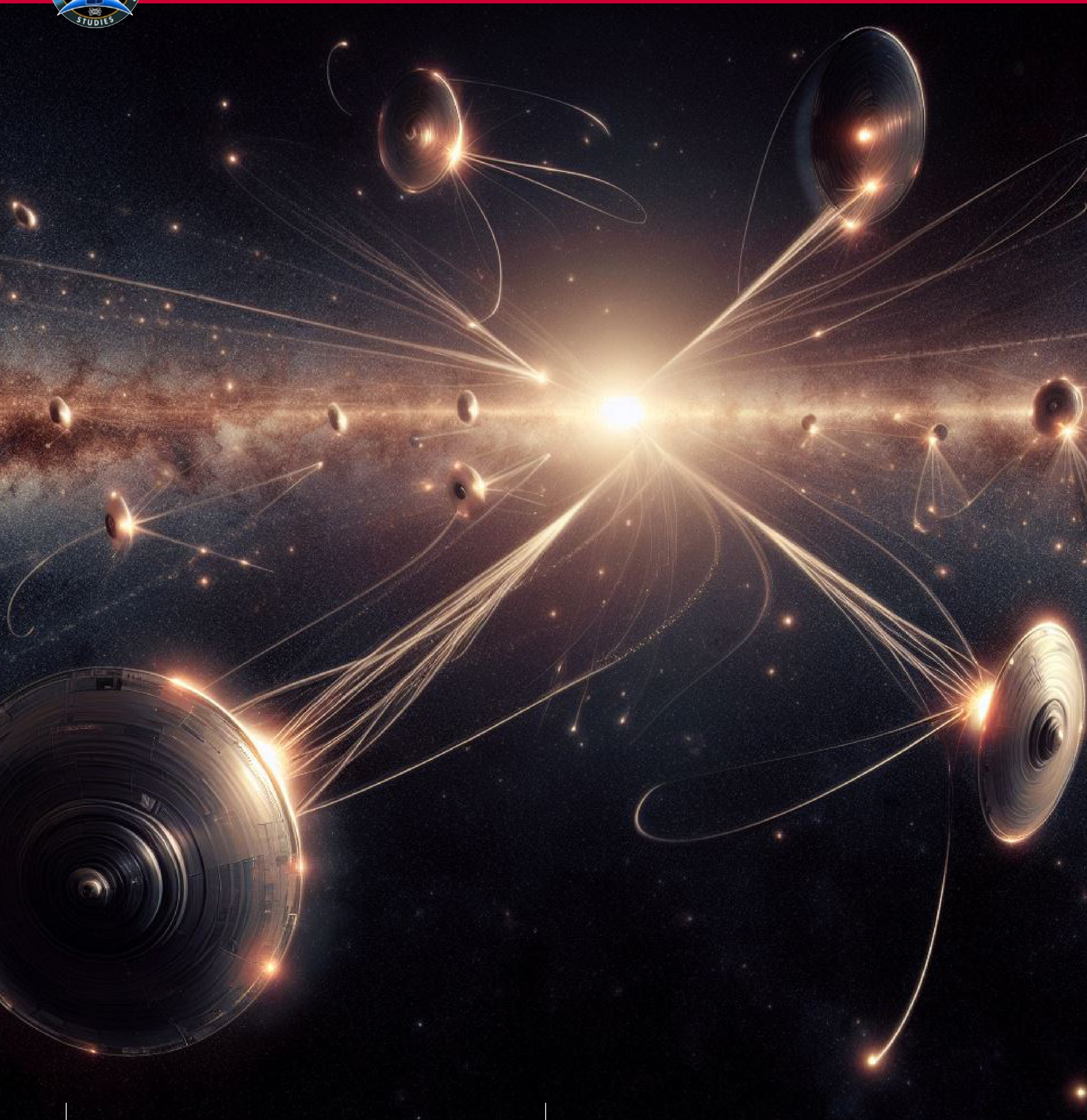
PRINCIPIUM

The Initiative and Institute for Interstellar Studies | Issue 43 | November 2023

SCIENTIA AD SIDERA | KNOWLEDGE TO THE STARS



Lead Feature: IRG23 - The Summaries

Natural Geo-engineering of the early Earth

News Features: more from IRG23, IAC23 report part 1

Interstellar Studies - Inspiring the next generation

Interstellar News

The Journals. JBIS and Acta Astronautica

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EDITORIAL

Welcome to issue 43 of Principium, the quarterly magazine of i4is, the Initiative and Institute for Interstellar Studies. This is a bumper news issue - reports and essays on the presentations at the Interstellar Research Group 2023 Symposium - including our Lead Feature. And in *BIS Symposium brings Project Icarus to a close* a brilliant summation of a landmark event. Also our first reports on items from the International Astronautical Congress, IAC2023, news of our Royal Institution Summer School and encouraging the rising generation at the University of Luxembourg (and we'll be reporting two schools events at the University of Lincoln in our next issue). We have 17 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*.

We feature an intriguing piece on natural geo-engineering based on work by Dr Phil Sutton at the University of Lincoln.

The front cover image is an AI image of probes at Alpha Centauri from work by Marshall Eubanks. The rear cover image shows the contrast between images from the Hubble and James Webb telescopes. 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, P44 in February 2024, will have -

■ Our postponed survey of *Current FTL Thinking* by Dan Fries and Parnika Singh.

■ A review of a new book - *Contact with Extraterrestrial Intelligence and Human Law - The applicability of rules of war and human rights* by Professor Michael Bohlander of Durham University.

■ More from IAC23 and IRG23

- and the usual Interstellar News and journal reports.

More details on P44 in *Next Issue* at the end of P43.

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, full-size on page 29. There's lots to do!

Please promote our work by printing and displaying i4is membership posters, see pages 47 (black) and 67 (white)

If you have any comments on Principium, i4is or interstellar topics more generally, we'd love to hear from you. Write us an interesting - or challenging - letter and we'll publish!

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

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

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Back issues of Principium, from number one, can be found at www.i4is.org/Principium

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

CONTENTS

IRG23: The Summaries

Edited by John I Davies

In our previous issue, P42 (i4is.org/principium-42/) we featured reports from delegates at the IRG23 Symposium. The programme is at irg.space/irg-2023/ with videos via the IRG channel [1]. Here our Principium reporters summarise the presentations or, where available, the associated papers (images are credited to the paper authors). These summaries are followed by a number of more detailed **News Feature** essays on selected presentations at the Symposium.
We will bring you more in our next issue P44 in February 2024.

Should we Colonise (Interstellar) Space?

Joe Gottlieb, Texas Tech University, Philosophy Department

Is space colonisation (SC) the right course for humanity, morally? Protecting the future means ensuring, first, that we have a future and, second, that it is a good one.

Would SC minimise the risk of extinction? Some writers are optimistic about this, some pessimistic. 'Decelerationists' are agnostic but favour caution before embarking on SC. Gottlieb lists six existential risks – nuclear war, climate change, super volcanic eruptions, stellar explosions, engineered pandemics and unaligned goal-directed AGI. The case for SC is that, if sufficiently scaled, it could in principle deliver 'catastrophe independence', by enabling the establishment of self-sustaining and distanced settlements (so that humanity's eggs are not all in one basket). Gottlieb however is sceptical, partly because he regards AGI as posing humanity's greatest threat and doubts that future settlements would be able to isolate themselves from its spread. Nevertheless, he accepts that distanced settlements would reduce the risk posed by some of the extinction threats.

If humanity has a future, can SC help ensure that it's a good one? What does a good future look like? Gottlieb touches on the debate between positive and negative utilitarianism, ie between those who prioritise maximising happiness and those who think it's more important to minimise suffering. The development of SC might lead to technologies which do both: eg in vitro meat, which would replace animals suffering in our food chain, and asteroid mining, which might dramatically increase sustainable economic growth.

SC may pose extinction risks of its own. One is 'chronic distance'. A civilisation spread too widely would become ungovernable, leading to value drift and perhaps anarchy. Even the nearest star (Proxima Centauri) might be too distant for governance. Gottlieb cites Daniel Deudney's six extinction risks arising from SC, including an increased risk of war and totalitarianism, deregulation leading to hazardous technology [2], and an extinction risk arising from extreme cultural and genetic diversification. However, Gottlieb notes that some of these risks could arise even if SC does not happen.

Gottlieb concludes with three points favourable to SC. 1. He rejects the slogan that we should make people happy, not make happy people. 2. An earth-bound civilisation has a much shorter habitable lifespan than a Milky Way-sized one, and therefore a much smaller future population capable of experiencing happiness. 3. Even if SC creates risks and disutilities, Deudney has failed to show that they would be reduced in its absence..

Godfrey Stadlen, MA (Philosophy), Birkbeck, University of London; MA Lit Hum, (Classics and Philosophy), New College, Oxford.

[1] Videos of each presentation are at - www.youtube.com/playlist?list=PLaEYPgNFlkhb2emnGXzC7Noy2JkqOGabh.
[2] *Dark Skies: Space Expansionism, Planetary Geopolitics, and the Ends of Humanity,* Daniel Deudney (Oxford University Press, 2020). See also review by Professor Ian Crawford, Birkbeck University of London, eprints.bbk.ac.uk/id/eprint/48805/8/48805a.pdf.

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

James C Bennett

James Bennett looks at how we might become an interstellar society, with emphasis on the effects of journey time, communication delay and - at higher speeds - relativistic time dilation. The talk explicitly excluded faster-than-light (FTL) in any form, human cryonics (though not excluding hibernation) and personality uploading to digital systems. However it did not mention the possibility of artificial general intelligence as a proxy for humanity or embryo/zygote storage to ensure genetic diversity in smaller worldship populations.

Using three scenarios for propulsion technologies -

- Pessimistic (0.05c)
- Optimistic (0.2c)
- Very Optimistic (0.3c)

- though not implying any particular technology (eg photon push or fusion rocket), Bennett suggests that scale economies will favour larger, fewer, starships leading to large populations moving at a single time. Longer average active lifespan through advances in medical technologies might allow a return journey in a single lifetime at "Very Optimistic (0.3c)" speeds. But time dilation would lead to a loss of generational synchronisation with Earth. With destinations such as Alpha Centauri (4.2 light years), Wolf 359 (7.8 light years) and Tau Ceti (12 light years) experiencing about 200 years round trip duration though crews would live only about 84 years. The cultural and linguistic divergence could thus be considerable (though Bennett does not consider the effects of cultural sharing with signal delays equal to light year distance). He also suggests that many worldship enterprises will arise from transcendental motives including both religious and secular (such as cosmism [1] and transhumanism).

He makes the bold claim that "Broadly speaking, human interstellar flight now stands at a similar state of development as did human cislunar spaceflight at the time of publication of the works of Tsiolkovski, Goddard, and Oberth". This suggests a gap of about 60 years (1969-about 1910) and thus that human interstellar flight will be achieved by 2083. This seems very optimistic since the first tiny interstellar probes are unlikely to be launched for at least 20 years which at 0.2c, takes us to 2063 with more powerful propulsion, presumably fusion, achieving human-rated launch only 20 years later in 2083. Overall this work presents a useful "thought experiment" imagining some of the consequences of human interstellar travel. There will be a peer-reviewed paper later this year.

John I Davies, BEng (Electronics) Liverpool, MSc (Computer Science) Manchester

The Search for Life and Habitable Worlds at NASA

In July, Becky McCauley Rench, a NASA astrobiologist, presented at the 8th Interstellar Symposium in Montreal. She discussed the philosophy of astrobiology at NASA in general, and the big questions they consider in the pursuit of extraterrestrial life: How life begins and evolves, whether life exists elsewhere in the universe, and what does life look like in the future of Earth and beyond? They address these aims both with exploratory missions – Viking, Kepler, Curiosity, and Perseverance all included experiments to look for signs of life – and studies of life on Earth, especially extremophiles, survival strategies in difficult environmental conditions, and metabolic diversity. NASA missions also look for evidence that compounds conducive to life as we know it are or were present, such as Curiosity's discovery of possible wave ripples on rocks in Gale crater that could be a sign of liquid water in Mars' history. Similarly, the James Webb Space Telescope may be able to detect "biosignatures" on exoplanets, or gases that could indicate biological metabolism.

