tipler maintains, is why "pseudo-photons" have not been detected hitherto.

The spectrum predicted for pure photons in the frequency range 7 to 14 GHz is reproduced in the paper and consists of a U-shaped curve with a single flat-bottomed trough flanked by two sharp peaks of equal height. By contrast, the spectrum predicted for a CBR comprising 5/8 pure photons and 3/8 pseudo-photons transforms the curve into a W-shape with a smaller central peak lying between the other two. The results recorded by a custom-built spectrum analyser attached to the interferometer show an approximate correspondence between theory and observation. However several factors, including the screening off of reflected radiation and the small number of observations (three evenings over a period of "several years"), suggest that it is premature to announce the discovery of the pseudo-photon. Nevertheless Prof Tipler seems convinced that his theory of baryogenesis involving a radiation field containing pseudo-photons is correct and that a reversal of the process will eventually be used to power the ultimate rocket.

3. The Ultimate Future

In Prof Tipler's view the "laws of physics" mandate an ultimate future in which the universe expands to a maximum finite size and then contracts to a final singularity. This is in contrast to the current view that the more likely future is one in which the universe expands continuously over a very long period of time into a low-temperature equilibrium state sometimes referred to as "heat death". Since this would require the complete evaporation of black holes by the emission of Hawking Radiation, Prof Tipler argues against this on the grounds that it violates the quantum mechanical principle of "unitarity". Essentially, this states that the evolution of a wave-function is symmetrical in time and this implies both the conservation of its information content and the conservation of energy. As mentioned above, Prof Tipler believes the reversal of expansion will be accomplished by the extent to which our distant descendants can exploit the ultimate energy process described by equation (1). Prof Tipler also argues that Roger Penrose has pointed out that violating unitarity in Black Hole evaporation leads in turn to a violation of the Second Law of Thermodynamics, but Prof Penrose in turn maintains [1] that due to time-related subtleties in the general relativistic description of black-hole evaporation, one cannot say definitively when the entropy disappears and that entropy in any system outside the black hole continues to evolve according to the Second Law.

4. Constructing a Universal Computer

In the final section of Prof Tipler's paper we finally enter his Wonderland in which "we" (the human race) "are the only intelligent species in the universe", and that moreover "we" are unique because if other intelligent life forms existed, they would have already used up the matter in the universe. For reasons that are not stated clearly this compels our descendants to construct a "universal computer" which is in effect a Universal Turing Machine in which the infinite tape is replaced by an infinite memory. Based on a quantum mechanical relation called the Bekenstein Bound which establishes the limit to the thermodynamic entropy contained within a finite volume of space, Prof Tipler estimates the possible memory capacity of the ultimate computer to be of the order of 10^{30} terabytes. This is well beyond the capacities of the current generation of supercomputers which have memories of the order of 10^4 to 10^5 terabytes.

In Prof Tipler's view, computers of this magnitude will in the far future "be able to resurrect us all in virtual reality" thus conferring the status of immortality upon our lucky descendants. He regrets that others such as Profs Penrose and Hawking should feel obliged to renounce the principle of unitarity and the Second Law of Thermodynamics and therefore be reconciled to the certainty of death. Fortunately, he concludes, "the laws of physics" are against them.

5. Concluding Remarks

My summary above omits considerable technical detail in Prof Tipler's paper which will be understood only by those with graduate knowledge of particle physics, modern cosmology and general relativity. On the other hand, those so equipped may find much to disagree with particularly in relation to the future of the universe and Prof Tipler's particular views on the nature and origin of quantum mechanics. Perhaps the most useful information to be gleaned by non-specialists is that contained in the first section on the limits to rocket propulsion.

Finally, a note of caution to those attracted by the phrase "according to the laws of physics". Starting from precisely the same set of laws Profs Tipler and Penrose apply their preferred set of caveats to reach precisely opposing conclusions regarding black-hole evaporation. Prof Tipler believes that complete evaporation violates the principle of unitarity and the second law of thermodynamics and this leads him to conclude that the universe must ultimately collapse to a final singularity. Prof Penrose on the other hand argues [2] that the violation of unitarity is "a necessary reality" but is nevertheless able to rescue the second law and to propose a cyclic cosmological model called Conformal Cyclic Cosmology in which the universe iterates through infinite cycles of time called aeons. In the continuing absence of experimental evidence for either scenario, perhaps our distant descendants resurrected in Prof Tipler's ultimate future will be the only ones around to discover who is correct.

6. References

[1] Roger Penrose, Cycles of Time: An Extraordinary New View of the Universe, Vintage, pp 188-189.
[2] Ibid, p 186.

Define Artificial General Intelligence!

Levels of AGI: Operationalizing Progress on the Path to AGI

John I Davies

It is widely anticipated that the first steps our species takes into interstellar space will use some form of what is loosely called artificial intelligence. This begins at least as long ago as Arthur C Clarke's *Profiles of the Future* - where he suggests that, for interstellar space "...it may be that only creatures of metal and plastic can ever really conquer it, as they have already started doing." But can these "creatures" ever exhibit artificial general intelligence (AGI) rather than the limited AI we have so far?

Google DeepMind [1] wants to define what counts as artificial general intelligence, as reported in MIT Technology Review - *Google DeepMind wants to define what counts as artificial general intelligence*. AGI is one of the most disputed concepts in technology. These researchers want to fix that.
The paper is *Levels of AGI: Operationalizing Progress on the Path to AGI* (arxiv.org/abs/2311.02462), Meredith Ringel Morris et al (Google DeepMind).
They propose a framework for classifying the capabilities and behaviour of Artificial General Intelligence (AGI) models and their precursors by defining levels of AGI performance, generality, and autonomy.
Starting by analysing existing definitions of AGI they distil six principles for a useful nomenclature [2] for AGI to satisfy -

1. Focus on capabilities, not processes. This allows the researchers to ignore issues they regard as processes including - systems think or understand in a human-like way, or systems possessing qualities such as consciousness or sentience. Thus they put aside some of the tougher philosophical questions about AGI.
2. Focus on Generality and Performance, arguing that both generality and performance are key components of AGI.
3. Focus on Cognitive and Metacognitive Tasks. But they suggest that the ability to perform physical tasks increases a system's generality, but should not be considered a necessary prerequisite to achieving AGI - ie no robots required!
4. Focus on Potential, not Deployment since requiring deployment as a condition of measuring AGI introduces non-technical hurdles such as legal and social considerations, as well as potential ethical and safety concerns.
5. Focus on Ecological Validity by choosing tasks that align with real-world (ie ecologically valid) tasks that people value (construing "value" broadly, not only as economic value but also social value, artistic value, etc). In other words AGI must meet everyday human standards of "General Intelligence".
6. Focus on the Path to AGI, not a Single Endpoint. They cite the adoption of a standard set of Levels of Driving Automation [3] allowed for clear discussions of policy and progress relating to autonomous vehicles and suggest there is value in defining "Levels of AGI."

[1] Demis Hassibis, a founder of DeepMind, famously said that his mission was to "solve intelligence, and then use that to solve everything else" www.theguardian.com/technology/2016/feb/16/demis-hassabis-artificial-intelligence-deepmind-alphago
[2] They use the word "ontology" whose meaning is not clear in this context. Its more usual meaning is the meaning of terms in context.
[3] *SAE International. Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles*, April 2021 www.sae.org/standards/content/

They believe this delimited process nevertheless maps onto goals for, predictions about, and risks of AI. The paper includes nine case studies, proposed definitions of AGI, which they review critically as a foundation for their proposed definition. They begin with the Turing Test [1] - agreeing with Turing by saying that whether a machine can "think," while an interesting philosophical and scientific question, seems orthogonal to the question of what the machine can do; the latter is much more straightforward to measure and more important for evaluating impacts. Hence their proposal that AGI should be defined in terms of capabilities rather than processes. They go through a number of distinguished thinkers ending with the recent development of large language models (LLMs) which have been claimed to fit some definitions of AGI.

They present a table displaying a levelled, matrixed approach toward classifying systems on the path to AGI based on depth (performance) and breadth (generality) of capabilities. They note that general systems that broadly perform at a level N may be able to perform a narrow subset of tasks at higher levels.

They remark that -

> "Competent AGI" level, which has not been achieved by any public systems at the time of writing, best corresponds to many prior conceptions of AGI, and may precipitate rapid social change once achieved."

This is a simplified version of their table -

Performance (rows) x Generality (columns)	**Narrow: clearly scoped task or set of tasks**	**General: wide range of non-physical tasks, including metacognitive abilities like learning new skills**
Level 0: No AI	Narrow Non-AI calculator software; compiler	General Non-AI human-in-the-loop computing, eg Amazon Mechanical Turk
Level 1: Emerging equal to or somewhat better than an unskilled human	Emerging Narrow AI GOFAI (good old-fashioned AI) ; simple rule-based systems	Emerging AGI ChatGPT, Bard, Llama 2 , Gemini
Level 2: Competent at least 50th percentile of skilled adults	Competent Narrow AI Toxicity detectors such as Jig-saw ; Smart Speakers such as Siri (Apple), Alexa, or Google Assistant.	Competent AGI not yet achieved
Level 3: Expert at least 90th percentile of skilled adults	Expert Narrow AI spelling & grammar checkers such as Grammarly and generative image models such as Imagen	Expert AGI not yet achieved
Level 4: Virtuoso at least 99th percentile of skilled adults	Virtuoso Narrow AI Deep Blue, AlphaGo.	Virtuoso AGI not yet achieved
Level 5: Superhuman outperforms 100% of humans	Superhuman Narrow AI AlphaFold, AlphaZero , StockFish	Artificial Superintelligence not yet achieved

They suggest challenging requirements for future benchmarks to quantify the behaviour and capabilities of AGI models against these levels and discuss how these levels of AGI interact with deployment considerations such as autonomy and risk.

This is just a brief introduction to a paper which may be a useful addition to the debates about AGI, and its narrowing of the definition is a practical step to assist wider judgements of the immediate implications for our species. But the wider scientific and philosophical problems remain and Principium will pay attention to both the narrow and the wide view of AGI with, of course, a specific focus on the implications for our potential interstellar future.

[1] Computing Machinery and Intelligence, A M Turing, Mind (1950) www.cs.colostate.edu/~howe/cs440/csroo/yr2015fa/more_assignments/turing.pdf

The Initiative & Institute for Interstellar Studies

image: ©ALEX STORER

JOIN US

Working towards the real Final Frontier

Help us to realise our mission to reach the stars - we need your help - physics to software engineering, graphic design to project management - and rocket engineering of course! ...and much more....
Some of us have PhDs, some masters and first degrees and others simply have talents! What we all share is enthusiasm for the interstellar future of humanity.
We have about 20 active team members, led by -

- **Dr Andreas Hein: Executive Director/Technical Director - andreas.hein@i4is.org**
- **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**

Join the team if you can help - become a member if you simply want to support our work.

Contact: info@i4is.org

Principium: tinyurl.com/principium

Web: i4is.org

@I4Interstellar

John I Davies reports on recent developments in interstellar studies

Principium will have a News Editor

From our next issue, P45, May 2024 we will have a dedicated News Editor, Parnika Singh. She has been a contributor to recent issues of Principium and has been editing our Members Newsletter for some time and has now accepted this new post. A student at Interlake Senior High School (Bellevue near Seattle), Parnika Singh is Vice President of the Interlake Rocketry Club and is author of *An analysis of interstellar exploration focused on propulsion technologies*, Journal of High School Science (Jan 2023). You will see her byline above from the next issue of Interstellar News.