As a field that uses novel technologies, technologies newly adapted to planetary exploration, and novel ways of thinking and defining life, Rench notes that astrobiology should use rigorous standards for evaluating and reporting new discoveries. There are some frameworks in place, including a five-question assessment for examining the authenticity of a signal, but further work is needed to introduce standards of confidence.

The search for life signs on Mars is proposed to continue with Mars Sample Return, which would allow NASA teams to analyze physical samples collected and sent back to Earth by Perseverance. Future missions to look for life beyond Mars include Dragonfly, scheduled to launch for Titan in

[1] Cosmism is a philosophical movement suggesting that humanity will become the master of the natural world and specifically the cosmos, see *Tsiolkovsky - Interstellar Pioneer* in Principium 20, February 2018. i4is.org/principium-20.

2027 to look at potentially prebiotic chemistry and Europa Clipper, set to look for subsurface lakes on Europa starting next year. Even further out, the planned Habitable Worlds Observatory would allow characterization of potentially habitable planets outside our solar system.

Cassidy Cobbs, Master of Science (MS, Evolutionary Biology) Vanderbilt University, Bachelor of Science (BS, Biological Sciences) North Carolina State University

A Near Term Interstellar Mission Enabled by the Space Launch System

Joseph Cassady & John Schumacher

What is the point of an interstellar probe? This concept is a mission beyond the heliosphere using current or soon-to-be-current tech, and is being actively pursued by JHU APL.

The following enumerates 3 principal goals:

1) To understand in more detail the nature of our 'heliosphere', particularly regarding its 'habitability', ie it protects Earth from high energy cosmic rays which would otherwise compromise the emergence of life.

2) To gain some 'ground truths' about our solar system, ie provide an extrasolar perspective so that we can determine a more accurate and useful 'baseline' applicable to the observation and study of other systems in our galaxy.

3) To acquire a more accurate picture of the 'extragalactic background light', which is hindered on Earth by the absorption of important wavelengths by the 'zodiacal dust' hanging around the inner solar system.

In order to achieve a rapid access to the heliopause and beyond generation of fast heliocentric speeds (10 AU/year has been mooted) is required which in turns needs a huge boost at Earth – thus the prospect of exploiting a super-heavy lift launch vehicle such as the future NASA Space Launch System Block 2. This Block 2 version of SLS will utilise an Exploration Upper Stage, EUS, which is far more capable than the Interim Cryogenic Propulsion Stage, ICPS, as used for Artemis 1, though it seems even this hugely powerful 2-stage launch vehicle would be inadequate.

Nevertheless such is the mass capability of SLS, further stages can be incorporated into its cargo. The following plot is quite useful in that it indicates the ultimate spacecraft mass achievable by an SLS Block 2- with extra stages - against C3 value. C3 is known as the 'Characteristic Energy' and is a measure of the kinetic energy of the Earth-escape orbit generated by the SLS + combination of extra stages as appropriate. The black horizontal bar is the spacecraft payload mass needed for the Interstellar Probe.

From this plot, the optimal extra stage combination appears to be a CENTAUR VI (LOX/LH2 combo) + the solid propellant stage STAR 48BV.

Adam Hibberd, Keele University (UK) BSc Physics and Mathematics

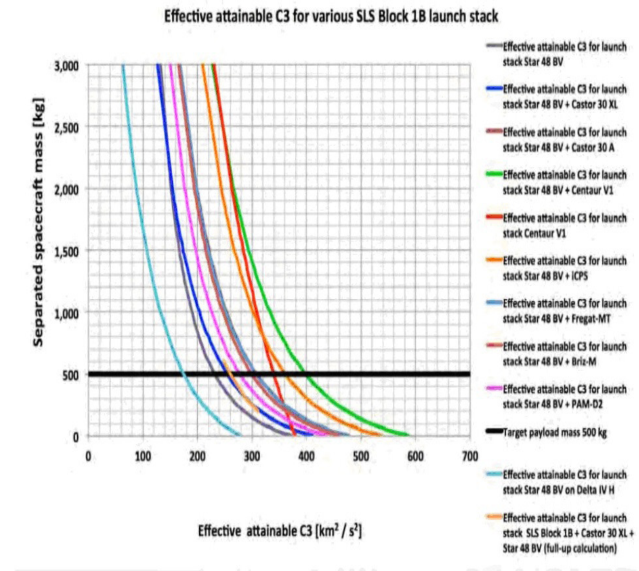


Figure 4 Separated Spacecraft Mass Curves for Various SLS Block 1b and Upper Stages

On the Wormhole - Warp Drive Correspondence

In their presentation, Remo Garattini and Kirill Zatrimaylov present an interesting approach to generalize warp drive metrics by switching to Gullstrand–Painlevé coordinates in the wormhole Morris–Thorne metric. This allows them to embed a warp drive shift vector in the wormhole metric and creates a metric that allows for the existence of a gravitational field on top of the warp drive bubble. Because the wormhole metric is related to the Schwarzschild metric for black holes, this also establishes a connection to analogue experiments that attempt to understand black holes in the lab, ie sonic black holes. Garattini and Zatrimaylov suggest that by extending the dimensionality of analogue gravity experiments one could potentially simulate a warp drive, which breaks the rotational symmetry usually assumed for black hole analogues. Moreover, they think that with additional degrees of freedom, varying the density and speed of sound as a function of radial coordinates, one could simulate the throat region of a wormhole. While the suggested experimental methods (photon superfluids and magnetic Feshbach resonance) are complex, the pay-off of successful implementation could warrant further exploration of the ideas. Finally, their generalized warp drive metric allows for the existence of intrinsic curvature. While Natario-type warp metrics always violate the null energy condition (NEC, ie the local energy density is below zero), arbitrarily small values of intrinsic curvature on the interior of a warp bubble could alleviate this issue. However, the consequences would be that any object transported inside the warp bubble would experience curved space-time. This poses the question of whether flat space-time itself (the curvature being zero) naturally mitigates the issue of violating the NEC, or if an engineered control of the background curvature super-imposed on the traditional warp bubble is necessary.

Dan Fries, PhD (Georgia Institute of Technology), Diplom Engineering (University of Stuttgart)

Helicity Space

Helicity Space develops in-space fusion propulsion and power technology. They held a three person panel session at IRG23. Their team was -

- Dr Alan Stern, Helicity Senior Advisor
- Dr Stephane Lintner, CEO
- Dr Setthivoine You, Chief Scientist - who provided information to Principium - and whose discovery of plectonemic jets prompted the company).

Their review of propulsion options - leading to their conclusion "Fusion has always been the answer to space travel"!

They see the advantages as -

- High Power: 100 kW to GW range
- Clean: No radioactive fuel required
- Agile: Abort, manoeuvre, fly anytime
- Compact: Fit for today's launchers
- Scalable: Cislunar to interstellar
- Re-Usable: Little propellant required

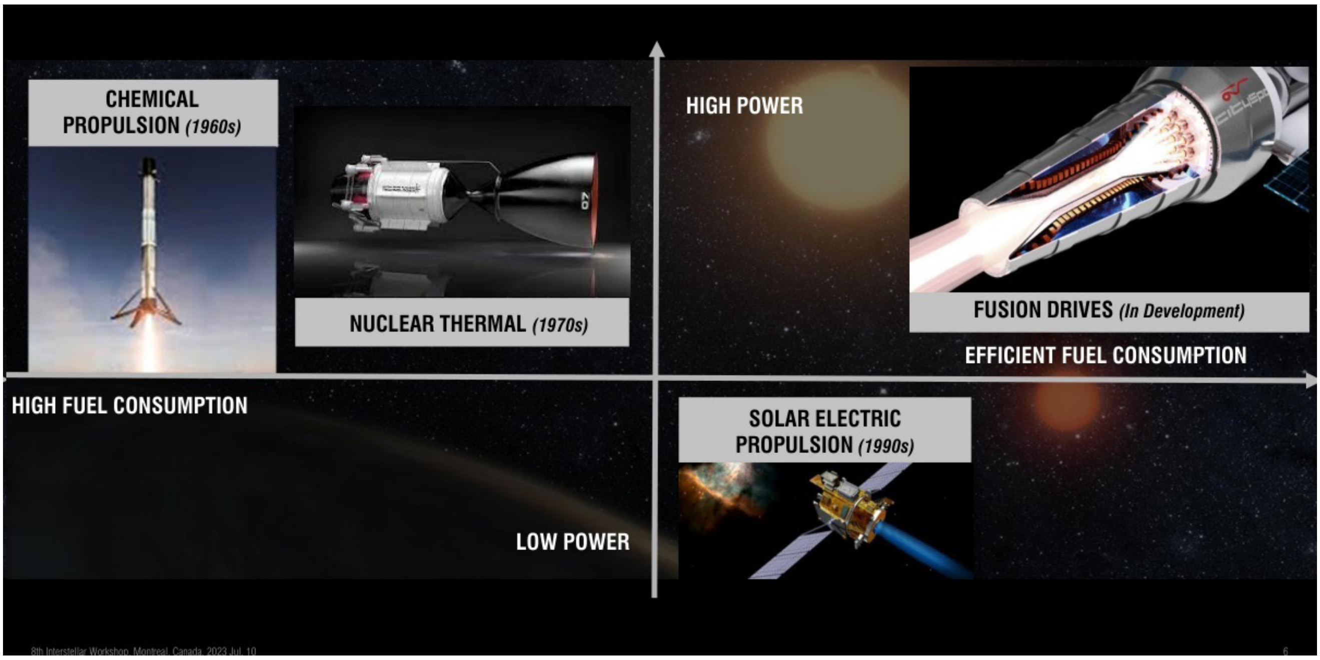
They envisage -

- Fusion Augmented Electric Propulsion (Class S - M Helicity Drives) for Cislunar cyclers and larger robotic missions to Mars & beyond in the 2030s
- Self-Sustaining Drives (Class L - XL Helicity Drives) for Human flight to Mars, Interstellar Missions, etc in the 2040s.

Dr Setthivoine You gave a technical outline of their project. Pulsed magneto-inertial fusion (MIF) exploits three key ideas -

1. Magnetic plectonemes (Taylor states) to confine the plasma [1].
2. Magnetic reconnection-heating to pre-heat.
3. Magnetic peristaltic compression to raise energy density.

See also *Helicity Drive: A Novel Scalable Fusion Concept for Deep Space Propulsion*, Setthivoine You [2].



[1] A plectoneme is a loop of helices twisted together (most often applied to nucleic acid in molecular biology). For Taylor state in plasma see - en.wikipedia.org/wiki/Taylor_state.

[2] With Stephane Lintner & Marta Calvo, AIAA Propulsion and Energy 2020 Forum, arc.aiaa.org/doi/10.2514/6.2020-3835, No public access available.