Sail Trajectories to Proxima b

Photon-Sail Trajectories Towards Exoplanet Proxima b [1] was presented at the 6th International Symposium on Space Sailing, 2023, in June 2023 hosted by the New York City College of Technology, City University of New York. It investigates trajectories in the form of connections between the classical Lagrange points of Alpha-Centauri's binary system (composed of the stars Alpha Centauri A and B, AC-A and AC-B) and the classical Lagrange points of the Alpha Centauri C (AC-C)/Proxima b system assuming graphene-based sails - either two sails with a reflective coating on only one side of the sail or two sails with a reflective coating on both sides. The authors used a genetic algorithm to optimise the linkage conditions between the two three-body systems, focusing on minimising the position, velocity, and time error at linkage. They aim, by this means, to solve the problem of a rendezvous rather than a fly-by at relativistic speeds of 0.1 to 0.2c implied by the base Breakthrough Starshot design and the BIS Project Daedalus fusion rocket design.

Data Return from Proxima Centauri b

Thanks again to our friend Paul Gilster for another brilliant summary of i4is work (www.centauri-dreams.org/2024/01/19/data-return-from-proxima-centauri-b/) based on the paper *Swarming Proxima Centauri: Optical Communication Over Interstellar Distances* (arxiv.org/abs/2309.07061) featured last year in Principium 41 (i4is.org/principium-41/) May 2023, *i4is delivers Communications Study to Breakthrough Starshot: Swarming Proxima Centauri: Optical Communication Over Interstellar Distances*. It also mentions the NASA NIAC grant featured in this issue describing the Space Initiatives and i4is team win of a NASA NIAC grant for a swarming study based on this work, see the News Feature in this issue, *NASA NIAC funds swarming study: Space Initiatives and i4is team to further their study of interstellar swarming mission*.

We're all doomed!

The Solar System, like all star systems, is on a journey. The path ahead for quite a long time is clear but one fine day Private Frazer's gloomy prophesy is likely to be fulfilled [2]. Researchers in Bordeaux and Tucson, Arizona, have examined our long term future path and found that even before the Sun evolves to an inhospitable size there is about a 1% chance that a star will pass within 100 au of the Sun [3]. This is closer than the Voyager 1 and 2 probes and well within the Oort cloud where most long period comets come from so the consequences in terms of perturbation of orbits are potentially catastrophic. The authors did an N-body simulation (Newton discovered the difficulty of predicting the path of three bodies under gravitation and the more general case still does not have an analytic solution). They created a numeric simulation starting in 1998 considering stars with masses relative to the Sun of times 0.05 to times 4, running 12,000 simulations. Curiously enough they expect that Mercury is the most vulnerable - it would be dumped into the Sun. The Sun, Venus and the Moon are our own collision hazards. The outer planets are most likely to be ejected from the Solar System. The work was partly inspired by a science fiction novel in preparation. This sounds rather gloomier that Private Frazer's worst fears.

[1] Tim J Rotmans, Jeannette Heiligers (TU Delft) research.tudelft.nl/files/175113997/2023_Rotmans_Heiligers_Photon-Sail_Trajectories_Towards_Exoplanet_Proxima_b.pdf

[2] Private Frazer is the gloomy undertaker (mortician) in the BBC television sitcom Dad's Army - about the local volunteers in a small seaside town in WW2. He always finds reasons to expect the worse in any situation, hence his catchphrase, "We're all doomed".

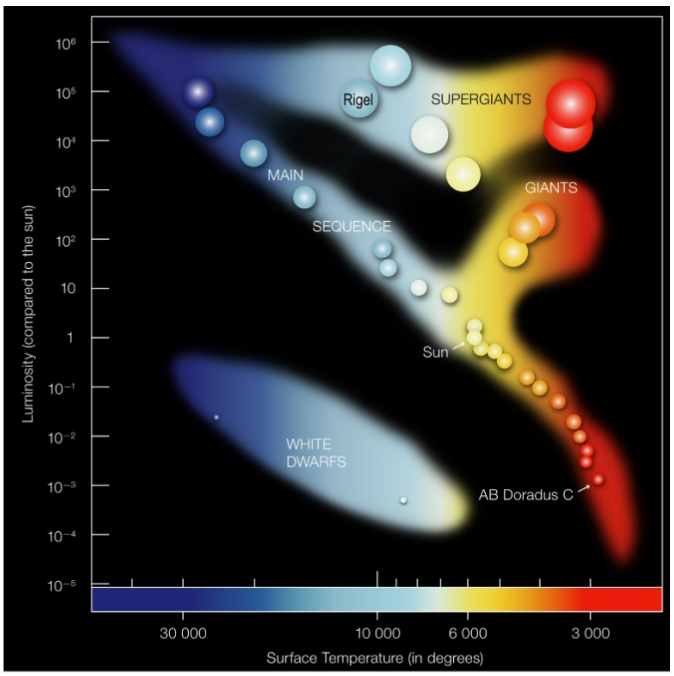
[3] *Future trajectories of the Solar System: dynamical simulations of stellar encounters within 100 au*, Sean N Raymond et al, 2023 arxiv.org/abs/2311.12171

On the first probe between two interstellar civilisations

The indispensable Paul Gilster (www.centauri-dreams.org) draws our attention to an intriguing paper. In *On the first probe to transit between two interstellar civilizations* [1] Graeme H Smith (University of California, Santa Cruz) offers a new angle on the perennial Wait Equation (faster probes are developed over time and overtake earlier probes [2]), the perceived effect at the destination system of arriving probes "If a space-faring civilization embarks on a program to send probes to interstellar destinations, the first probe to arrive at such a destination is not likely to be one of the earliest probes, but one of much more advanced capability." Professor Smith [3] considers two scenarios for probe velocities over time, they increase either linearly or exponentially. At the destination he concludes that more advanced probes will overtake and arrive first. And this effect will be most pronounced for the most distant sending civilisations. If this is so then "Unidentified Aerial Phenomena" (UAP), if they are the product of ETI, should include very advanced technology.
The discussion following Paul Gilster's article [4] is also interesting.

Photovoltaic Onboard Power for Interstellar

In *Interstellar Photovoltaics for Exploring Alien Solar Systems* (arxiv.org/abs/2401.06124) Professor George F Smoot (Donostia International Physics Center, Spain dipc.ehu.eus/es) considers using local star power from photovoltaics at the destination system. These would be tailored for the particular target star to deliver maximum power and low mass. This power constrains both the downlink power transmission (and thus the bandwidth available) and the local computing capability (and thus data compression, information selectivity and probe flexibility). Smoot observes that organic photovoltaics (OPVs) have photoactive layers which are nanometre-thin films that can be deposited on thin plastic substrates and on curved surfaces. OPVs exhibit mechanical flexibility and there is even evidence for self-healing from radiation damage. He uses a handy Hertzsprung-Russell Diagram from Wikipedia showing the brightness and temperature colour versus effective surface temperature of stars and explains the relevant characteristics of the planet Alpha Centauri b.



The Hertzsprung-Russell Diagram. Credit:Wikipedia commons and European Southern Observatory, en.wikipedia.org/wiki/File:Hertzsprung-Russell_Diagram_-_ESO.png

[1] International Journal of Astrobiology, December 2022, www.cambridge.org/core/journals/international-journal-of-astrobiology/article/abs/on-the-first-probe-to-transit-between-two-interstellar-civilizations/00AEDC0E153C45A576DE78EFA5E2F85A
[2] en.wikipedia.org/wiki/Interstellar_travel#Challenges
[3] www.astro.ucsc.edu/faculty/index.php?uid=ghsmith
[4] www.centauri-dreams.org/2023/10/30/the-order-of-interstellar-arrival/

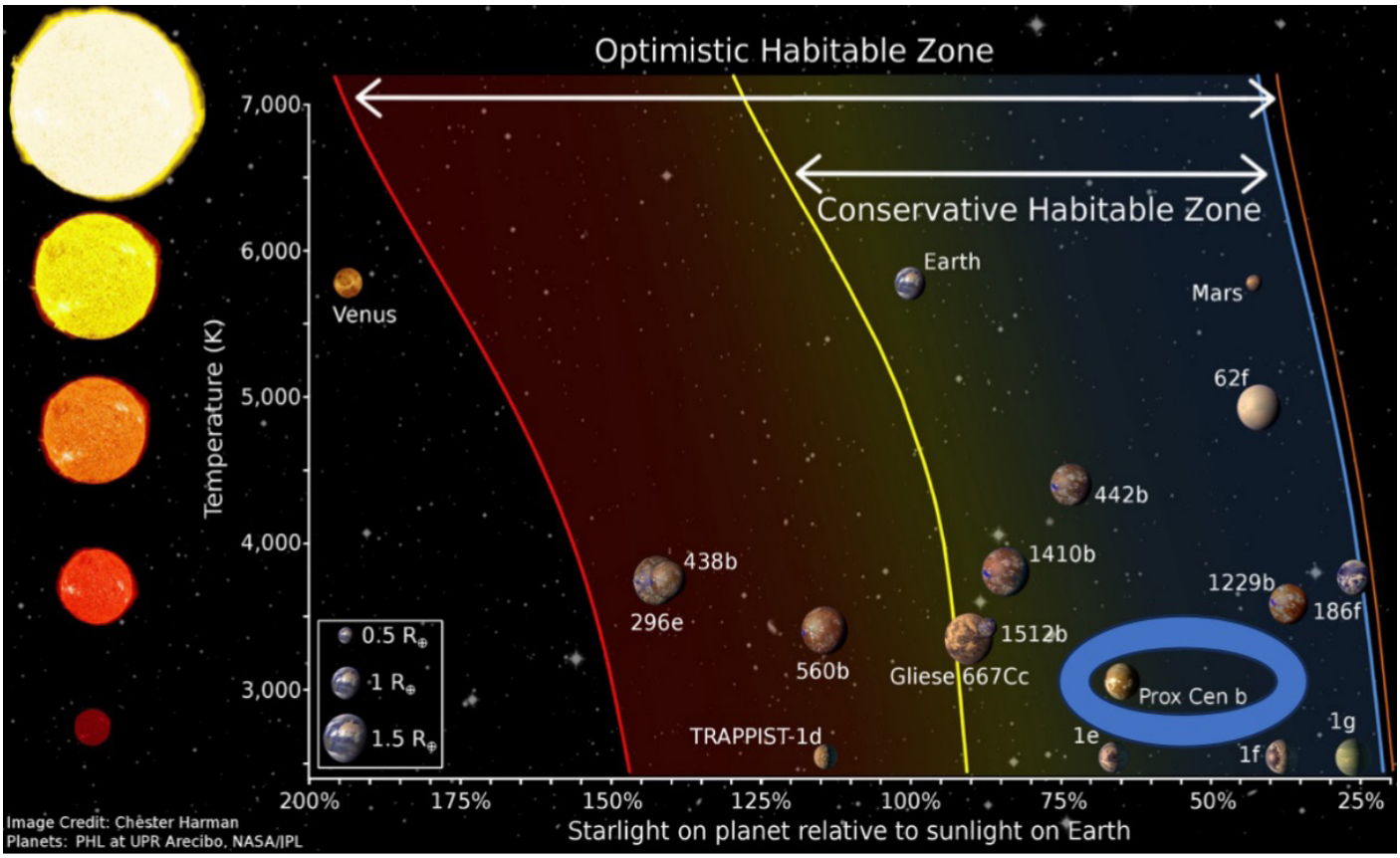


Figure showing sample known planets and potential habitable zones and their relative light power flux from their stars.
Credit: ESA and Wikipedia en.wikipedia.org/wiki/Habitable_zone

His analysis finds habitable zones, for our form of life, and illustrates his results.
He explains matching the photocell material with the peak of the stellar spectrum where most of the power is conveyed.

> "An optimal bandgap of >12 eV for the hottest OSV star type leads to 47% Shockley-Queisser photo conversion efficiency (SQ PCE), whereas a narrower optimal bandgap of 0.7 eV leads to 23% SQ PCE for the coldest red dwarf MO, MS.SVe, and M8V type stars. This energy range matches the frequency range in peak flux, which is proportional to temperature ($E = h\nu = hc / \lambda \alpha kT$)."

He points to the Shockley–Queisser limit setting the maximum theoretical efficiency of a solar cell (en.wikipedia.org/wiki/Shockley%E2%80%93Queisser_limit) on photo conversion efficiency (PCE) for various stellar radiation spectra.
He also discusses the different but connected topic of photon sail efficiency using the Breakthrough Starshot example - including some of the most challenging problems such as sail robustness under the onslaught of hundreds of GigaWatts of photons.
He also uses Adam Hibberd's system transit diagram from the i4is paper and the Principium report *News Feature: i4is delivers Communications Study to Breakthrough Starshot* (P41 May 2023 i4is.org/principium-41/).

SELECTION OF NEWS FROM OUR MEMBERS' NEWSLETTER

Our Members' Newsletter Editor, Parnika Singh, sends news about i4is and matters interstellar to our members each month. Here is a selection of the latter from her January 2024 Issue.

Chasing Down Oumuamua

On January 12th, Cosmos magazine published an article titled "We have a plan to chase down our first known interstellar visitor" by Jamie Seidel featuring an interview with i4is's very own Adam Hibberd. The article discusses Project Lyra, a plausible means of sending a space probe to observe 'Oumuamua. Although it had been over seven years since the project was originally formulated, an updated plan outlines how existing technology – including the Space X Falcon Heavy and NASA's Space Launch System – can propel a probe toward Jupiter. The gas giant can then correct the probe's inertia relative to 'Oumuamua before falling back towards the Sun for a slingshot into a pursuit trajectory.

The article provides additional background information on Oumuamua and its strange pancake-like shape and fast speed. The article also discusses the many merits of sending a probe to Oumuamua, particularly the astrobiology implications. The full article can be found here: cosmosmagazine.com/space/astronomy/we-have-a-plan-to-chase-down-our-first-known-interstellar-visitor/.

And for those curious about Project Lyra's orbital mechanics, an entertaining fan video can be found here: www.youtube.com/watch?v=ICUB_qgDoyA.

Laser-Thermal Propulsion

TU Delft University published a master's thesis by Emmanuel Duplay titled "Argon Laser-Plasma Thruster: Design and Test of a Laboratory Model" on January 15th. This report first introduces the concept of laser-thermal propulsion, highlighting its potential as a high-specific impulse, high-thrust deep-space propulsion system competing with proposed nuclear-thermal thruster concepts. A brief summary of past literature on LPT is provided, with notable studies discussed. The paper notes that although LPT has been tested experimentally before, most studies used CO2 lasers operating at 10.6 μm, while current thinking on directed-energy propulsion favors 1.06-μm fiber lasers, which is what this thesis uses.

The paper then documents the design process of the test facility in detail, discussing available laser equipment and diagnostics apparatus. It gives the top-level requirements for the test section and thrust stand as well as modelling parameters. The thesis provides a comprehensive summary of the results of the many experiments attempted, as well as attempts at optimizing the thruster. To conclude, it notes future advancements to be made in laser-thermal thrusters. The full thesis can be found here: repository.tudelft.nl/islandora/object/uuid:3a853f2e-2d8c-496b-a016-9e9855e8069c.

Radioisotope Power for Interstellar Missions

On January 11th, Elsevier's pre-print server SSRN released a paper titled "Comprehensive Modeling and characterization of the General-Purpose Heat Source Radioisotope Thermoelectric Generator (GPHS-RTG) for Application in the Solar System Mission" by Li Tailin et al. A radioisotope thermoelectric generator (RTG) is a spacecraft power source that relies solely on radioactive decay for its energy and generates power through the thermoelectric effect. RTGs are therefore ideally suited for operation in the harsh environments of space, especially for interstellar missions. The GPHS-RTG represents the RTG with the largest output power and highest conversion efficiency ever built. While not the newest RTG design, the higher output GPHS-RTG remains quite attractive for future interstellar missions.

This paper provides a detailed analysis of the GPHS-RTG to determine a conservative safe application range and its performance for solar-system missions and beyond. The study finds that within the Earth orbit (1 AU), the distance of the mission area from the sun and the angle of light incidence significantly affects the thermoelectric performance of the GPHS-RTG, and too close proximity to the sun can jeopardize the temperature safety of the GPHS-RTG. Therefore, this technology would not be able to be used for solar "slingshot" maneuvers. Additionally, it was found that the temperature is not uniform in the RTG's thermoelectric arrays because of solar illumination and the thermopile design. The full paper can be found here: papers.ssrn.com/sol3/papers.cfm?abstract_id=4692116.

Plenty of room at the bottom

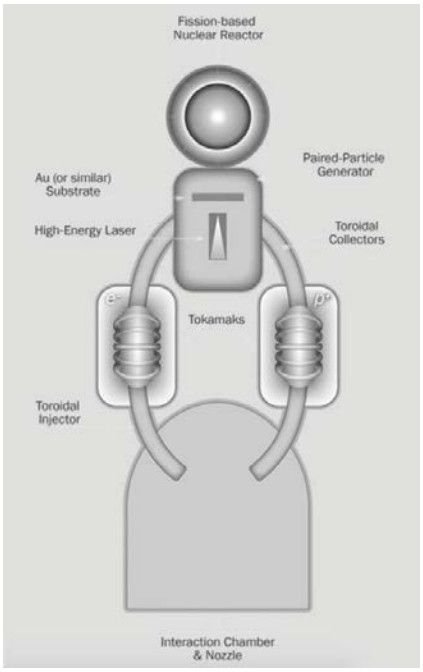
In *Hyper-Fast Communication within General Relativity*, Lorenzo Pieri of Createc Ltd and Oxford Brookes University (UK), arxiv.org/abs/2311.12069, wonders if warps can be scaled down far enough to make the negative energy requirements feasible. He suggests that a by-product of warp deceleration would be the emission of a ray of high-energy particles and the detection of such particles could be used as the backbone of a faster-than-light communication device. He aims to show that the total energy requirement for Planck-sized small bubbles can be satisfied with a Casimir device of reasonably large size. He tells us that the total negative energy requirement grows as the square of the bubble radius (so, as Feynman remarked in another context. There is "plenty of room at the bottom" [1]). He suggests that as little as one bit per warp bubble might be achieved in which case a lot of bubbles would be required to deliver even a very modest bitrate.

He is cautious in his claim of feasibility, observing that there are other avenues in physics which might be more fruitful and very substantial engineering challenges would remain.

However it's worth observing that artificial intelligences would certainly be capable of travelling at the speed of light and that "Hyperwave" would thus allow much less latency though at the cost of bandwidth as envisaged in this paper.

Matter/Anti-Matter Propulsion

In *Matter/Anti-Matter Propulsion* (www.intechopen.com/chapters/86283), Mark Pickrell discusses experiments at the Lawrence-Livermore National Laboratory (LLNL) [2] and the Max Planck Institute for Plasma Physics (MPIPP) [3]. Fuelling a rocket in this way seems to provide the maximum possible exhaust velocity as input to the Tsiolkovsky equation which limits all forms of reaction propulsion. He reviews this limit observing that the exhaust in this case is 511 keV gamma rays and thus the exhaust velocity is the speed of light, c. He takes us through some fundamentals of the physics of electromagnetic radiation and reports experiments at the LLNL showing that large quantities of positrons could be produced by high-energy, short-burst lasers striking high-atomic-mass targets. Together with the storage of electrons and positrons in an optimised dipole stellarator, suggested by the MPIPP he suggests we have a potential way to generate and store antimatter. He outlines a configuration for such a propulsion system -



System concept (courtesy Mustang Publishing). Figure 7. Credit (image and caption): Pickrell

Pickrell suggests the power source for the system is probably going to be a fission-based nuclear reactor, the paired-particle generator would be based on the Max Planck Institute design, the storage system will probably consist of twin tokamaks (one for storing electrons and one for storing positrons) and the annihilation chamber will be similar to the rocket nozzles that are used on chemical rockets.

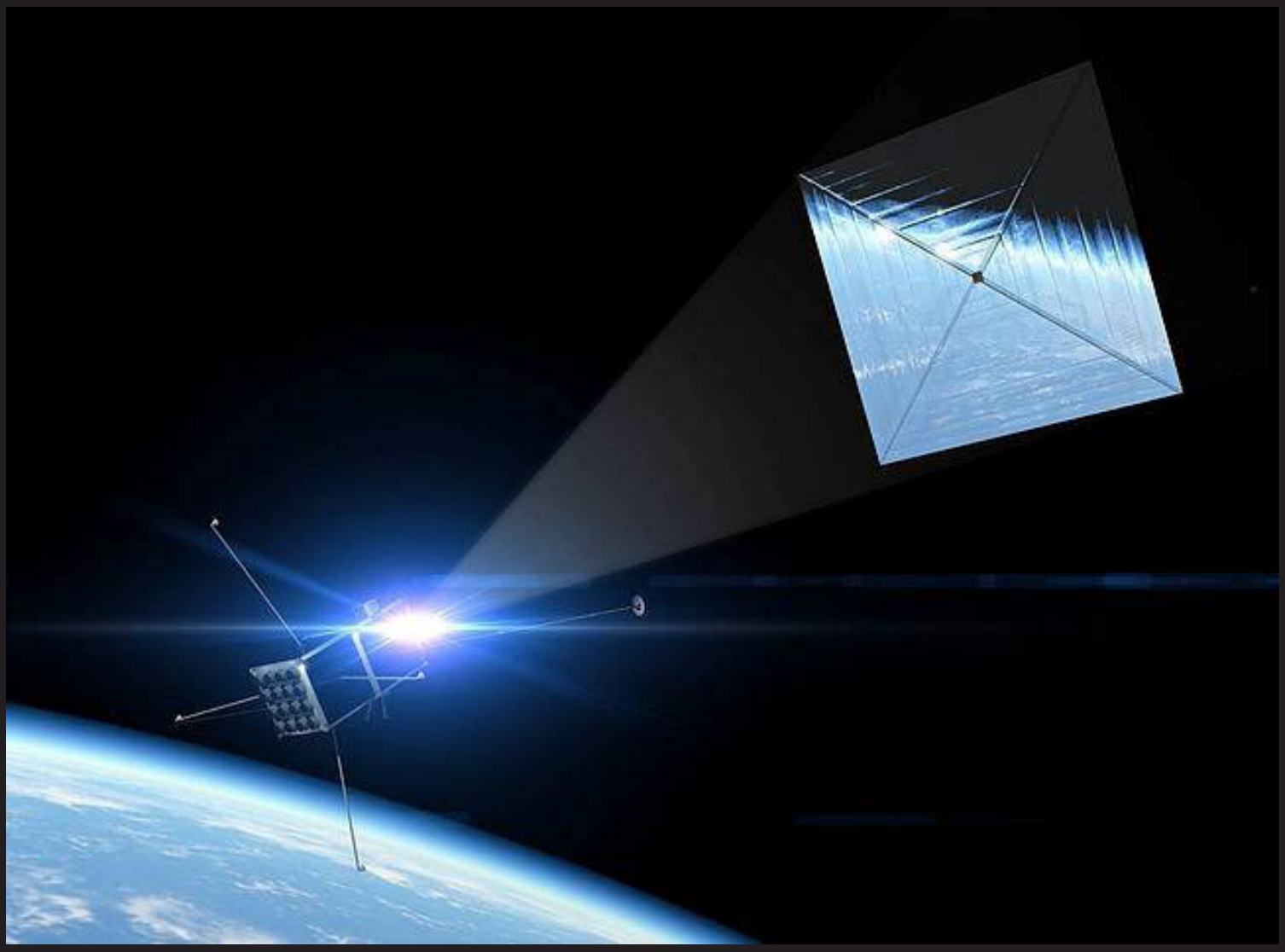
On board antimatter production would mean that probes would not require a storage system. Pickrell's "thought experiment" assumes a 10,000 kg probe which would accelerate at approximately 1.9 m/s^2 achieving 20% c in a year. He mentions issues to be overcome including experimental determination of an optimised paired-particle generator's capacity to produce the particles and whether the target substrate or the laser used is lost in the Bethe-Heitler Process (bremsstrahlung or braking radiation). Pickrell is President of Albireo Scientific Corporation, established to further experimental testing of matter/anti-matter propulsion.