He showed -

Results in scalable performance:

$nT\tau$ scales with $N^{3/2}$ - where -

$n \sim N$, $T \sim I_{gun}^2$, $\tau \sim \sqrt{N}$

Number of guns, N, is a new control knob (in addition to the usual plasma current, magnetic field, plasma size, & compression ratio):

- Can compensate for uncertainties in τ
- Spread input energy over N guns
- Development path is analogous to "cylinders in car engine"

Dr Alan Stern suggested some in-space applications of the drive -

Kuiper Belt Science

- Improve on New Horizon Data
- Measure Surface Composition and Dust Grains for KBOs
- Use a large on-board telescope to measure KBOs still distant from fly-by trajectory

Heliospheric/Interstellar Medium Science

- Image the entire heliosphere
- Determine the heliosphere's shape
- Aim to fly through the "ribbon" feature
- Achieve a complete transect of the heliosphere and ISM

Solar Gravitational Lens

- Direct imaging of exoplanets in specific star systems
- Achieve <10 km feature resolution for exoplanets 100 light years away
- Use the same 2-5 m telescope as for KBOs
- Cross-tracking manoeuvring & slow-down capabilities

Launching such a vehicle with a NASA SLS or SpaceX Starship would allow missions to fly by Kuiper Belt objects in 0.3-0.6 years, heliosphere edge in 0.5-0.7 years, solar gravitational lens focal line in 1.9 – 2.8 years and Oort cloud inner edge in 2.8 years. Other example applications include -

- Far Quicker Human Mars Missions
- Giant Planet and Ocean World Orbiters, Landers, and Probes
- Cislunar Agility and Heavy Lift

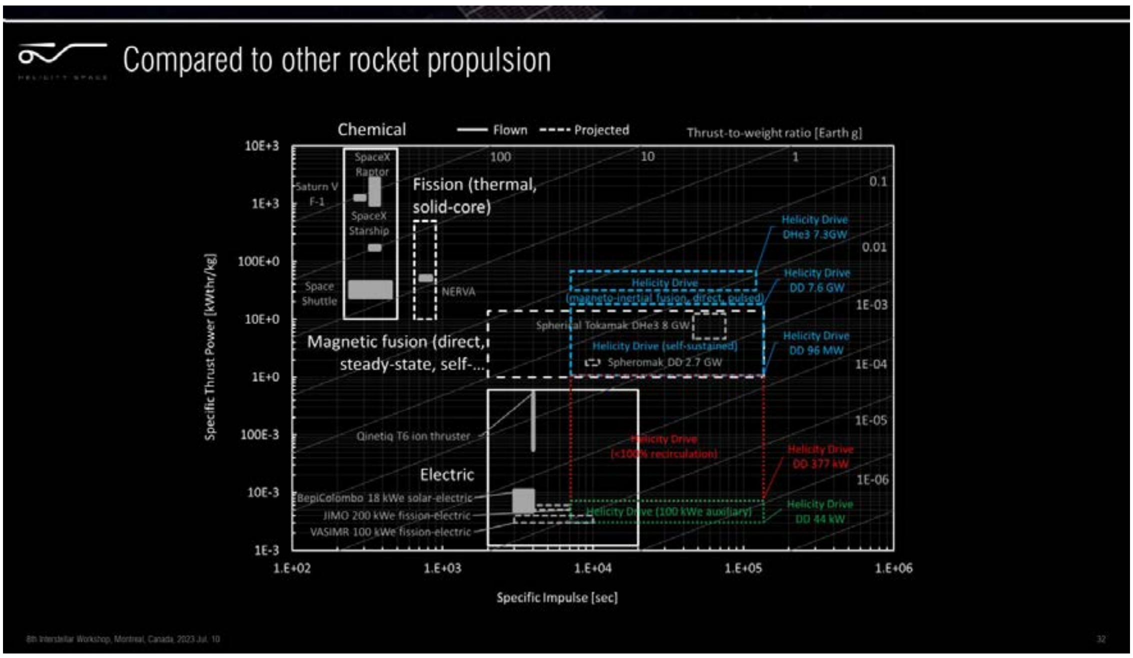
So they ask "What would you do with this kind of capability?"

The old engineering question arises, "Will it work?" by which I mean both - Is it cost effective? - and - How will the company succeed as a commercial enterprise?. Helicity is addressing both these questions - the former with both lab setups and using plasma supercomputer simulations - collaborating with Los Alamos National Laboratory.

The latter we shall see!

More at - *Helicity Working to a Practical Fusion Drive with a Path to Large Ships at 1%+ Lightspeed* February, 2023, Brian Wang [1].

John I Davies, BEng (Electronics) Liverpool, MSc (Computer Science) Manchester



[1] www.nextbigfuture.com/2023/02/helicity-working-to-a-practical-fusion-drive-with-a-path-to-5-ton-payload-at-5-lightspeed.html

IRG 23: X-ray and γ-ray Beam Interstellar Communication and Implications for SETI

Peter Milne

At the IRG 23 Symposium in July 2023 Gerrit Bruhaug[1] presented work by Lucas Beveridge, *X-ray and γ-ray Beam Interstellar Communication and Implications for SETI*. In this report Peter Milne summarises the associated draft paper kindly provided by Dr Beveridge, due for publication in Acta Astronautica in the near future.

Recent decades have seen the development of both X-ray and gamma-ray (γ-ray) beam sources [2]. These have been used for scientific purposes, but they raise the possibility that such devices could also be used for communications. Plasma based x-ray lasers were first demonstrated in 1980 and have been shown to lase in wavelengths as short as 0.15 nm (8.27 keV photon energy), while being developed for applications as wide ranging as materials science and national defence. Free electron x-ray lasers are now operating at >12 keV of x-ray photon energy (<0.1 nm wavelength) and with watts of X-ray power available in a widely tunable (250 eV – 20 keV) and high pulse rate (120 Hz – 929 kHz) source. Future designs seek to combine these two X-ray laser technologies and achieve even higher laser powers. The use of X-ray optics already allows for keV class X-rays to be focused to near diffraction limited [3] spots and may allow for X-ray recycling cavities in the near future to further increase total laser power and efficiency. Gamma ray sources are more difficult to develop, but many decades of work have left firm theoretical ground for potential gamma ray lasers using either antimatter or excited nuclear states as the source material.

Since the diffraction limited beam spread is proportional to wavelength, a gamma-ray or x-ray laser generating a beam at even modest power could be detectable at enormous distances, and with potentially enormous bandwidth. This implies that any civilisation needing to communicate across interstellar distances may choose X-ray or gamma-ray beams due to low background noise, high efficiency, and high bandwidth. Searching for these signals would have the same issues as trying to detect incidental broadcasts, ie, the presumed low probability of having a detector looking in the right place at the right time. However, if there are many interstellar civilizations, they may be using an efficient communications scheme like this, making the odds of catching a beam passing the Earth more likely. It's also possible that such signals may have been detected already without being recognized, since X-ray and gamma-ray telescopes don't collect data on short time scales (milliseconds) unlike X-ray/gamma ray spectrometers used for radioactive material assay.

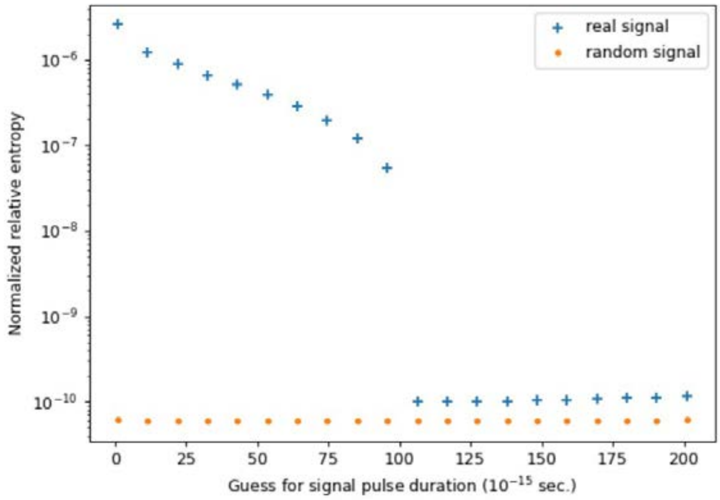
OOK (On-Off-Keying) modulation was assumed for this study, but similar conclusions could be reached for other forms of modulation. Various file types were analysed, spanning a wide range of signal sizes and compression types (where information might be obscured by the compression). There was no discernable difference between the artificial signals and a random signal when considering only Shannon Entropy. Entropy refers to a measurement of vagueness and randomness in a system and the concept of entropy was used by Shannon in information theory for the data communication of computer sciences.

[1] Video of the presentation at - www.youtube.com/watch?v=AZfGnmA3GfY&list=PLaEYPgNFlkhb2emnGXzC7Noy2JkqOGabh&index=32&pp=iAQB

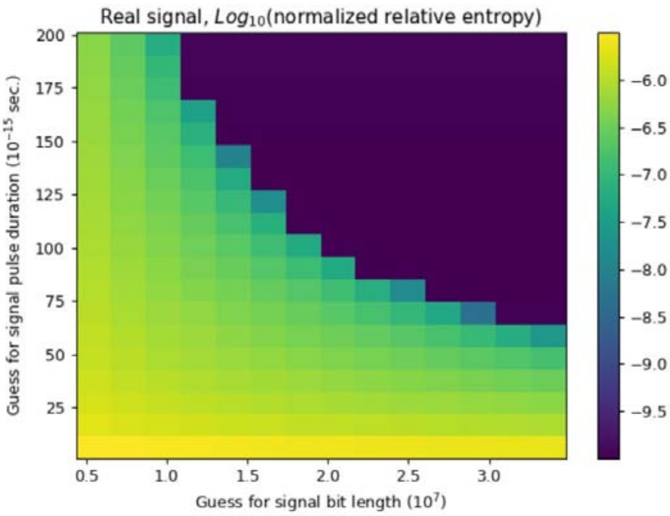
[2] X-rays: wavelengths between 0.01 – 10 nanometres and Gamma rays: wavelengths less than 0.01 nanometres

[3] en.wikipedia.org/wiki/Diffraction-limited_system

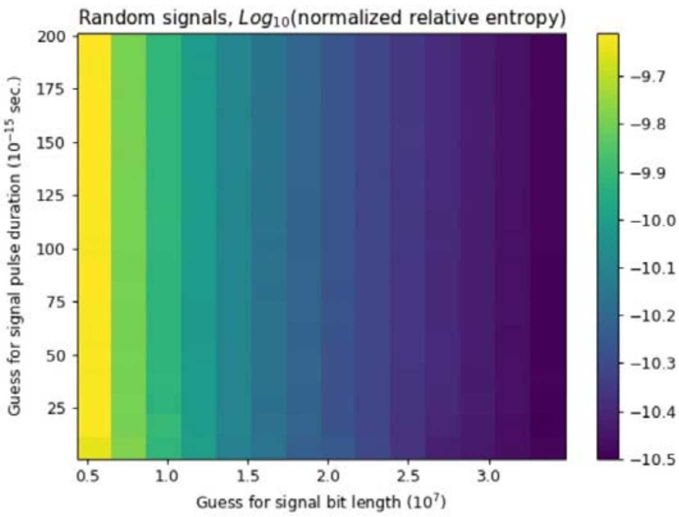
However, a computation of the Kullback–Leibler divergence of the signal [1], compared to a signal of all 1s, resulted in a clear difference, as illustrated in Figures 7, 8 and 9 (referring to the paper - see below).



Relative entropy for a candidate bit length,
Credit (image and caption): Beveridge
Figure 7.



Artificial signal relative entropy,
parametric sweep,
Credit (image and caption): Beveridge
Figure 8

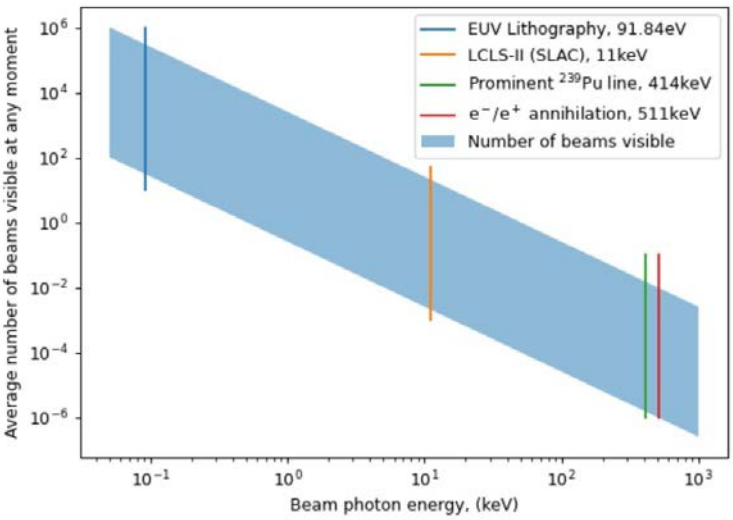


Random signal relative entropy,
parametric sweep,
Credit (image and caption): Beveridge
Figure 9

[1] See en.wikipedia.org/wiki/Kullback-Leibler_divergence and also *The physical limits of communication or Why any sufficiently advanced technology is indistinguishable from noise*, M Lachmann, MEJ Newman, C Moore - American Journal of Physics, 2004 (arxiv.org/abs/cond-mat/9907500) which states "It has been well-known since the pioneering work of Claude Shannon in the 1940s that a message transmitted with optimal efficiency over a channel of limited bandwidth is indistinguishable from random noise to a receiver who is unfamiliar with the language in which the message is written."