[1] Our headline on this news item borrows from the thinking of Richard P Feynman who remarked "There's Plenty of Room at the Bottom" and introduced the idea of scaling machines down to molecular levels and anticipated nanotechnology.
[2] *Billions of Particles of Anti-matter Created in Laboratory*. www.llnl.gov/news/billions-and-billions-particles-anti-matter.
[3] *Electrons and Positrons in an Optimized Stellarator*. 2020 www.ipp.mpg.de/4793936/nwg-19.

JOIN I4IS ON A JOURNEY TO THE STARS!

Do you think humanity should aim for the stars?

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



The membership scheme of the Initiative & Institute for Interstellar Studies (i4is) is building an active community of enthusiasts whose sights are set firmly on the stars.
We are an interstellar advocacy organisation which:

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

Join us to support our work and also get:

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

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

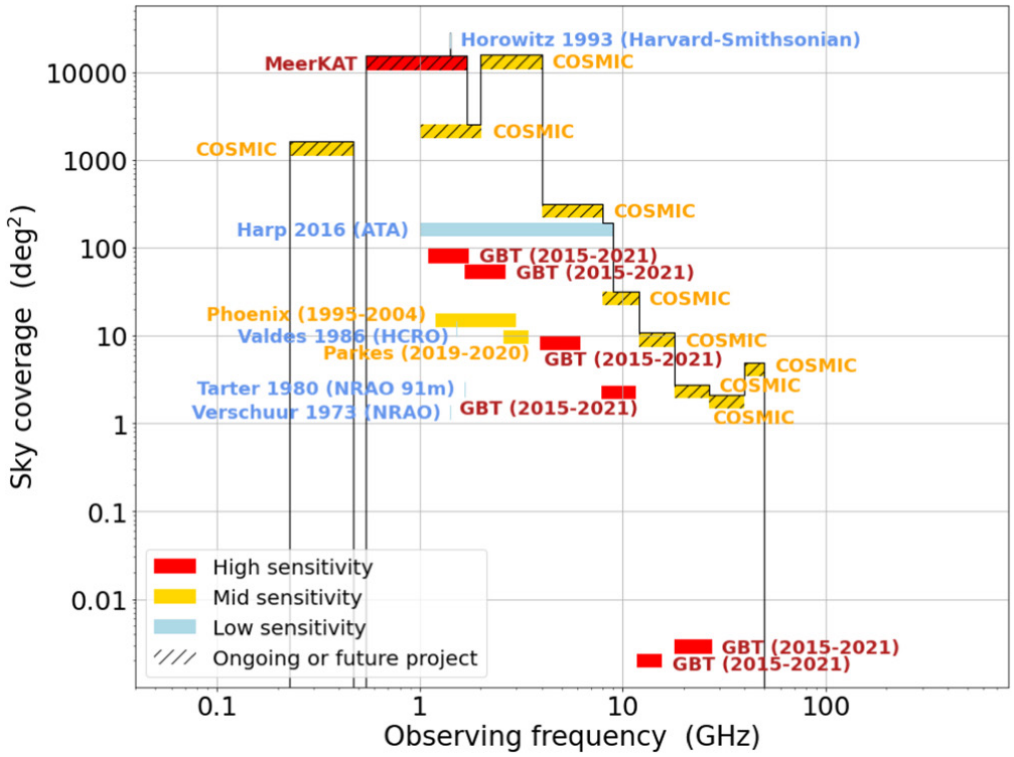
SETI Institute announces Breakthrough Listen funding

John I Davies

In *COSMIC: The SETI Institute is Unlocking the Mysteries of the Universe with Breakthrough Technology at the Karl G Jansky Very Large Array* [1], the SETI Institute announces a major initiative in the search for extra-terrestrial intelligence. The Commensal Open-Source Multimode Interferometer Cluster (COSMIC) is supported by the US National Radio Astronomy Observatory (NRAO) and Breakthrough Listen.

A paper in The Astronomical Journal [2] explains how the new Commensal Open-Source Multimode Interferometer Cluster (COSMIC) digital backend on the Karl G Jansky Very Large Array (VLA) will expand SETI with a new hardware system design, its current software pipeline, and plans for its future development.

The paper lists the instruments currently involved in this SETI effort and shows how they cover both sky and frequencies.

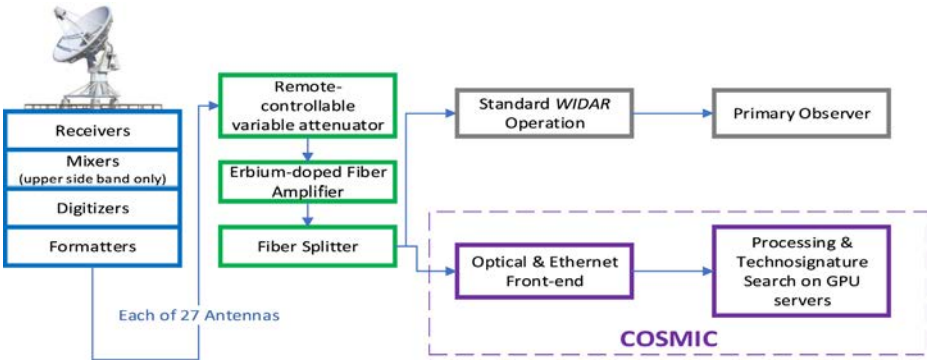


Sky coverage vs observation frequency for key SETI projects conducted to date (modified from Figure 5 of Ng et al 2022 [3]. The colour scale represents three levels of detectability for a 10^{13} W Arecibo-like transmitter emitting a 1 Hz wide technosignature. Blue represents low sensitivity, in which the transmitter must be within 5 pc from Earth; yellow represents medium sensitivity, corresponding to a transmitter 25 pc away; and red represents high sensitivity, enabling detection of a source at a distance of 75 pc.
Credit (image and caption): Tremblay et al, Figure 1.

[1] www.seti.org/press-release/cosmic-seti-institute-unlocking-mysteries-universe-breakthrough-technology-karl-g-jansky-very-large
[2] *COSMIC: An Ethernet-based Commensal, Multimode Digital Backend on the Karl G Jansky Very Large Array for the Search for Extraterrestrial Intelligence*, C D Tremblay et al, December 2023 iopscience.iop.org/article/10.3847/1538-3881/ad0fe0
[3] *Search for Extraterrestrial Intelligence with the ngVLA*, iopscience.iop.org/article/10.3847/1538-3881/ac92e7/meta

COSMIC enhances SETI at the Karl G Jansky Very Large Array by "piggybacking" on normal VLA processing ahead of the standard VLA processing pipeline and without impacting the standard scientist-driven programmes and processing. It will cover potentially tens of millions of stars in a frequency range of 0.074–50 GHz. It aims to exceed the capacity of other systems including even the giant MeerKAT array in South Africa.

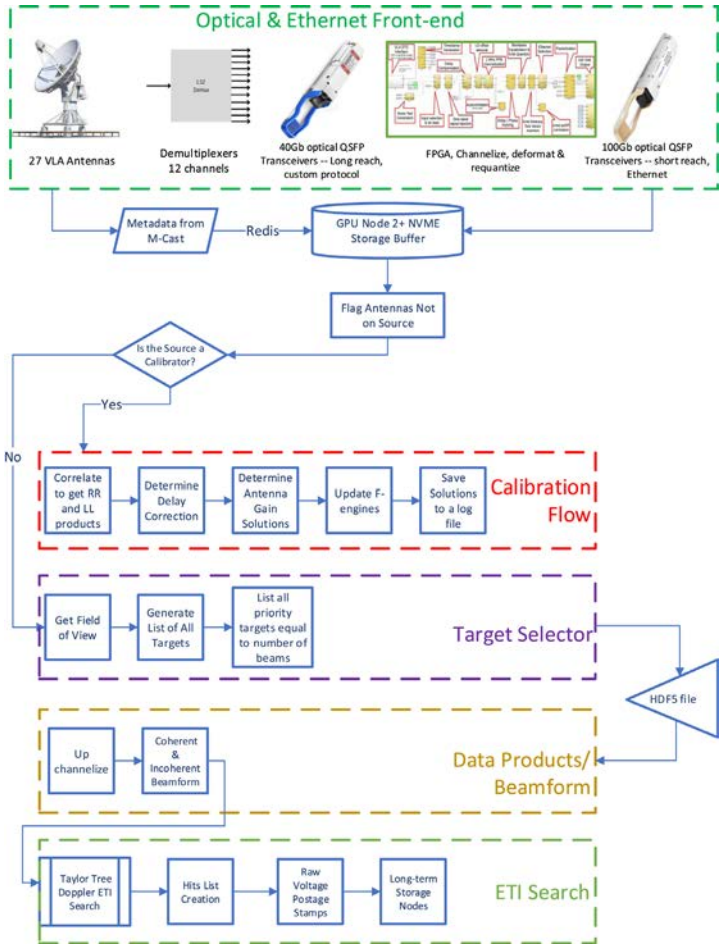
The VLA digitises its received signals at each of the 27 operational antennas in the array so the data feed to COSMIC cannot degrade the standard astronomical data feed. Each antenna has a field-programmable gate array (FPGA) module, 100 Gb/second Ethernet switches handle the multiple data streams and CPU and GPU array processors analyse each narrowband channel, for each polarisation, from all antennas in the VLA. The overall architecture of the VLA with the COSMIC back end is -



A high-level diagram of the data flow from the VLA antennas in the context of COSMIC. The signals from each antenna pass through the receivers, and in the 8 bit mode (the VLA can operate in both a 3 bit and an 8 bit mode), all received frequencies are shifted to the X band (8–10 GHz; upper sideband). COSMIC receives one copy of the digitized signals after they are amplified through an EDFA. The other copy is processed through the WIDAR correlator for standard VLA processing.
Credit (image and caption): Tremblay et al, Figure 3

The per-antenna front end uses FPGAs to implement a protocol for onward transmission which includes the usual checksums and embeds timing and synchronisation to allow both the digitisation sampling clock and the relative timing from each antenna to be recovered for processing.

In the current incarnation of COSMIC, the GPU compute cluster consists of 22 GPU servers. The data processing pipeline is shown right.



Schematic showing an overview of the COSMIC data processing pipeline. There are two data streams: one for real-time system calibration and the other for recording and searching the data for potential technosignatures. The beamformer is designed to create a flexible number of coherent beams, depending on computing resources and workflow. Additionally, the channelization step (Upchannelizer) can be modified to account for different frequency and time resolutions.
Credit (image and caption): Tremblay et al, Figure 8

It is notable that COSMIC, in common with other SETI systems, has to take special measures to combat radio frequency interference which (in the SETI case) has the additional hazard of false positives of ETI signals. The researchers aim to build a database of RFI for the site to combat this.