◀ It may be possible to search archival X-ray or gamma-ray telescope data to find artificial signals hiding within them. In particular, treaty-enforcement spacecraft such as the Vela series might be a good place to look since those spacecraft were designed to observe the “double-flash” of an atmospheric nuclear detonation, which only lasts for about 1 ms, and thus these satellites had adequate time resolution for signal detection and observed a wider portion of the sky than a telescope. Other instruments on past or present missions may also have the time resolution required as well. It’s assumed that they should be able to detect at least 1,000 distinct pulses per second so that the received signal is broken into enough pieces to show a high relative entropy, although this limit is somewhat arbitrary because there is no way of knowing the transfer rate of an alien signal.

The probability of detecting an incidental signal may be negligibly low due to the narrow beams (unless there are at least trillions of transmitters), however if this is indeed a common means of communication, other civilizations may be making extensive use of it, perhaps even contacting any planet that appears to have intelligent life on it. If this is the case, then we are far more likely to detect a beam, since at least one would be intended for us. If there are 2,500 civilizations in the galaxy, and each one was beaming signals at 1 keV to any planet that shows signs of intelligent life (assumed here to be equivalent to mammals), and the lifetime of such intelligence is 100 million years then we would expect at any given time to see around 25 beams. This estimate has quite a large uncertainty associated with it of course, but this sort of estimate can be used to provide upper and lower bounds. Figure 10 shows the band of probabilities of detecting an incidental beam at any given time as a function of photon energy. This assumes there are 250 to 25,000 transmitting civilizations, and 125,000 to 1.25M worlds with signs of intelligence (such as mammals).



Probability of detecting an incidental beam, Credit (image and caption): Beveridge Figure 10

The assumption that every civilisation is transmitting to every potentially habitable world is likely too optimistic, but even if each civilization was only transmitting to every other civilization, we might expect to see multiple beams per year. In any case, this should be a compelling type of signal to search for, but with the understanding that any signal may not repeat, which necessitates analysis that can identify an artificial signal without repetition.

About the Author

Peter Milne was lead author of *Project Icarus: Communications Data Link Designs between Icarus and Earth and between Icarus spacecraft*, in the Journal of the British Interplanetary Society, Vol. 69, pp.278-288, 2016; see also *The Icarus Firefly Downlink* in Principium 36, February 2022. He is recently retired as Principal Consultant at Aetheric Engineering Ltd an independent consultancy specialising in telecommunications (and, in particular, all aspects of satellite communications) and has had a long career in satellite design, manufacture, test, launch and operation. He is a Chartered Engineer and a corporate member of both the Institution of Engineering and Technology and the Institute of Physics.

IRG 23: Applications and Design Guidelines for High Power Lasers in Space Exploration

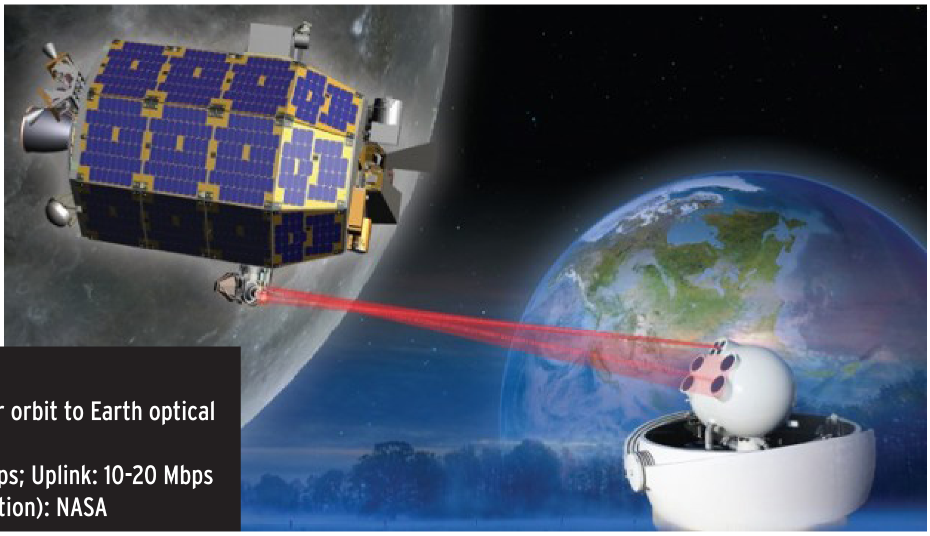
David Gahan

Aradhana Choudhuri, Canadian Space Agency, presented Applications and Design Guidelines for High Power Lasers in Space Exploration. Here David Gahan summarises this work by Dr Choudhuri based upon his draft paper kindly provided to Principium.

I was once privileged to chat with Jim Bilbro, one of the architects of the NASA Technology Readiness Level rubric, now much used (and misunderstood) by industry. He told me that a TRL greater than 4 couldn't be declared without a detailed Mission Specification - and the examples in the link bear this out. The breadth of possible scenarios is dizzying, from the surfaces of Mars and Venus to "remote sensing in an alien atmosphere" and "laser operation in high gravity gradient fields". Slightly less challenging applications might be "direct infrared laser irradiation of tumours and laser microsurgery for extremely delicate tissue like the larynges [which] may become a vital part of space medicine for treating the elevated rate of cancers in astronauts expected after exposure to the space radiation environment". Future astronauts will be relieved that lasers will be there ready to help.

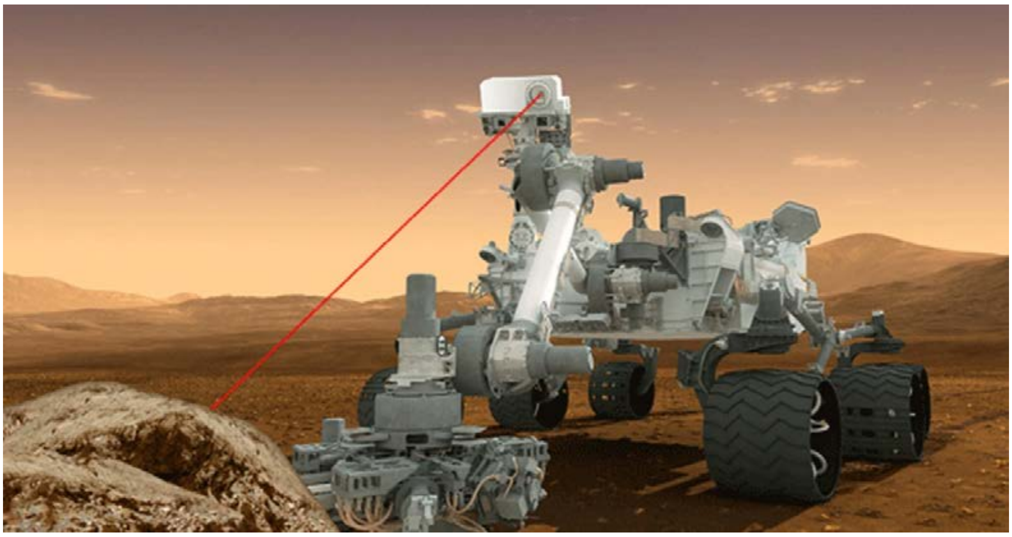
All of this comes back to Mission definition. Technology can best be assessed – and developed – against a well worked-out requirement. At least Breakthrough Starshot (which is quoted) has the start of a mission spec, ie to propel a gram-scale spacecraft to 20% the speed of light. Calculations indicate that a 100 GW Earth-based laser array would be necessary to provide the push (which would require some fancy beam-forming adaptive optics to overcome Earth atmosphere distortions). The laser requirements of how the gram-scale spacecraft would communicate back to Earth aren't quoted but everything is referenced to allow further enquiry.

It is useful to have compendium papers like this is, at least to list the most prominent current state-of-the-art examples. In free space communications, this seems to be The Lunar Laser Communication Demonstration (LLCD) on NASA's LADEE mission back in 2014.



NASA LLCD 2013/2014
-High bandwidth, lunar orbit to Earth optical link
-Downlink: 40-622 Mbps; Uplink: 10-20 Mbps
Credit (image and caption): NASA

◀ Benefiting from the investment in terrestrial fibre-optic comms at the wavelength of 1.55 micrometres, the LLCD demonstrated data rates of up to 622 megabits per second from lunar orbit to Earth over a distance of approx 400 thousand kilometres. Promising. For complex systems operating in a harsh environment, there's a nice example of the ChemCam instrument on NASA's Mars Rover Curiosity which employs a 1067 nm Nd:YAG laser (pulse energies ranging between 10-50 mJ) to generate plasma from Martian rocks. Analysing the emitted light from the plasma gives composition data and the system works at distances of up to 7 metres from the rover (and is working well *Pew! Pew! Curiosity fires off 100,000th laser shot on Mars*, www.nbcnews.com/sciencemain/pew-pew-curiosity-fires-100-000th-laser-shot-mars-2D11703507). All this in a high radiation environment which gives data on component reliability - good for future missions.



The ChemCam system uses Laser Induced Breakdown Spectroscopy to analyse the Martian surface
https://mars.nasa.gov/msl/spacecraft/instruments/chemcam/
Image credit: NASA

But maybe the subject is too broad and concentrating on narrower areas would make for a better paper. The main message seems to be: 'Boy, lasers are difficult to make and operate here on Earth but it would be even harder in Space!'

My Interest

If we make contact with other civilisations, it's most likely that lasers will play a role. The Feb 2021 issue P32 (i4is.org/principium-32) of Principium featured my paper on my proposal on communications to/from a Schelling point, which I dubbed the 'AMiTe Point' . This required an admittedly long 'daisy-chain' (time being no object) of laser communications between ships at a 4 light-year separation, similar to Project Icarus (at moderate bandwidth). If this is possible in principle, demonstrating the possible utility of viable Schelling Points, then there may be observationally testable hypotheses. Work in progress!

About the Author
David F Gahan is a physicist, engineer and tech-entrepreneur, graduating from Imperial College London in 1984 (BSc Physics). He is the co-inventor of the world's highest temperature commercially available pressure/temperature sensor (1,000 Celsius, fibre-optic based), and was the Founder and CEO of Oxsensis Ltd (oxsensis.com), which developed the sensor for gas-turbine aero and power applications and worldwide deployment. He has been CEO/CTO and occupied senior commercial positions in a number of companies and specialises in the development of technical/business opportunities in the physics based industries, from start-ups to major international enterprises in UK, France and USA.
He has a side-line in classical composition, based on the writings of Charles Darwin, which led to a string-quartet performance at the Oxford Museum of Natural History in 2015 and public performance at Darwin College Cambridge in October 2022.

IRG 23: Silence is Golden: SETI and the Fermi Paradox

Mark Wardman

Here Mark Wardman presents a lay person's summary of a presentation by Dr Steve Webb, University of Portsmouth [1], to the Interstellar Research Group's 8th Interstellar Symposium, based upon Dr Webb's IRG23 presentation kindly provided to Principium.

Introduction

Are we alone in the Universe and if so, what should we do about it? If extra-terrestrial intelligent life exists in the universe, then where is it? Assuming the Copernican Principle is true, there should be many intelligent species in the universe, some of which could have developed Interstellar Travel (IST) millions or billions of years ago.

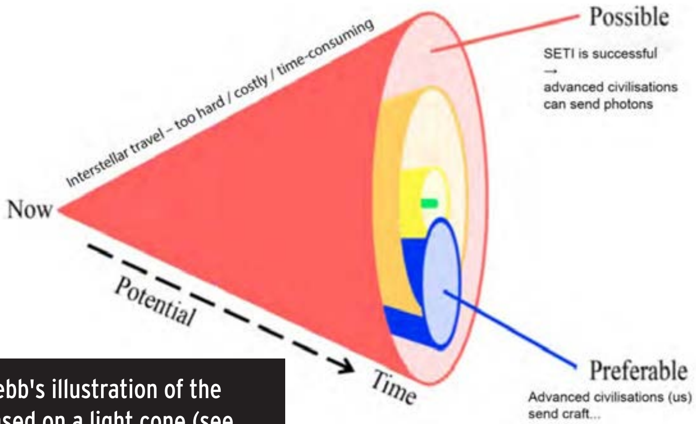
The SETI community focuses mainly on detecting photons and waves from other galaxies and is confident it will detect them with the advances in AI and new observatories. But this outcome would disappoint Steve Webb, since it would imply IST is too difficult. He would prefer a Star Trek-type universe, in which we voyage to other galaxies, and his presentation explores whether IST will ever be possible and whether we should pursue it.

Is IST possible?

Webb suggests that we should adopt the approach followed by Olaf Stapledon, a British philosopher and science fiction writer, who was interested in what the human species might become and how it might 'disturb the universe', subject to the laws of physics.

This mindset involves thinking about a much longer time frame than we are used to bringing to bear on problems. But if we do, then from any point in time we can imagine five future outcomes:

1. Possible – future knowledge might enable it to happen
2. Plausible – based on our current knowledge, it could happen
3. Probable – based on current trends, it is likely to happen
4. Projected – a default extrapolation of the most likely to happen
5. Preferable – our desired future outcome.



Stephen Webb's illustration of the possible based on a light cone (see en.wikipedia.org/wiki/Light_cone).

Some current ideas, such as Warp Drives for IST, he describes as 'preposterous' – they can't happen.

[1] Dr Webb became a freelance writer in September 2023. He was Head of Technology Enhanced Learning at the University of Portsmouth from 2006 to 2023. He holds a PhD, Physics, University of Manchester 1988.

He knows of around 90 proposed solutions to the Fermi Paradox that are based on IST and he focuses on one: the Armstrong-Sandberg 2013 model [1] of intergalactic travel, which is based on two assumptions:

1. if nature can do something (eg a tiny Acorn will in time produce a self-replicating organism), then the same thing can be done under human control; and
2. any task that can be performed can be automated.

As a means of enabling IST, therefore, this model, subject to technological progress, would allow us to: build a solar panel on Mercury to dismantle it in stages; use the resulting material to build a Dyson Swarm or Sphere of solar captors to capture the Sun's output (10^{26} Watts), at which point we become a Kardashev Type II civilisation (we're currently at about 0.75 KI); use this to create self-replicating probes (like the Acorn) with AI, data storage, deceleration mechanisms; and then use only 6 hours of sunshine to launch about a billion of these probes into outer space in a directed fashion to replicate themselves in a couple of generations across all stars in the Galaxy.

William Olaf Stapledon, 1886-1950
Image credit: Wikipedia, en.wikipedia.org/wiki/Olaf_Stapledon

Should we develop IST?

Leaving aside whether this particular model is plausible, it raises two key questions:

1. would we as a species (or some of us) want to commit to such a long-term project? We have before – see pyramids, Stonehenge, great wall of China; but more fundamentally
2. would we as a species want to spread throughout the Galaxy?

Various rationales for IST have been suggested, including: colonise others before they colonise us; spread a certain religious or political viewpoint or culture; and hedge against existential risks like nuclear war, famine or cosmic destruction. Philosophers have a role to play in the ethical considerations of IST: Luca LoSapio, for example, believes that survival at any cost should guide our actions. A sentient universe is richer and more interesting than a non-sentient one, so if we are alone, we are responsible for protecting and spreading intelligent life through the cosmos.

While the universe seems not to have space-faring species (observations might change that), we don't know if that's because of insuperable hurdles in developing IST. Such hurdles might lie in the future – eg technological problems with IST, war, climate change. But perhaps the hurdles are already behind us: the creation of life from non-life (abiogenesis); the evolution of multicellularity, of intelligence, of science; or the sheer luck of living on a planet with long-term climate stability.

So we should act as if we will one day develop technology that we can't currently envisage. IST is hard and we won't be around to see it, but the work is vital. We could be the species that disturbs the universe and takes life to the stars.

[1] *Eternity in six hours: Intergalactic spreading of intelligent life and sharpening the Fermi paradox*, Stuart Armstrong & Anders Sandberg, Future of Humanity Institute, Oxford University, Acta Astronautica 2013, www.fhi.ox.ac.uk/wp-content/uploads/intergalactic-spreading.pdf

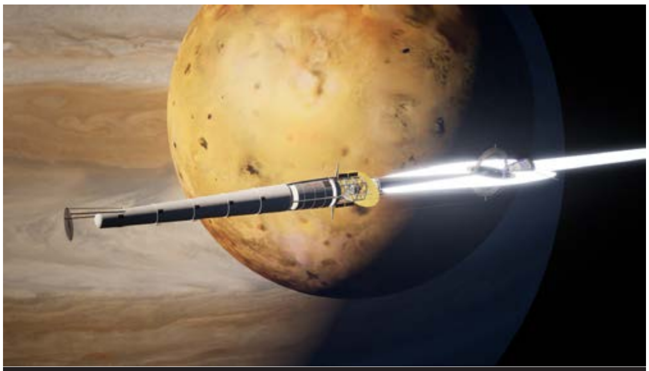
About the Author
Mark Wardman is a retired public policy analyst with a BA in Economic and Social Studies and an MSc in Organisational Behaviour. At school, he was in the same class as David Deutsch, but unlike the Professor, he dropped physical sciences at the age of 14. Late in life, he developed a strong interest in philosophy and particularly metaphysics. He now describes himself as 'Sci-curious' and while he would love to understand quantum mechanics and the multiverse, he'd settle for being able to mend his CD player, which is in pieces on his desk.

IRG 23: Infrastructure Development Leading to the First Long-Duration Interstellar Probe

John Davies

Robert Freeland II is the developer of the Icarus Firefly fusion powered probe study, with Michel Lamontagne [1], building on BIS Daedalus design of the 1970s. At IRG23 he considered a wider perspective, the human developments required for production and launch of large scale interstellar probes and the consequences for probe propulsion technology.

Robert considered how infrastructure development is vital to a massive probe such as the Daedalus/Icarus designs. He considers the existing relevant studies and the basics of fusion propulsion. He suggests that a Solar System-wide economy will be required to support the project and looks at how human population might affect this. Quoting the UN he expects the world population to peak between 10 and 12 billion people sometime this century. Orbital habitats can be venues for continued human expansion, with four decisive advantages

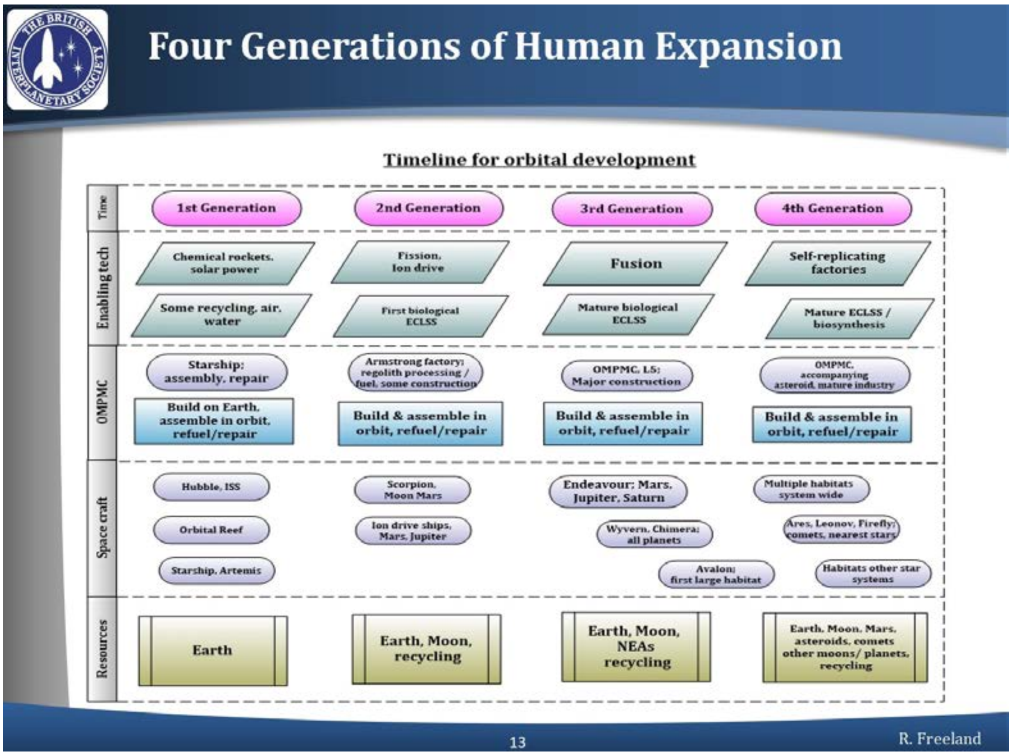


Revised Firefly in accelaration phase. Note the white hot radiator "wings".
Credit: Michel Lamontagne from Robert Freeland II *Infrastructure Development Leading to the First Long-Duration Interstellar Probe*

- Earth-like conditions (gravity, temperature, atmosphere, and day length)
- Abundant mineral resources that can be extracted with minimal environmental impact to inhabited bodies
- Almost uninterrupted access to solar power (as opposed to a planet's day-night cycle and clouds)
- Easy access to further space travel

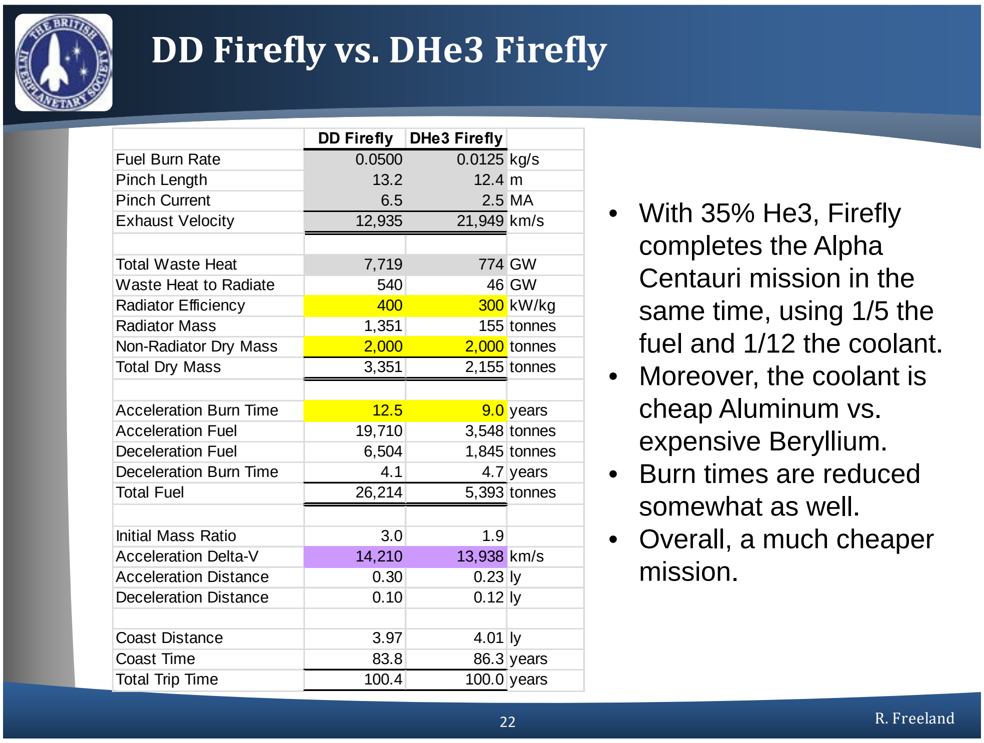
Recently the BIS SPACE Project (papers in 2019 & 2020 [2]) describes a re-engineered O'Neill orbital habitat. Life on Earth depends on the environment to which it has adapted including gravity, air, water, food, building materials and usable energy. In an extraterrestrial habitat, most/all of these must be provided artificially, and thus will be fundamentally fragile. They therefore need robust connection to a "restorative reservoir" implying a large fleet of vessels to provide the connection. This will limit the rate of sustainable human expansion into our Solar System. Working from the BIS SPACE findings he projects up to 10 billion people in Earth orbital settlements, matching Earth population and constructed from Lunar material. Longer term the Solar System out to the gas giants might support 150 billion. He expects population growth rates to follow Pierre François Verhulst's logistics function, which constrains the growth of populations in nature to available resources and competition [3].