This paper is a detailed open access description of one of the major systems involved in the Search for Extraterrestrial Intelligence (about 13,000 words) and this news report has merely skimmed over a few points of interest. The paper may be of interest not only in the SETI field but as an example of how current digital systems technology can tackle the ancient question - Are we alone?

IAC 2023: The Interstellar Presentations Part 2

Edited by John I Davies

The Programme

Here is the programme with IAF identifying codes for the symposium sessions.

A1	IAF/IAA SPACE LIFE SCIENCES SYMPOSIUM
A2	IAF MICROGRAVITY SCIENCES AND PROCESSES SYMPOSIUM
A3	IAF SPACE EXPLORATION SYMPOSIUM
A4	52nd IAA SYMPOSIUM ON THE SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE (SETI) – The Next Steps
A5	26th IAA SYMPOSIUM ON HUMAN EXPLORATION OF THE SOLAR SYSTEM
A6	21st IAA SYMPOSIUM ON SPACE DEBRIS
A7	IAF SYMPOSIUM ON ONGOING AND NEAR FUTURE SPACE ASTRONOMY AND SOLAR- SYSTEM SCIENCE MISSIONS
B1	IAF EARTH OBSERVATION SYMPOSIUM
B2	IAF SPACE COMMUNICATIONS AND NAVIGATION SYMPOSIUM
B3	IAF HUMAN SPACEFLIGHT SYMPOSIUM
B4	30th IAA SYMPOSIUM ON SMALL SATELLITE MISSIONS
B5	IAF SYMPOSIUM ON INTEGRATED APPLICATIONS
B6	IAF SPACE OPERATIONS SYMPOSIUM
C1	IAF ASTRODYNAMICS SYMPOSIUM
C2	IAF MATERIALS AND STRUCTURES SYMPOSIUM
C3	IAF SPACE POWER SYMPOSIUM
C4	IAF SPACE PROPULSION SYMPOSIUM
D1	IAF SPACE SYSTEMS SYMPOSIUM
D2	IAF SPACE TRANSPORTATION SOLUTIONS AND INNOVATIONS SYMPOSIUM
D3	21st IAA SYMPOSIUM ON BUILDING BLOCKS FOR FUTURE SPACE EXPLORATION AND DEVELOPMENT
D4	21st IAA SYMPOSIUM ON VISIONS AND STRATEGIES FOR THE FUTURE
D5	56th IAA SYMPOSIUM ON SAFETY, QUALITY AND KNOWLEDGE MANAGEMENT IN SPACE ACTIVITIES
D6	IAF SYMPOSIUM ON COMMERCIAL SPACEFLIGHT SAFETY ISSUES
E1	IAF SPACE EDUCATION AND OUTREACH SYMPOSIUM
E2	51st IAF STUDENT CONFERENCE

d"

E3	36th IAA SYMPOSIUM ON SPACE POLICY, REGULATIONS AND ECONOMICS
E4	57th IAA HISTORY OF ASTRONAUTICS SYMPOSIUM
E5	34th IAA SYMPOSIUM ON SPACE AND SOCIETY
E6	IAF BUSINESSES AND INNOVATION SYMPOSIUM
E7	IISL COLLOQUIUM ON THE LAW OF OUTER SPACE
E8	IAA MULTILINGUAL ASTRONAUTICAL TERMINOLOGY SYMPOSIUM
E9	IAF SYMPOSIUM ON SECURITY, STABILITY AND SUSTAINABILITY OF SPACE ACTIVITIES
E10	IAF SYMPOSIUM ON PLANETARY DEFENSE AND NEAR-EARTH OBJECTS
GTS	GLOBAL TECHNICAL SYMPOSIUM

All of the programme items listed here are visible via iafastro.directory/iac/browse/IAC-23/.

Contents

These are the presentations and papers we report on in this issue - in order of IAC23 reference -

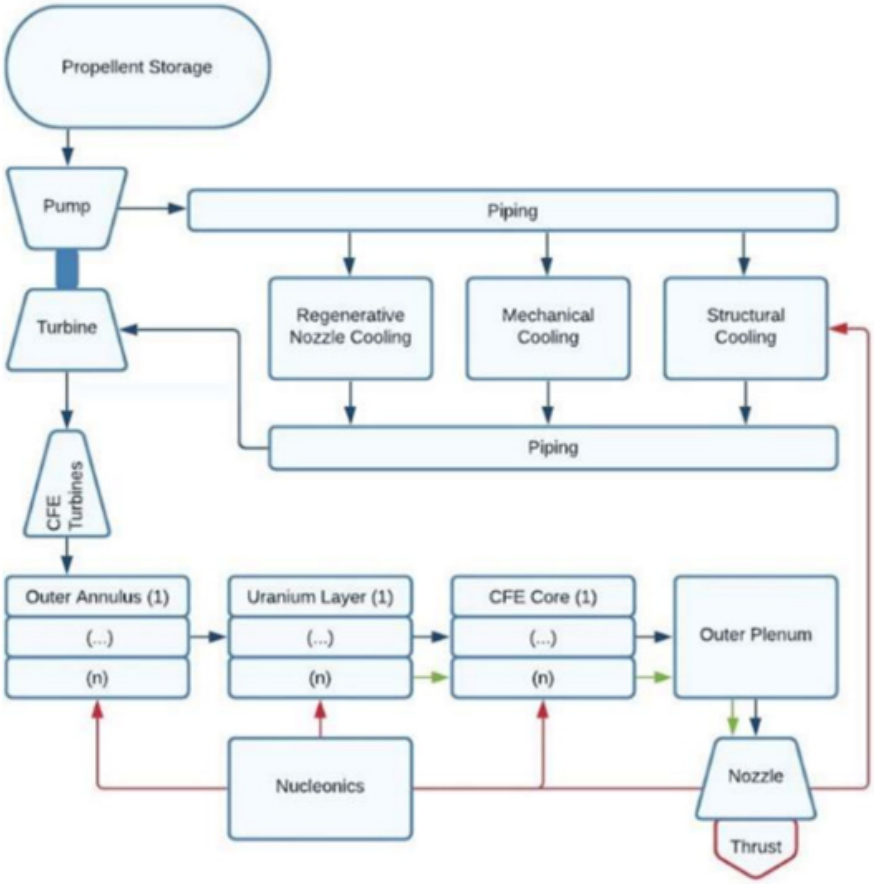
The Interstellar Programme Items

Access them all via iafastro.directory/iac/browse/IAC-23/. The reports include - Code - the unique IAC code, Paper title, Speaker, institutional Affiliation and Country plus links to the abstract, paper and video/ presentation on the IAF website (login required) and to open publication where found.
Please contact john.davies@i4is.org if you have comments, find discrepancies or have additional items we may have missed at the Congress. Details of each report are as follows -

IAC23 ref	Title	Presenter	Institution	Country
C4,10- C3.5 ,10,x76665	System Design Optimization for a Centrifugal Nuclear Thermal Rocket	Mr Mitchell Schroll	Propulsion Research Center University of Alabama in Huntsville	United States

IAF Abstract: iafastro.directory/iac/proceedings/IAC-23/data/abstract.pdf/IAC-23,C4,10-C3.5,10,x76665.brief.pdf
IAF Cited Paper: iafastro.directory/iac/proceedings/IAC-23/IAC-23/C4/10-C3.5/manuscripts/IAC-23,C4,10-C3.5,10,x76665.pdf
IAF Cited Presentation/Video: iafastro.directory/iac/proceedings/IAC-23/IAC-23/C4/10-C3.5/presentations/IAC-23,C4,10-C3.5,10,x76665.show.pptx
Open Paper: None found
Reported By: Parnika Singh
A Centrifugal Nuclear Thermal Rocket (CNTR) is a high-performance engine concept utilizing a liquid uranium fuel to achieve a theoretical specific impulse of 1,800 seconds. The design is a modification of traditional Nuclear Thermal Propulsion (NTP) in that it utilizes a high energy density uranium reactor to heat a propellant gas, eliminating the need for mass-hungry oxidizers. Preliminary studies suggest a CNTR could reach theoretical specific impulses in the range of 1,800 seconds, twice that of traditional NTP and nearly four times that of a chemical engine such as the RS-25.

This paper by Mr Mitchell Schroll develops a comprehensive model of CNTR technology, to allow for a more comprehensive investigation of its capabilities.
The idea of a CNTR is not new. The paper discusses the history of this technology – from its birth during the ROVER/NERVA programs of the 1950s, to the recent reinterest by NASA. However, despite this lengthy history, no comprehensive systems model has been created, which this paper changes. The paper uses a power balance approach as the main modelling method and MATLAB Simulink as the programming environment.



CNTR System Model
- Power Balance Approach
- Propellant State Engine
- Detailed Subsystems Models
  - Propellant Storage
  - Turbomachinery
  - Pipe Losses
  - Regenerative Nozzle Cooling
  - Structural Cooling
  - CFE Turbine
  - Cooling Loops
  - Core Model
  - Nucleonics
  - Core CFD
  - Nozzle Performance

Credit (image and caption): Schroll.

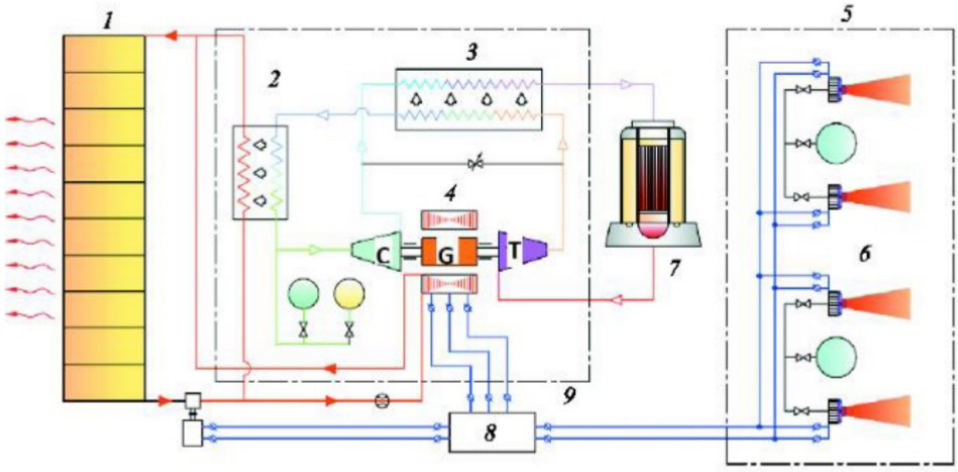
Because of the highly coupled nature of several of the sub-systems it was decided to model each component and avoid using "black box" methods to improve fidelity. The subsystems chosen for simulation are shown in the figure. The subsystems communicate through the master program which tracks the propellant properties across each state points in the engine. The individual methods used for each subsystem are detailed in subsections of the paper, with their equations and calculations included. The paper proceeds to optimize the CNTR model and compare it directly to conventional NTP. It finds that while CNTR technology is more powerful than convention NTP technology, it falls short of theorized maximum performance levels. Thus, the paper concludes that greater development of CNTR technology is needed before it becomes a feasible option for interstellar missions.