[1] See *Reaching the Stars in a Century using Fusion Propulsion - A Review Paper based on the 'Firefly Icarus' Design,* Patrick J Mahon, Principium 22 August 2018 (i4is.org/reaching-the-stars-in-a-century-using-fusion-propulsion/) also *The Icarus Firefly Downlink*, Principium 36, February 2022 (i4is.org/wp-content/uploads/2022/02/The-Icarus-Firefly-ownlink-Principium36-AW-2202191002opt.pdf).
[2] For example see *ORBITAL CIVIL ENGINEERING: Waste Silicates Reformed Into Radiation-shielded Pressure Hulls*, Richard Soilleux, JBIS 72 #7 JULY 2019 www.bis-space.com/membership/jbis/2019/JBIS-v72-no07-July-2019%20-%20Subscription%20Copy.pdf#page=34
[3] en.wikipedia.org/wiki/Pierre_Fran%C3%A7ois_Verhulst#Logistic_equation



Robert outlined Four Generations of Human Expansion [1].
Image credit: Richard Soilleux, project lead for the BIS SPACE project

Only by the fourth generation will Humanity expand to the outer planets and their moons. Economical extraction of Helium3 (He3) from Uranus is finally achievable by ~2500 AD via aerostat mining rigs in the upper atmosphere and D-He3 transport vessels. Deuterium-He3 (D-He3) [2] has a number of advantages over the base design for Firefly using a Deuterium-Deuterium (D-D) reaction including heat radiation output reduced by ~75% (reducing radiator mass), higher exhaust velocity (reducing total propellant mass), beryllium coolant can be replaced with the next best alternative: Aluminium (reducing cost) and thus a smaller vessel with the same payload.



	DD Firefly	DHe3 Firefly	
Fuel Burn Rate	0.0500	0.0125	kg/s
Pinch Length	13.2	12.4	m
Pinch Current	6.5	2.5	MA
Exhaust Velocity	12,935	21,949	km/s
Total Waste Heat	7,719	774	GW
Waste Heat to Radiate	540	46	GW
Radiator Efficiency	400	300	kW/kg
Radiator Mass	1,351	155	tonnes
Non-Radiator Dry Mass	2,000	2,000	tonnes
Total Dry Mass	3,351	2,155	tonnes
Acceleration Burn Time	12.5	9.0	years
Acceleration Fuel	19,710	3,548	tonnes
Deceleration Fuel	6,504	1,845	tonnes
Deceleration Burn Time	4.1	4.7	years
Total Fuel	26,214	5,393	tonnes
Initial Mass Ratio	3.0	1.9	
Acceleration Delta-V	14,210	13,938	km/s
Acceleration Distance	0.30	0.23	ly
Deceleration Distance	0.10	0.12	ly
Coast Distance	3.97	4.01	ly
Coast Time	83.8	86.3	years
Total Trip Time	100.4	100.0	years

Comparison of Icarus Firefly vehicle fuels, Deuterium-Deuterium (D-D) versus Deuterium-Helium3 (He3)
Image credit: Freeland

Robert acknowledged Uri Shumlak, for his ongoing research into Z-pinch fusion, and NASA, for its support of basic aerospace research.

[1] In a personal communication (October 2023) Robert tells me "On my more optimistic days, I think maybe we could have sufficient quantities of He3 as early as 2200 AD."

[2] en.wikipedia.org/wiki/Aneutronic_fusion#3He

IRG 23: The Linguistics of *Arrival*

Universal Grammar and Interstellar Communication

Alan Cranston

Alan Cranston reviews Jessica Coon's banquet talk at IRG23, *Heptapods, field linguistics, and Universal Grammar*, based on her - *The linguistics of Arrival: Heptapods, field linguistics, and Universal Grammar In Language Invention*, in, *Language Invention in Linguistics Pedagogy* [1].

The central character in *Arrival*, linguist Louise Banks (Amy Adams), attempts to interpret the visual langiage of the aliens. Credit: Paramount Pictures

Jessica Coon is a professor of linguistics at McGill University. She was the linguistics expert consultant for the 2016 film, *Arrival* [2] in which extraterrestrial beings visit earth with a complex but hard to understand message of great mutual importance. As Prof Coon says, 'It is the uncertainty about how an alien language might differ from human language – and whether and how we humans might be able to learn such a language – that makes the premise of "Story of Your Life" (the book on which the film was based) and *Arrival* so thought-provoking.'

The arriving extraterrestrials' first task, of course, is to establish communication. Prof Coon gives us a primer in language and its relationship to meaning. She starts with an engaging story from her early career in which she was, without much preparation, left to her own devices in a Mexican village to learn and study Ch'on, a Mayan language or dialect.

She succeeded, attributing this in part to her understanding of language structure and, indeed, the 'universal grammar' of Chomsky. That concept remains controversial but there seems little doubt that the human brain is indeed 'hard wired' for certain language structures. And that, for example, this hard wiring is essential to childhood learning of language and to communication across human cultures. But how might that work with non-humans?

[1] Edited by: Jeffrey Punske, Nathan Sanders, and Amy V Fountain, Oxford University Press, 2020, academic.oup.com/book/31973

[2] A 2016 film based on the the Ted Chiang novella *Story of Your Life*, en.wikipedia.org/wiki/Story_of_Your_Life

◀ *Arrival* grapples with some of the issues, explored further in this article. First, at a highly practical level, there's how an extraterrestrial language might sound. For example it might be inaudible or in some other way indecipherable to the human ear. This is the case in *Arrival* but happily the written (non-spoken would be a better term) variant of the language is more accessible.

Second, there is the structure itself. In learning Ch'on Prof Coon started with some confidence, not least based on her knowledge of other Mayan languages, that it would follow universal grammar rules. Why would an extraterrestrial language follow such rules? Would it have to have subject, object, verb and so on? We can't know but on chauvinistic principle it is the only place we can start. Or perhaps at a more abstract level we have to suppose some structure in a language, without which it simply could not support communication.

But could we decipher that structure? There are grounds for optimism if we are dealing with other beings who live in a world of objects, time and action. Although philosophical understanding of language has moved on from a presumption of a one-to-one modelling of the world, those basics are still there. (But consider: how much must we assume to suppose that 'I kick the ball' is translatable?)

There might be other structural difficulties. The human brain has relatively limited short-term processing capacity. Prof Coon's language example is embedded clauses. We can cope with 'the dog that chased the cat was punished by its owner' but start to struggle as soon as we get much further than 'the dog that chased the cat which failed to catch the mouse was punished by its owner'. Although programming languages have multiple embedded clauses, happily people don't normally speak those to us. But other beings might, their language skills making use of mental capabilities perhaps evolved for other environmental reasons. Equally, our structures might defeat non-humans, such as the Oasans in Michael Faber's "The Book of Strange New Things" [1] to whom conditional clauses are incomprehensible.

Reading her article, though, I wondered if Prof Coon gives enough space to semantics rather than structure. She is disparaging about linguistic relativism, the idea that language is culturally determined. She takes the famous trope about Inuit peoples having more words for snow than Europeans (which is false) to discredit the idea that different cultures need or create different words and meanings. And likewise, the claim that the Hopi people might have different concepts of time than do those in the Western tradition. I think she overdoes this out of a concern for the dangers of what she calls 'linguistic exoticism'.

Our Western view of the way the mind shapes the world was largely invented by Kant, who never left his native town of Königsberg in what was then East Prussia. It is doubtful that he was capable of considering the world as other than perfect Euclidian/Newtonian space. It's right to be sceptical of imperialist world views but it would be deeply ironic if doing so led us to dismiss real cultural differences in perception and language. It's a big jump from universal grammar to universal semantics.

Wittgenstein was famously more challenging of conceptual orthodoxies, for example when he teasingly said, 'If a lion could speak we could not understand him.' What he meant was that the lion would think lion, and his perception of the world – and his language – would reflect that. The implication is that the lion would have ideas – in his head and in his language that, because they do not exist in our world view, we could not understand.

I imagine Prof Coon would say in response that yes, we could understand the lion just by virtue of a necessary structure in his speaking. Where the concepts were difficult, inference and approximation could carry us along. And yet birds can have complex languages (in their calls as well as their songs) that we humans are only beginning to understand. Actually, I reckon I probably could get to understand a speaking lion. But an octopus or a being from another world? I'm not sure, but I enjoyed this good and thought-provoking piece.

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

About the Author
Alan Cranston graduated in Philosophy from the University of Bristol in 1973. He held a number of senior positions in UK government service. More recently, he has been and remains a trustee of a number of charity and voluntary organisations. He helped establish Islington u3a, where he is still an active contributor to the Philosophy group. Now living in Edinburgh he has started a similar group there.

IRG 23: The Promise of Beamed Energy for Spacecraft Propulsion and Power

Adam Hibberd

In this presentation Colin Warn reviewed the indirect use of laser power, as a means of supply energy to a spacecraft. Adam Hibberd considers his work.

Recently I have done work for i4is concerning the various communication challenges and potential solutions associated with the realization of the Breakthrough Starshot Initiative. This Initiative will ultimately involve a GigaWatt laser accelerating a space sail and payload to a fair fraction of the speed-of-light in order to reach our nearest neighbouring system, Proxima Centauri, well within a human lifetime. This acceleration would be achieved through radiation pressure of the beam reflecting off the surface of the sail and exerting a force, which depending on the sail orientation, would propel it towards the desired target.

The presentation I review here looks at alternative 'beamed power' solutions (ie exploiting lasers), to propel a spacecraft NOT with radiation pressure, but with electric propulsion, where the power source would NOT be solar radiation incident on photovoltaic cells but a laser beam instead. I shall attempt to walk you through some of the concepts and equations referred to in the presentation.

First of all, let us assume we have some power module associated with a spacecraft intended to propel a vehicle (in the words of the author a 'PPE' = Power and Propulsion Element). The PPE is contained within a mass, m and has an energy-generating potential, E. Let us designate the energy per unit mass of this PPE, μ, in which case the OPTIMAL exhaust velocity of this PPE (where all this energy is converted to exhaust velocity) is as follows:

$$v_{ex} = \sqrt{\frac{2E}{m}} = \sqrt{2\mu} \qquad (1)$$

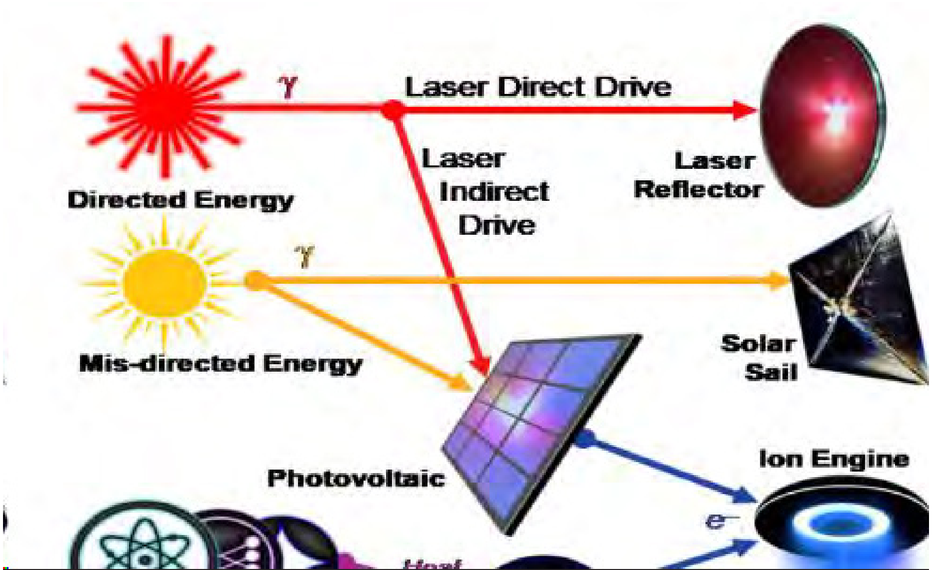
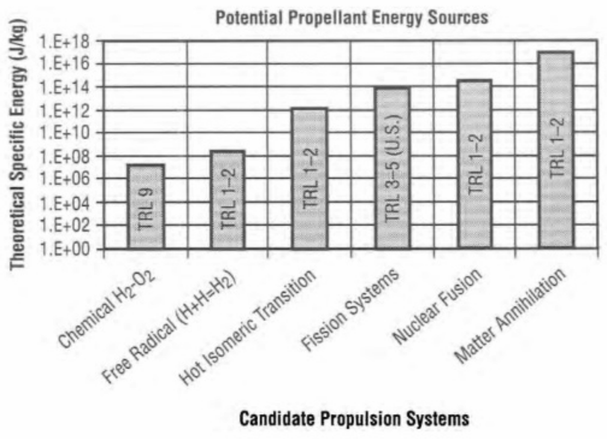


Image credit: Colin Warn

The energy per unit mass (or specific energy), μ , for various propulsion options are as follows:

Credit: Colin Warn



R. L. Sackheim and M. Houts, "In Space Nuclear Power As An Enabling Technology For Deep Space Exploration," Nasa Technical Reports Server, 2000.