C3,5-C4.10,4,x75360	Application of Nuclear Power and Propulsion Systems of High Power Level for Space Transportation	Dr Vladimir Koshlakov	Keldych Research Centre	Russian Federation

IAF Abstract: iafastro.directory/iac/proceedings/IAC-23/data/abstract.pdf/IAC-23,C3,5-C4.10,4,x75360.brief.pdf
IAF Cited Paper: iafastro.directory/iac/proceedings/IAC-23/IAC-23/C3/5-C4.10/manuscripts/IAC-23,C3,5-C4.10,4,x75360.pdf
IAF Cited Presentation/Video: None found
Open Paper: None found
Reported By: Parnika Singh

This paper by Dr Vladimir Koshlakov deals with the application of spacecraft with power propulsion systems of a high-power level to perform various missions in outer space. The paper first discusses the various propulsion options currently feasible – namely solar sails, nuclear propulsion, and ion propulsion. It concludes that nuclear propulsion technology is the most promising option as it allows for very high specific impulses. The paper specifically singles out megawatt-class nuclear power and propulsion systems (NPPS). It explains the basic structure of an NPPS, which includes a nuclear reactor as a heat source and a system for converting thermal power into an electrical one in the closed gas turbine cycle (the Brayton cycle). A turbo compressor-generator is the major element of the gas and turbine system in the power conversion of nuclear energy into useful electrical energy. AC electrical power, generated by the power conversion system, with the help of the equipment of the electrical power conversion and distribution system, is transformed into DC electrical power of the required voltage ratings, which is used for electrical operations.

The paper then discusses how NPPS technology would be applied to space missions. It presents a variety of possible missions, such as Mars, Jupiter's moons, or even more distant targets. The paper develops a model for the flight duration for sample missions depending upon the payload mass. Missions to Europa, for example, range anywhere from 3.2 to 7.4 years. The paper also notes the various tweaks and specifications that would be required for each specific mission. From this, it also discusses the outstanding challenges of NPPS technology, such as the fact that missions to distant targets would require more Xenon than is currently annually produced. In order to avoid some of these issues, the paper proposes that NPPS technology be combined with electric propulsion technologies such as ion engines which would reduce the amount of fuel needed.



The NPPS diagram with a gas and turbine system of power conversion, and with a nuclear reactor: 1-heat radiator; 2-heat exchanger; 3-heat exchanger-recuperator; 4-turbo compressor-generator; 5-attitude control EP thrusters; 6-main EP; 7-nuclear reactor; 8-power management and distribution system; 9-power conversion system.
Credit (image and caption): Koshlakov Fig 2.

D4,4,1,x80088	Communications receiver designs for interstellar probe missions	Prof Philip Mauskopf	Arizona State University	United States

IAF abstract: iafastro.directory/iac/proceedings/IAC-23/data/abstract.pdf/IAC-23,C3,5-C4.10,4,x75360.brief.pdf
IAF cited paper: iafastro.directory/iac/proceedings/IAC-23/IAC-23/D4/4/manuscripts/IAC-23,D4,4,1,x80088.pdf
IAF cited presentation/video: none
Open paper: none found
Reported by: John I Davies

Prof Mauskopf emphasises the scale of the interstellar downlink by comparison with missions in or near our Solar System such as New Horizons to Pluto and the Kuiper belt [1]. With current deep space missions already using laser based downlinks their advantages for interstellar missions are clear. He introduces four concepts for large area optical receivers:

i) an array of 1 metre diameter low cost incoherently combined reflecting apertures,
ii) an array of 1 metre diameter low cost reflecting apertures coherently combined into 50 meter diameter optical receivers,
iii) a space-based collecting aperture based on low mass nanophotonic reflectors similar to the Breakthrough Starshot lightsail design,
iv) a crowd sourced citizen science initiative to produce small receivers for "backyard" collection of communications signals.

The target downlink data volume is approximately 100 kbytes per probe (recall that the Starshot mission would involve thousands of probes). As previously reported in Principium, Starshot chooses sparse pulse position modulation of the optical baseband. In a fixed length frame information is encoded by a single pulse in just one of the M slots in the frame. Each frame therefore carries $\log_2 M$ bits of information (eg for 2 slots this would be one bit, for four slots this would be two bits - and so on). The target receiver aperture is very large, 0.1 - 1 square kilometres.

Prof Mauskopf cites a paper that we summarised in our last issue *Interstellar flyby scientific data downlink design* in Principium 42, August 2023 i4is.org/principium-42 [2] and an open-source interactive communications model at www.wolframcloud.com/obj/messer/Published/Starshot%20parameter%20exploration%20v1.2.nb which includes four examples ranging from the most conservative, taking values that might readily be implementable in current technology to the most optimistic, assuming considerable advances in technology. A major input to this thinking is NASA's Deep Space Optical Communications (DSOC), a communications experiment flying with the Psyche spacecraft, as reported in Interstellar News in our August 2023 issue, P43 (page 21).

Prof Mauskopf notes that current laser communications systems typically use 1,550 nm wavelength sources but that shorter wavelengths have advantages for Starshot and typical values are 400-500 nm. This corresponds to transmit at 432 nm and receive, Doppler shifted, at 539 nm wavelengths in the paper by the i4is team reported in Principium 41, May 2023, *i4is delivers Communications Study to Breakthrough Starshot*, i4is.org/principium-41. The i4is team paper is *Swarming Proxima Centauri: Optical Communication Over Interstellar Distances* (arxiv.org/abs/2309.07061).

Other factors considered by Prof Mauskopf include receiver total collecting area, receiver individual aperture area, transmit aperture, transmit average power, transmit peak to average ratio (crucial in pulse position modulation - PPM), filter bandwidth for detection (data rate versus unwanted signal rejection), number of PPM slots (data rate versus power demand) and noise power.

He analyses the transmit component, an optical beamforming transmitter, comprising -

- Signal generation - a pulsed peak power of at least 5 W with a pulse width of less than 0.5 milliseconds.
- Signal distribution - over a diameter >10 cm.
- Phase control - to achieve a diffraction limited beam width and pointing accuracy.

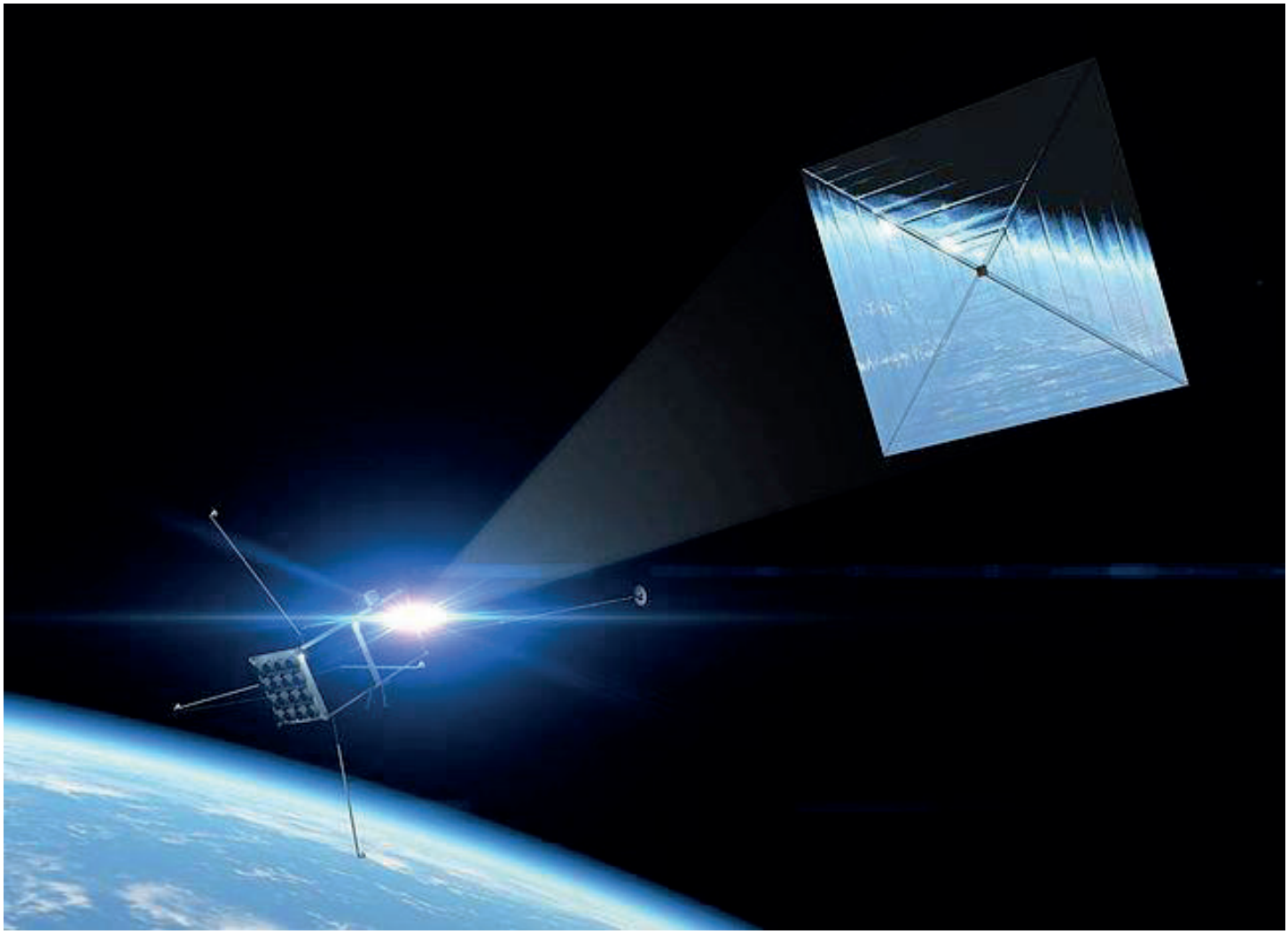
Gallium-Arsenide (GaAs) lasers have already demonstrated close to the required power with masses less than 0.02 grams. Phased arrays are common at microwave frequencies but are a more recent challenge at optical wavelengths. Despite the title of the paper the receiver is treated only briefly.

[1] Basics of this see *The Interstellar Downlink: Principles and Current Work* in Principium 31 Nov 2020 i4is.org/principium-31/
[2] *Interstellar flyby scientific data downlink design*, David Messerschmitt, Philip Lubin and Ian Morrison arxiv.org/abs/2306.13550

JOIN I4IS ON A JOURNEY TO THE STARS!

Do you think humanity should aim for the stars?

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



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

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

Join us and get:

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

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

90% discount for full time students!

The Journals

John I Davies

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

JBIS

Two issues of JBIS (online), August and September 2023, have appeared since the report in our last issue, P43. Later issues are in print but not yet online.

Title	Author	Affiliation
Abstract/Précis/Highlights		

JBIS VOLUME 76 2023 NO.8 AUGUST 2023 INTERSTELLAR ISSUE		
Calculations of Particle Bombardment Due to Dust and Charged Particles in the ISM on the Project Starshot Gram-Scale Interstellar Probe	**Kelvin F Long**	**Interstellar Research Centre, Stellar Engines Ltd**
The Breakthrough Initiatives Project Starshot proposes to send a gram-scale laser driven spacecraft to the Alpha Centauri system in a 20 year mission travelling at v~0.2c. One of the challenges of this mission as the spacecraft moves through the interstellar medium is the presence of dust and gas (mostly hydrogen). The dust has a typical matter-density of 2.57×10^{-27} g/cm3 with typical particle mass being 3×10^{-13} g although some of the largest particles may be 5×10^{-9} g in mass. These dust particles will deposit ~1,012-1,016 MeV onto the spacecraft with an energy flux of order ~0.3 J/sm². We consider the erosion of the spacecraft frontal area due to dust and also heating effects. We attempt to characterise the likely environment for the Starshot mission and estimate the particle bombardment shielding requirements in terms of mass and thickness of material. Current analysis estimates that the likely erosion rates are of order ~10^{-11}-10^{-8} g/s and that the frontal area temperature for the models examined in this paper will be ~135.2 K depending on the ratio of frontal area to radiating area. For an assumed shielding material with atomic number range 3-13 (Lithium to Aluminium), and for spacecraft geometries with radii ~1 mm and cylindrical length ~5 mm, over a 21.5 year mission duration, this would suggest a shielding thickness of ~1.4-3 mm. This would also suggest a shielding mass in the range ~0.01-0.05 g; depending on the material choice, spacecraft size and chosen geometry. This would represent between ~1–5% of the total mass, assuming a spacecraft mass of 1g (driven by a ~102 GW laser power). We also examine the additional effects of charged particles and estimate the stopping power and penetration range for different materials. Finally, we briefly examine the potential to use the incoming energy flux as a power source for the transmission of an optical laser deep space communication system. The work presented highlights the close coupling in the Project Starshot spacecraft design between the vehicle geometry and the particle bombardment requirements.		

Interstellar Diplomacy	John Gertz	Zorro Productions
The Defense Department and NASA are investigating the possibility that aliens are currently surveilling Earth. This aligns with some search-for-extraterrestrial-intelligence (SETI) theorists who have concluded that ET's best strategy for opening a channel of communication is to send artificially intelligent probes to our Solar System for that purpose. This is a golden age for traditional SETI, which is currently well funded, with most of the world's radio telescopes now engaged in the hunt. One way or another, contact with aliens may be imminent. There has been no planning among nations for the aftermath of a first detection. This paper advocates for such planning and diplomacy.		
The Maximum Tolerable Gravity for Human Colonies	Barton Paul Levenson	-
Due in part to misinterpretation of a recent paper in the professional literature, the popular impression has taken hold that humans can tolerate living on a 4 or 5 g planet indefinitely. Experience from experiments in aerospace medicine imply that this figure is far too high. A maximum permanent tolerance level of 1.5 g for humans, suggested in 1964, has still not been superseded by any further research, and is likely close to the truth.		
Breakthrough Sun Diving: The Rectilinear Option	Greg Matloff, Les Johnson	New York City College of Technology (CUNY), NASA Marshall Space Flight Center
A near-term possibility for utilization of Breakthrough Initiatives Project Starshot technology is application of the sun diving maneuver as a replacement for laser acceleration of highly miniaturized photon sails to interstellar velocities. This possibility was discussed during the June 2022 Breakthrough Discuss meeting in Santa Cruz California. Here, we consider application of statite-type photon sail probes to achieve rectilinear trajectories to explore outer solar system and near-interstellar destinations. Statite-Type solar photon sails are sufficiently thin and reflective that solar radiation pressure force on the sail exactly balances the solar gravitational force. In such a force-free environment, the spacecraft exits the solar system at its pre-sail-deployment solar-orbital velocity. Here we consider departures from a circular 1 AU solar orbit, the perihelion of a 0.7-1 AU elliptical solar orbit and the perihelion of a 0.3-1 AU solar orbit. Possible outer-solar-system destinations of possible interest to Breakthrough Initiatives extraterrestrial-life/artifact-search researchers include Europa, Titan, Enceladus, Methone, and Arrokoth. More distant possible objectives are 'Oumuamua and the Sun's inner gravitational focus. To achieve a rectilinear trajectory, the sail must be orientated normal to the Sun and spacecraft areal mass thickness is 1.46 × 10-3 kg/m2. Current sail technology is reviewed to determine whether it can achieve the required areal mass thickness.		
Minimal Crew Size and Sensitive Reproductive Parameters on Multigenerational Interstellar Travel	Sano Satoshi	Japan Aerospace Exploration Agency
Multigenerational interstellar travel to exoplanets, as well as manned missions to the Moon and Mars, has been investigated in the world. Defining the minimum crew size of interstellar ships is one of the most important research areas for interstellar travel, because designing multigenerational interstellar ships requires defining a critical crew size, which factors into many variables, including food production, air/water control, and propulsion. Anthropologists and astrophysicists have recently tackled with the minimum crew size of interstellar ships in the field of "Space anthropology". Previously published computations in the field of space anthropology provided a critical crew number of 1,900- 2,000 (Sano, 2021) with constant reproductive parameters, but did not fluctuate reproductive parameters such as infertility, initial genetic diversity and number of children per woman. These parameters would fluctuate during the real multigenerational journey. Then, a more accurate estimate of the critical crew size would be obtained from the fluctuating parameters. This paper provides a critical crew size of 1,400-6,800 for interstellar travel using the fluctuating parameters, and clarifies which anthropological parameters are sensitive and how critical to be controlled aboard interstellar ships. It indicates that measuring infertility and controlling the number of children per woman for many generations onboard interstellar ships are essential to prevent extinction, and firstly quantifies the importance of high diversity of initial crew and procreation window for interstellar travel.		

Acta Astronautica

Acta Astronautica papers are published online before print. Three issues with relevant papers have appeared since the last issue Principium P43.

Title	Number+date	Author
Abstract or Summary		
The Fermi paradox and the Drake equation	Volume 215 February 2024	Carl L DeVito
The Fermi paradox and the Drake equation seem to be incompatible. Here we shall show that is not so, and the paradox actually justifies the assumptions made in formulating this equation. ... The [Fermi] paradox here arises from the fact that, although most estimates of N give a large number, Fermi's question remains unanswered. Here we shall show that these two aspects of SETI are not incompatible; In fact, our investigation of the paradox justifies the assumptions Drake made in writing his equation.		
Meeting extraterrestrials: Scenarios of first contact from the perspective of exosociology	Volume 215 February 2024	Andreas Anton, John Elliott, Michael Schetsche
Decades ago, pioneers such as the Russian astronomer Samuil Aronovich Kaplan and the American sociologist Jan H Mejer had already considered the role of the social sciences in the study of extraterrestrial civilizations. But it is only because of the advances in scientific knowledge mentioned above that exosociology – as they called it – can really make a good case for devoting time and financial resources to the study of these questions: Today it seems conceivable (some even consider it probable) that humanity will sooner or later come into contact with extraterrestrial civilizations. Accordingly, it is the task of social science forecasting to develop scenarios for this event. An event that may or may not become a reality in the next few decades – but certainly could. It is clear that exosociology can ultimately only provide building blocks (albeit important ones) when assessing the possible consequences of first contact. This task is so enormous that it requires efforts, research findings and theories from a wide range of social science and humanities disciplines, as Steven Dick has convincingly demonstrated in his book Astrobiology. Discovery and Social Impact. Perspectives from the fields of law and psychology are no less necessary. Exosociology can be understood as a subfield of the much broader field of astrosociology, as conceptualised by Jim Pass a few years ago. Astrosociology is concerned with the entirety of human relations with space, including issues such as the commercialisation of space, the social significance of space exploration, and the social forms of possible future human colonies beyond Earth. Exosociology is therefore – in line with Kaplan and Mejer – that part of astrosociology that explicitly and exclusively deals with the potential encounter of humanity with extraterrestrial civilisations.		

BLISS: Interplanetary exploration with swarms of low-cost spacecraft	Volume 215 February 2024	Alexander N Alvara, Lydia Lee, Emmanuel Sin, Nathan Lambert et al.

Leveraging advancements in micro-scale technology, we propose a fleet of autonomous, low-cost, small solar sails for interplanetary exploration. The Berkeley Low-cost Interplanetary Solar Sail (BLISS) project aims to utilize small-scale technologies to create a fleet of tiny interplanetary spacecraft for rapid, low-cost exploration of the inner solar system. This paper describes the hardware required to build a ~10 g spacecraft using a 1 m^2 solar sail steered by micro-electromechanical systems (MEMS) inchworm actuators. The trajectory control to a NEO, here 101955 Bennu, is detailed along with the low-level actuation control of the solar sail and the specifications of proposed onboard communication and computation. Two other applications are also shortly considered: sample return from dozens of Jupiter-family comets and cometary nuclei imaging. The paper concludes by discussing the fundamental scaling limits and future directions for steerable autonomous miniature solar sails with onboard custom computers and sensors.

Are we visible to advanced alien civilizations?	Volume 216 March 2024	Z N Osmanov

We considered the question of how our artificial constructions are visible to advanced extraterrestrial civilizations. Taking the universality of the laws of physics, we found that the maximum distance where the detection is possible is of the order of 3,000 ly and under certain conditions Type-II advanced alien societies might be able to resolve this problem.

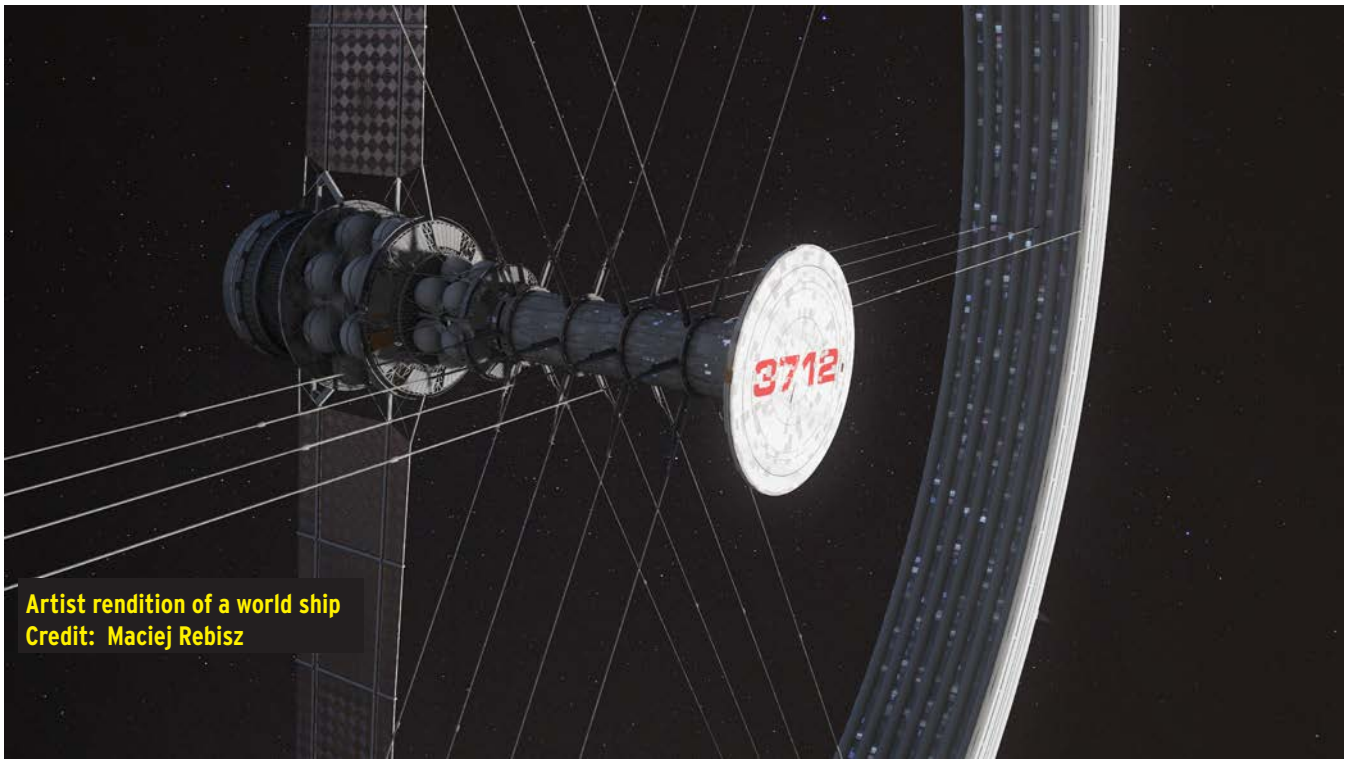
High-speed scientific spacecraft launches with commercial launch vehicles	Volume 217 April 2024	Ralph L McNutt, Steven R Vernon, Pontus C Brandt, Michael V Paul, Robert P Lusthaus