If we have the ΔV for a particular mission (ie the required total velocity increment) then the best case mass fractions for the selected PPE, assuming the optimal exhaust velocity is achievable, can be calculated from the famous Tsiolkovsky equation.

By the way, this mass fraction is the ratio of final mass (once all the energy of the PPE is depleted), designated mf ,and the total initial mass, mo, in other words that of the payload and undeployed PPE element.

In the presentation, various different propulsion options, PPEs, are selected and assessed against a wide variety of different mission candidates. For a Mars mission with a chemical PPE, ideal mass fractions of 45.6% can be evinced. However, unsurprisingly, when chemical propulsion is applied to interstellar missions (ΔVs of 10,000 km/s upwards) then mass fractions go down to zero. In other words, no feasible interstellar mission can be achieved with chemical propulsion.

There is a solution of course to utilising a PPE whose energy potential is contained wholly within, it is one where instead the energy source is contained at a distance, at a convenient location where in comparison huge reserves of energy are available. These reserves can be tapped and transported efficiently to the spacecraft's PPE, via converting this energy to electromagnetic radiation and beaming it onto the PPE's photovoltaic cells.

Let us derive an equation for the mass fraction of an electric propulsion system, where the electrical power is supplied by photovoltaics and a propellant is deployed with total initial mass Δm. Let us further assume a LOSS IN EFFICIENCY, η, of conversion of the energy potential, E, of this propellant mass to kinetic energy. If the total propellant ejection time is T and the average power available over this period is P_E, then clearly $E=P_ET$. We can now adjust equation (1) to make it more realistic as follows:

$$\mu_p^2 = \frac{2\,P_E T \eta}{\Delta m} \qquad (2)$$

Where μ_p is now the real exhaust velocity of the propellant.
If we break the total initial mass, mi, down into its components, then we have the following:

$$m_i = m_{pay} + \Delta m + m_{pp} \qquad (3)$$

Where m_{pay} is the payload mass and m_{pp} is the mass of the PPE, WITHOUT PROPELLANT.
If ΔV for the mission in question is known then we have the following by Tsiolkovsky:

$$e^{\frac{\Delta V}{\mu_p}} = \frac{m_i}{m_{pay}+m_{pp}} \qquad (4)$$

Let us further define a parameter we call the 'Characterstic Velocity', v_c, as follows:

$$v_c^2 = \frac{2\,P_E T \eta}{m_{pp}} \qquad (5)$$

Combining (5) & (2) we have:

$$\frac{v_c^2}{\mu_p^2} = \frac{\Delta m}{m_{pp}} \qquad (6)$$

Adding 1 to both sides and multiplying by mpp:

$$m_{pp}\left(\frac{v_c^2}{\mu_p^2} + 1\right) = \Delta m + m_{pp} \qquad (7)$$

Rearranging (4) we get the following equation:

$$e^{\frac{-\Delta V}{\mu_p}} = \frac{m_{pay}}{m_i} + \frac{m_{pp}}{m_i} \qquad (8)$$

And re-ordered:

$$\frac{m_{pp}}{m_i} = e^{\frac{-\Delta V}{\mu_p}} - \frac{m_{pay}}{m_i} \qquad (9)$$

Dividing (3) by mi we get:

$$1 = \frac{m_{pay}}{m_i} + \frac{(\Delta m + m_{pp})}{m_i} \qquad (10)$$

Combining (10) & (7) we get the following:

$$1 = \frac{m_{pay}}{m_i} + \frac{m_{pp}\left(\frac{v_c^2}{\mu_p^2}+1\right)}{m_i} \qquad (11)$$

Inserting (9) into (11) we find as follows:

$$1 = \frac{m_{pay}}{m_i} + \left(e^{\frac{-\Delta V}{\mu_p}} - \frac{m_{pay}}{m_i}\right)\left(\frac{v_c^2}{\mu_p^2} + 1\right) \qquad (12)$$

$$1 = \frac{m_{pay}}{m_i} - \frac{m_{pay}}{m_i}\left(\frac{v_c^2}{\mu_p^2} + 1\right) + e^{\frac{-\Delta V}{\mu_p}}\left(\frac{v_c^2}{\mu_p^2} + 1\right) \qquad (13)$$

$$1 = -\frac{m_{pay}}{m_i}\left(\frac{v_c^2}{\mu_p^2}\right) + e^{\frac{-\Delta V}{\mu_p}}\left(\frac{v_c^2}{\mu_p^2} + 1\right) \qquad (14)$$

$$\frac{m_{pay}}{m_i}\left(\frac{v_c^2}{\mu_p^2}\right) = e^{\frac{-\Delta V}{\mu_p}}\left(\frac{v_c^2}{\mu_p^2} + 1\right) - 1 \qquad (15)$$

$$\frac{m_{pay}}{m_i} = e^{\frac{-\Delta V}{\mu_p}}\left(1 + \frac{v_c^2}{\mu_p^2}\right) - \frac{v_c^2}{\mu_p^2} \qquad (16)$$

$$\frac{m_{pay}}{m_i} = e^{\frac{-\Delta V}{\mu_p}}\left(1+\frac{v_c^2}{\mu_p^2}\right) - \frac{v_c^2}{\mu_p^2} \quad (17)$$

This can be reorganized to get the following equation:

$$\frac{m_{pay}}{m_i} = \frac{1}{e^{\frac{\Delta V}{\mu_p}}}\left(1+\frac{v_c^2}{\mu_p^2} - \frac{e^{\frac{\Delta V}{\mu_p}} v_c^2}{\mu_p^2}\right) \quad (18)$$

Or as written in the presentation:

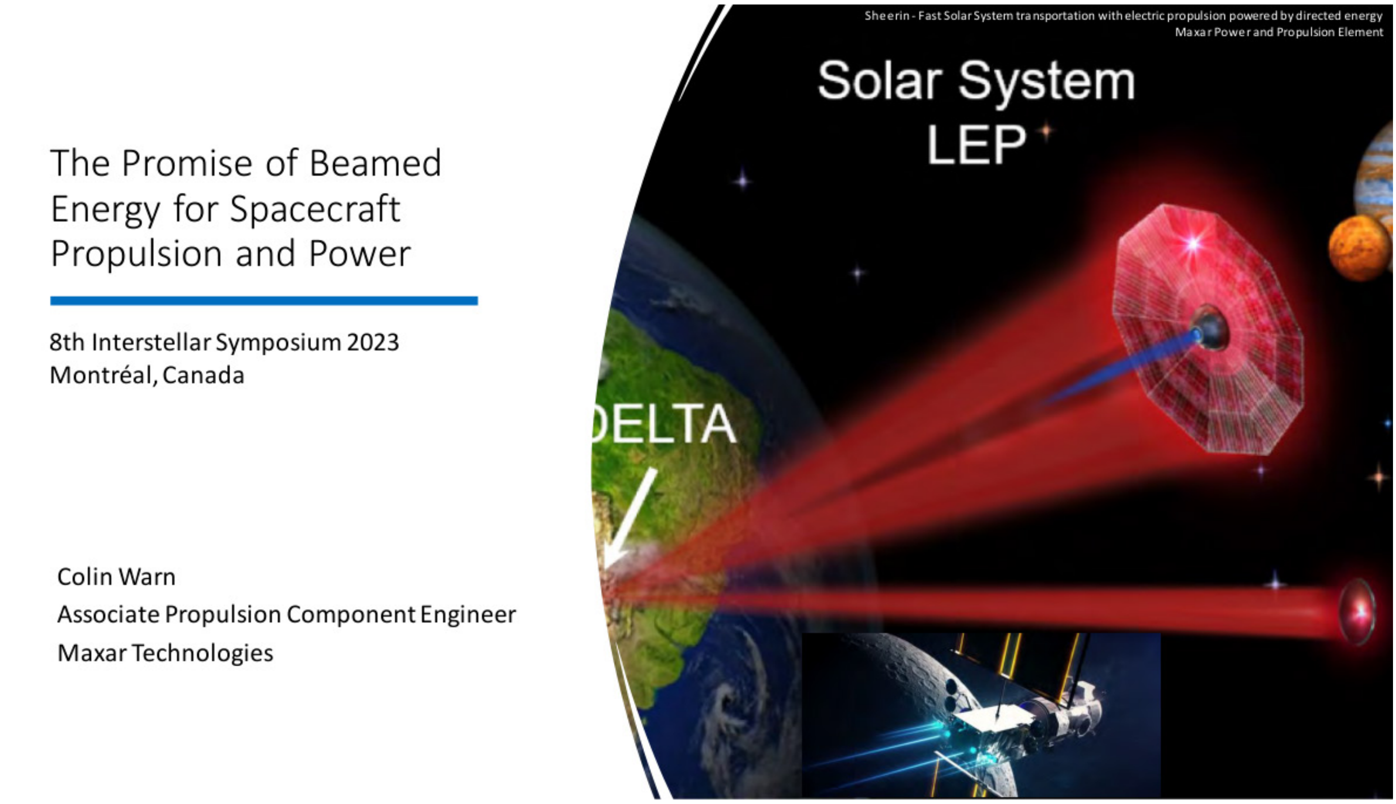
$$\frac{m_{pay}}{m_i} = \frac{\left(1-\left(e^{\frac{\Delta V}{\mu_p}}-1\right)\frac{v_c^2}{\mu_p^2}\right)}{e^{\frac{\Delta V}{\mu_p}}} \quad (19)$$

We also can define the empty (Dry) PPE to have a mass to power ratio as follows:

$$\alpha_{pp} = \frac{m_{pp}}{P_E} \quad (20)$$

The lower the value of αpp, then the more efficient is the PPE. A nuclear fission propulsion system for example has αpp = 10 – 150 kg/W, Solar Power to Mars has a value of 0.10-23 kg/W whereas a directed energy beam to power an electric propulsion system would have only 0.0043-1 kg/W, and the limitation of the latter is simply the cost of power generation at the site of the laser. But what is this cost?

At this point Colin calculates a total cost for a 45 day Lunar Gateway trip to Mars of ~$17M. This assumes the gas Xenon as the propellant. Colin next provides a comparison of all the possible propellant options, including Bismuth, which is solid at nominal thermal environments experienced by spacecraft, and therefore also occupies very little volume. The cost of the laser-beamed power phased array would be ~$100M for a 10 metre circle, but the prices of the various components of such arrays is halving every two years.



Credit: Colin Warn

IRG 23: Constraints on Interstellar Sovereignty

A summary

Max Daniels

The extension of legal processes into space is already a very active area but taking this into the interstellar environment has, of course, received less attention. Max Daniels has provided much insight into current space law matters (see *Territory in Outer Space*, Principium 24 February 2019; *The Artemis Accords: what comes after the Moon?*, Principium 32 February 2021; *Finding new ways to share resources in space - A review of Dennis O'Brien: "Is outer space a de jure common-pool resource?"*, Principium 37 May 2022.)
Here Max reviews a presentation at IRG23 which ventures a little further.

In his article Jacob Haqq-Misra seeks to evaluate how interstellar space travel will be governed. He considers three factors that may influence the success of such activity: the main body of existing international law that relates to space, which centres around the Outer Space Treaty (1967); pragmatic constraints that focus on spacefaring states looking to maintain the status quo; and 'hard' constraints that cannot be avoided, such as having technology that enables survival in space. This article summarises his points and offers some commentary.