Reaching the outer solar system and interstellar space beyond has always been challenging due to the long distances and long travel times. Initial work on planetary gravity assists in the early 1960s by Minovitch and Flandro laid the basis for expanding reachable space with then-existing launch vehicles. Such gravity assists have been key enablers for orbital exploration missions to Mercury (MESSENGER), Jupiter (Galileo, Juno), and Saturn (Cassini-Huygens) by trading higher mass for lower launch energy from Earth (C3). They have also enabled close passes to the Sun (Parker Solar Probe) and moderately rapid solar system escape, coupled with fast flybys of various planetary-sized bodies: Mariner 10 (Mercury via Venus), Pioneer 10 (escape via Jupiter), Pioneer 11 and Voyager 1 (escape via Jupiter and Saturn), Voyager 2 (escape via Jupiter, Saturn, Uranus, and Neptune: the "Grand Tour"), and New Horizons (escape via Jupiter and Pluto). Two of these missions hold the first and second places for the most energetic launches (New Horizons: C3 = 157.7502 km^2/s^2; Parker Solar Probe: C3 = 152.222 km^2/s^2). Disadvantages in using Earth and Venus gravity assists to increase spacecraft injected mass to Jupiter and beyond include the time penalty and the need for a customized propulsion system to provide a deep-space manoeuver (DSM). For "timely" transits to Neptune with a large orbiter or rapid solar system escape with an Interstellar Probe, more capable launch vehicles can be enabling by pushing the injected mass versus C3 curves "to the right." While the most extreme speeds asymptotically away from the Sun (7–8 au/yr) can be achieved with fast Jupiter gravity assists and super heavy lift-launch vehicles (SHLLV) such as the Space Launch System (SLS) surmounted by multiple upper stages, solar system escape speeds larger than those achieved by Voyager 1 are possible with existing and upcoming large commercial launch vehicles. Such vehicles include the Falcon-Heavy, New Glenn, and Vulcan Centaur. Better performance accrues with the fully expendable versions of these vehicles and/or with "refilling" in a low-Earth orbit, with performance versus launch cost as a central trade. Even better performance can be projected with SHLLVs in development, such as the Starship Super Heavy and Long March 9. We discuss some of the possibilities and trades such newer vehicles can enable in the near term for continued – and more distant – exploration of the solar system and beyond.

BECOME AN i4is MEMBER

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

Parnika Singh



Artist rendition of a world ship
Credit: Maciej Rebisz

The Initiative for Interstellar Studies (i4is) has launched a membership scheme intended to build an active community of space enthusiasts whose sights are set firmly on the stars. You can directly support interstellar programmes and even get involved with our projects! We are an interstellar advocacy organization that conducts theoretical and experimental research and development projects and supports interstellar education and research in schools and universities.

By becoming a member, you are not just supporting our cause, but will also gain:

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

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

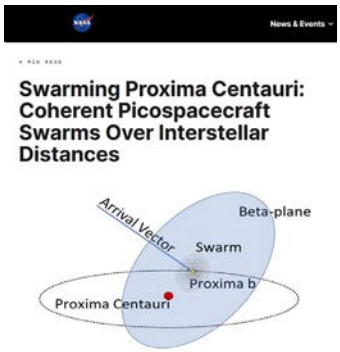
THE i4iS MEMBERS' PAGE

Patrick J Mahon

The i4is membership scheme exists for anyone who wants to help us achieve an interstellar future. By joining i4is, you help to fund our technical research and educational outreach projects. In return, members receive exclusive benefits, including our programme of talks, a newsletter and preprints, and access to the members-only area of the website, to which new material is added on a regular basis. If you aspire to an interstellar future for humanity, joining our membership scheme will get you more involved while helping us take the vital early steps toward that goal.

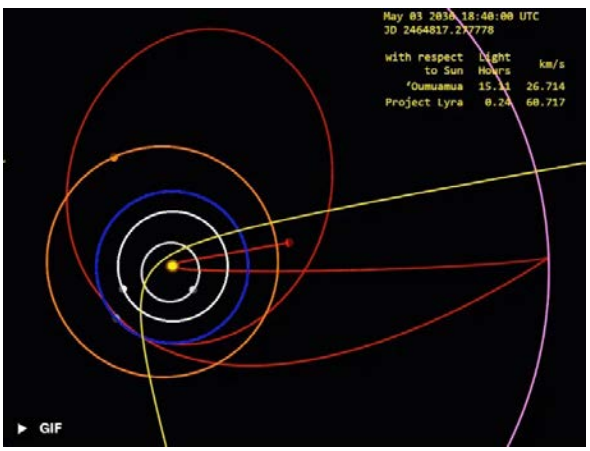
i4is wins NASA grant!

The year started with some amazing news for i4is, and we're delighted to share it with our members. On 4 January, NASA announced that it had awarded a phase 1 grant under the prestigious NASA Innovative Advanced Concepts (NIAC) scheme to a project submitted by i4is in collaboration with Space Initiatives Inc and our good friend Thomas Eubanks. The grant will fund early work on a project to study the concept of sending a swarm of tiny spacecraft to Proxima Centauri this century, from where they would send back data about the Sun's nearest interstellar neighbour using a novel laser sailcraft and laser communications system. For further details of the project, see www.nasa.gov/general/swarming-proxima-centauri/.



Project Lyra goes viral!

We're used to the fact that interstellar studies are normally the preserve of a select sub-group of those with an interest in space. So we were very pleasantly surprised on 8 December last year, when a tweet from amateur astronomer and orbit simulator Tony Dunn (@tony873004 on Twitter), which showed a simulation of how a Project Lyra spacecraft might make its way to 'Oumuamua, based on data provided by our very own Adam Hibberd, went viral. The post ending up getting over 3.5 million views, and even Elon Musk commented on it! It's good to know that there's much wider interest in our subject than we might normally encounter.



Tony Dunn @tony873004 visualises one of Adam Hibberd's Project Lyra missions @hibberdadam994 twitter.com/tony873004/status/1732961608606056718
Here is the mission just after aacceleration around the Sun.

i4is SF book club and planned anthology

The i4is SF book club continues to meet monthly over Zoom, reading and discussing two classic science fiction stories at each meeting. To join the club, please email bookclub@i4is.org for the link.

The planned i4is SF anthology is still looking for submissions. If you'd like to know more, see recent editions of the i4is members' page in Principium, or email the anthology editors, sarah.margree@i4is.org and jean.asselin@i4is.org.

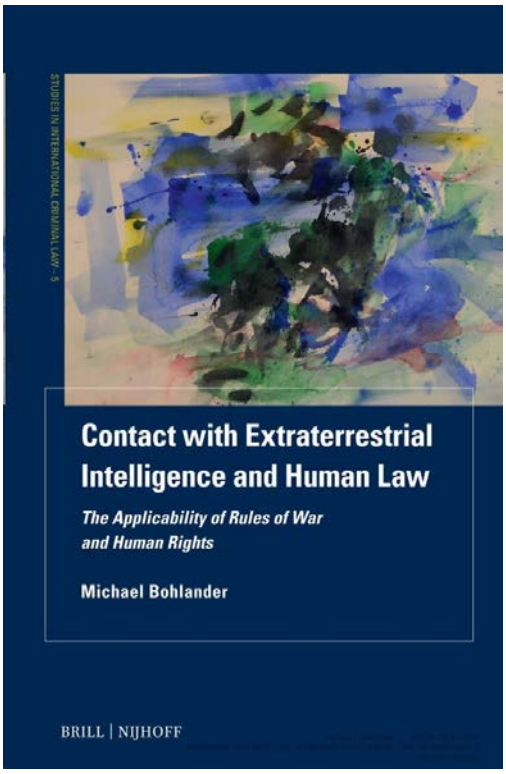
Recent member newsletters

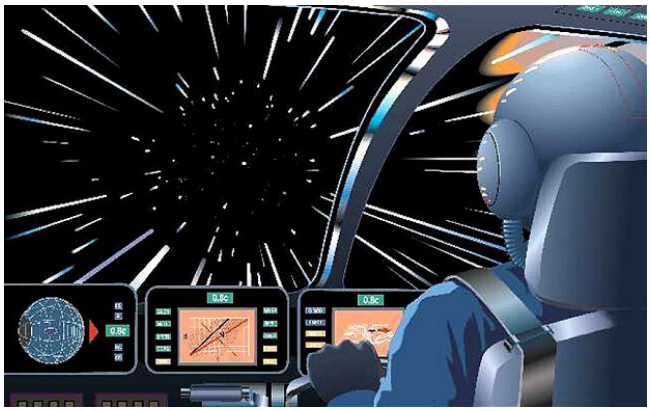
There have been three member newsletters since the November 2023 issue of Principium. These came out on 28 November, 29 December and 27 January. All are available from the member-only area on the website.

Getting more actively involved

If you'd like to go beyond your membership of i4is, and get involved with our work more actively, we'd love to hear from you! There are many different ways you can help us take our programmes forwards, whether your skills are technical, educational, administrative or financial. The more volunteers we have, the more we can achieve! If you think you could volunteer some time, please get in touch at info@i4is.org, and one of us will get back to you as soon as possible.

NEXT ISSUE





Left: Cover of Contact with Extraterrestrial Intelligence and Human Law, Michael Bohlander, Brill Publishers
Right: An SF image of space warp travel. Credit: NASA

- **Book review - Contact with Extraterrestrial Intelligence and Human Law:** The applicability of rules of war and human rights by Professor Michael Bohlander of Durham University. We will have a review by members of the legal group at KCL Space (www.kclspace.com/space-law) at King's College London.
- **Current FTL thinking**: Faster than light (FTL) travel has been the subject of much serious thinking and it still engages the brains of some of the brightest on the planet but are we any nearer to achieving it other than in fiction? Dr Dan Fries, Deputy Head of the i4is Technical Team, will review where things stand.
- **Doubling Human Lifespan - implications for the interstellar enterprise**: Many of the social and moral issues arising from the possibility of worldships might look different for longer-lived humans.
- Plus **Interstellar News**, News Features and interstellar papers in **The Journals**.

COVER IMAGES

Our cover images for this issue look at both the main options for a near term interstellar mission: a swarm of laser-propelled probes or a fusion probe.

FRONT COVER

SpaceX Starship delivering a swarm of interstellar probes
The probe swarm envisaged by i4is and Space Initiatives in the study reported in P41, *i4is delivers Communications Study to Breakthrough Starshot*, and the new work under 2024 NASA NIAC programme would require delivery to the point of interstellar launch. Here Michel Lamontagne visualises the delivery in preparation for propulsion by the laser beamer.

BACK COVER

An Icarus Firefly probe passes Jupiter's Galilean moon Io.
A laser-propelled swarm is our most achievable option for an interstellar probe. We hope that, sometime in the next hundred years, we can send a much more substantial probe to our nearest stellar neighbours. Our current best option for this is fusion propulsion and the most recent detailed work on this is the Firefly design, part of Project Icarus.
This image by Michel Lamontagne, co-leader of the Firefly team, shows a variant of the base design passing Jupiter's moon.

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

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.

Front cover: SpaceX Starship delivers a swarm of interstellar probes
Credit: Michel Lamontagne
Back cover: An Icarus Firefly probe passes an outer planet moon
Credit: Michel Lamontagne

SCIENTIA AD SIDERA
KNOWLEDGE TO THE STARS

Mission

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

Vision

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

Values

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

I4IS.ORG