Interplanetary vs interstellar

In his analysis he often compares the interstellar with the interplanetary, drawing on the latter to inform understanding of governance in the former. This makes sense in that we are increasingly exploring and using our immediate surroundings, as seen with the prevalence of mega-constellations in low-Earth orbit. Geographical differences will likely lead to different needs for governance, even if terrestrial politics remains linked to all parts of outer space.

The Outer Space Treaty

He methodically considers relevant aspects of the the Outer Space Treaty. First, 'expansion' highlights how the treaty prohibits territorial claims. There are bans on weapons in space, and Haqq-Misra makes an interesting suggestion, based on Miller (2018), for a 'celestial subjectivity model' where outer space is defined not as the space beyond Earth, but the space beyond the celestial body of the state in question, with implications for where laws relating to outer space can be applied. 'Oversight' is what rights states have in space, including inspections of each other's installations. This is already present in the 'safety zones' outlined in the Artemis Accords, which are areas around instruments or stations where others cannot operate.

Pragmatic constraints

He defines his pragmatic constraints as those which are likely to affect future space laws, based on historical precedence. New international organisations will not have jurisdiction over space, mandatory equitable sharing of space resources will not take place, and no new treaties will gain signatories, all because of opposition from spacefaring states. This envisions a scenario of a status quo of certain countries maintaining their outer-space sovereignty; while Haqq-Misra is certainly within his rights to suggest this, global politics is never predictable and the longer we look into the future, who knows who the dominant players in space will be?

He refers to the example of the UN Convention of the Law of the Sea (UNCLOS) as a failure of a global treaty as it has not been ratified universally, notably the United States. He believes this was in part because UNCLOS created the International Seabed Authority to direct how minerals would be extracted from the sea floor over sovereign countries. To a certain extent this is right, even if Reagan's decision was as much about promoting market forces as maintaining sovereignty, while there were other factors such as a rejection in sections of American politics of multilateralism.

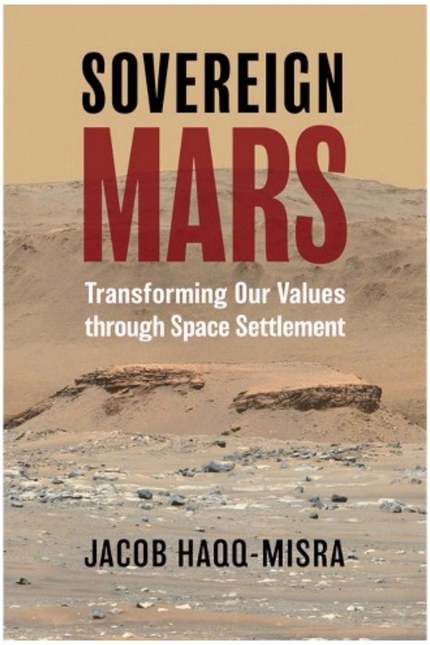
His third pragmatic constraint is the lack of new space treaties. Wisely, he refers first to non-treaty international agreements that influence norms in outer space, including working groups looking into space policy, or the Artemis Accords; and second, commercial activities such as the proliferation of satellite systems including Starlink and OneWeb.

Hard constraints

The 'hard' constraints he refers to are ones that cannot be changed and will always affect future governance models. He begins by saying that there must be the technical ability to survive in space: the infrastructure and raw materials to run a habitat must either be transported from Earth or developed in-situ. Future interstellar missions will need their models of governance to be grounded in today's political realities, as a society that may take years or generations to form is still a product of a time it was founded. Third is the 'carrying capacity' of a settlement: how large it is, what infrastructure and resources it has and so how many people it can support.

Conclusion

The article offers a grounded and, to take his term, pragmatic view of governance in what remains a hypothetical activity. He combines reference to the physical factors that underpin existence in space with the political framework that could govern its expression. Some of the ideas are novel and interesting, such as the celestial subjectivity model, but he would do well to expand his conceptual horizons to embrace the unknown and unpredictable.



Jacob Haqq-Misra is a Research Scientist at Blue Marble Space Institute of Science (bmsis.org/leadership/jacob-haqq-misra/). His book, *Sovereign Mars: Transforming Our Values through Space Settlement*, was published in 2023 by the University Press of Kansas.

IRG 23: Vanquishing Dark Skies

The role of national space forces in security, safety, and prosperity through space exploration.

Rob W Swinney

In this personal review Rob W Swinney looks at the presentation to IRG23 by Dr Brent D Ziarnick, Associate Professor, US Space Force, Johns Hopkins University. Rob and Brent are both air force professionals with a long-established interest in space and interstellar issues.

I first met Brent Ziarnick at the USAF Air University when he was at the USAF Staff College, and I was invited to speak to a class on advanced space propulsion systems as part of a space defence planning week. Even then it was clear he was a fellow of great thought on the military role in space. And from this presentation to the IRG conference he clearly knows his MCRN frigate from his ***Spaceball One***, so even though I had not been in attendance this time, when the request came from the Principium editor, it seemed a great opportunity to review the vanquishing dark skies material and enjoy the many science fiction references used to illustrate different aspects.

Ziarnick, a former USAF Lieutenant Colonel and now Associate Professor of Space Strategy, and a Space Force Civilian at Johns Hopkins University, was quick to point out that the thoughts and ideas expressed were his own opinion and not endorsed or necessarily reflective of the policy of the US Government etc etc. Any errors or poor jokes in representing his material here are all mine.

Fortunately, he extended me the great honour of going through his presentation a second time, one on one and in the end we were chatting for several hours while he was admitting it was source material for a 3-hour presentation at JHU.

His first port of call was to describe what Space Forces are or rather could look like. We have no strictly independent forces; most are currently joint space services or auxiliaries of a nation's Air Force. The USSF was perhaps nearest yet the independent Space Force that would be Starfleet-like are still in the future. Although according to Bill Shatner they should have naval ranks of Captains etc rather than Colonel's etc. Ziarnick's own preference for a 'Navy-like' type space force was something of a surprise given his Air Force background.

Credit: Brent D Ziarnick

He then described a clear and present need with the growing economic value of space and he illustrated how we would soon require frontier constabularies to defend all our interests including the commerce in space – after all he is American and us Brits are a nation of shopkeepers. The near-term value of 'space' was estimated to be $1 trillion by 2030 although I am beginning to think that might be an underestimate.

So, he deliberated, how can national space forces support security, prosperity, and peace in the following three eras:

• Past and Present – Earth Orbit Competition
• Near Term – Cislunar
• Far Term – Monsters in the Dark

First, he looked at the past and present: stating how space force partnerships (eg the Five Eyes and now more) will be essential; and quoted others who pronounced partnerships as ultimately critical – an asymmetric advantage for allies. An example of how this could be developed might be the Artemis Accords which now has many more signatories than originally imagined. Science fiction often envisions some type of United Earth government, but he suggested an alternative might be an alliance/coalition operation like in the Artemis Accords. Another example might be the 1,000-ship navy idea…the "Global Maritime Partnership Initiative" that represents a new way of thinking about international naval and maritime cooperation and collaboration on maritime security and could directly transfer to space.

In the nearer term, thinking primarily cislunar, he illustrated a potential 30-year roadmap and the need for posturing space forces for operations beyond GEO. Again, he highlighted cislunar resources – both the fundamental financial economics and sheer quantity and the potential need for rescue and recovery (not unlike the US Coast Guard). He also mentioned support for services such as the cislunar autonomous positioning system CAPS, akin to a cislunar GPS. And perhaps for this audience he added that space forces could offer mitigation of the UFOs/UAPs scenario… but more of that next.

By addressing the far term, potentially the area that will interest our readers most, Ziarnick focusses on answering some of the claims made in 'Dark Skies' – the 2020 book by Professor Daniel Deudney (Oxford University Press). Interestingly, Ziarnick starts by highlighting some irony, confounding British comments of Americans not understanding irony… pointing out that Deudney warns space exploration will give rise to totalitarian societies and could lead to the extinction of humanity; where Duedney's solution is a totalitarian Earth government to restrict humans to Earth.

But the main thrust is to try to counter Deudney's "Monsters in the Dark" and that space expansion "enlarges the probability and scope of catastrophic and existential risks confronting humanity in six ways:" malefic geopolitics, natural threat amplification, restraint reversal, hierarchy establishment, alien generation, and monster multiplication. You can find more details in Deudney's book [1]. But the intent of the presentation was to show how and in different ways, space forces could help mitigate some of these monsters. I'll highlight some points of interest here.

Ziarnick sees a natural function of any space force would be space domain awareness and planetary protection, but he also points out that any deflection technology could equally be turned to a weapon of mass destruction. Large-scale deep space travel will inevitably require harnessing massive amounts of energy, which could be used for destructive purposes, and for an example he illustrated the Orion atomic rocket design. Who might be responsible for such awesome power?

With a large-scale proliferation of different societies into the solar system this might create more existential issues – think 'The Expanse' if you are familiar with that book/TV series. This could be answered by an alliance of Nations like in the series 'Space: Above and Beyond' agreeing to abide by relevant principles perhaps extracted from the Outer Space Treaty. The alien generation discussed highlights and refers to human species 'radiation' due to these new environments. Monster multiplication envisages even bigger and wider problems that might only be mitigated by national space forces prepared to collectively destroy threats to system peace. That last thought comes directly from the famous SF author Heinlen in his book Space Cadet of 1948 which I will come to again shortly.

[1] *Dark Skies: Space Expansionism, Planetary Geopolitics, and the Ends of Humanity*, Daniel Deudney, Oxford University Press 2020. global.oup.com/academic/product/dark-skies-9780190903343?cc=gb&lang=en&

At this point Ziarnick introduces a seventh point to go with Deudney's six, Cixin Liu's answer to the Fermi Paradox, The Dark Forest. In this forest it's all quiet as any space-faring civilization would view any other intelligent life as an inevitable threat, and thus destroy any nascent life that makes its presence known. So, without any evidence of intelligent alien life otherwise, as in a "dark forest", it could be filled with "armed hunters stalking through the trees like a ghost". If you feel that is a bit paranoid/sceptical/cynical it doesn't mean they aren't out there. As outmatched as they might be, national space forces could be humanity's first line of defence. He then makes another interesting point, psychological defence: as an example, if Aztecs would have met the Spanish at sea, would they have considered them gods?

Now mentioning Heinlen, Ziarnick brings up the first American Space Force Proposal published in Collier's Magazine, 30th August 1947 (two weeks before the US Air Force became independent!), by Capt Caleb Laning, USN and… Lt Robert A Heinlein, USN (ret'd). Heinlein's aforementioned book Space Cadet was published by Scribner's in 1948 and much of his story telling of the Space Patrol is worth considering when thinking of a space force. A main aim of the Space Patrol is to uphold solar system peace and to do so the Patrol is given a monopoly of nuclear weapons.

He brings things more up to date by mentioning, The Guardians of Space – Organising America's Space Assets for the Twenty First Century by Lt Col Cynthia A S McKinley, USAF that was published in the Aerospace Power Journal, Spring 2020. Lt Col McKinley describes the Guardians 2050… who declare to 'guarantee peaceful use of space to enhance life on Earth and beyond' and it also reflects the Heinlein Space Patrol Oath…'Of my own free will, without reservation I swear to uphold the peace of the solar system…'. Great sentiment and we should be hopeful that they will be in there somewhere and that we don't end up on the wrong path suggested by the slide (above). Whichever, the future imagined by people like Heinlein with their confident view of advances in space was imminent, but never happened. That time is now arriving.

If you get the chance to see Ziarnick deliver his material in future, make sure you do. With all the SF references and plenty of light-hearted slides included with the military space defence theory it would be well worth it. If you have read this far and my personal review hasn't quite answered all your questions about 'Vanquishing Dark Skies', then perhaps take a look at the works he has authored -

- *Developing National Power in Space*, McFarland 2015 mcfarlandbooks.com/product/developing-national-power-in-space/
- *21st Century Power: Strategic Superiority for the Modern Era - 21st Century Foundations Series*, Brent D Ziarnick (editor), Naval Institute Press 2018 www.usni.org/press/books/21st-century-power
- *To Rule the Skies - General Thomas S Power and the Rise of Strategic Air Command in the Cold War*, Naval Institute Press 2021 https://www.usni.org/press/books/rule-skies

The Initiative & Institute for Interstellar Studies

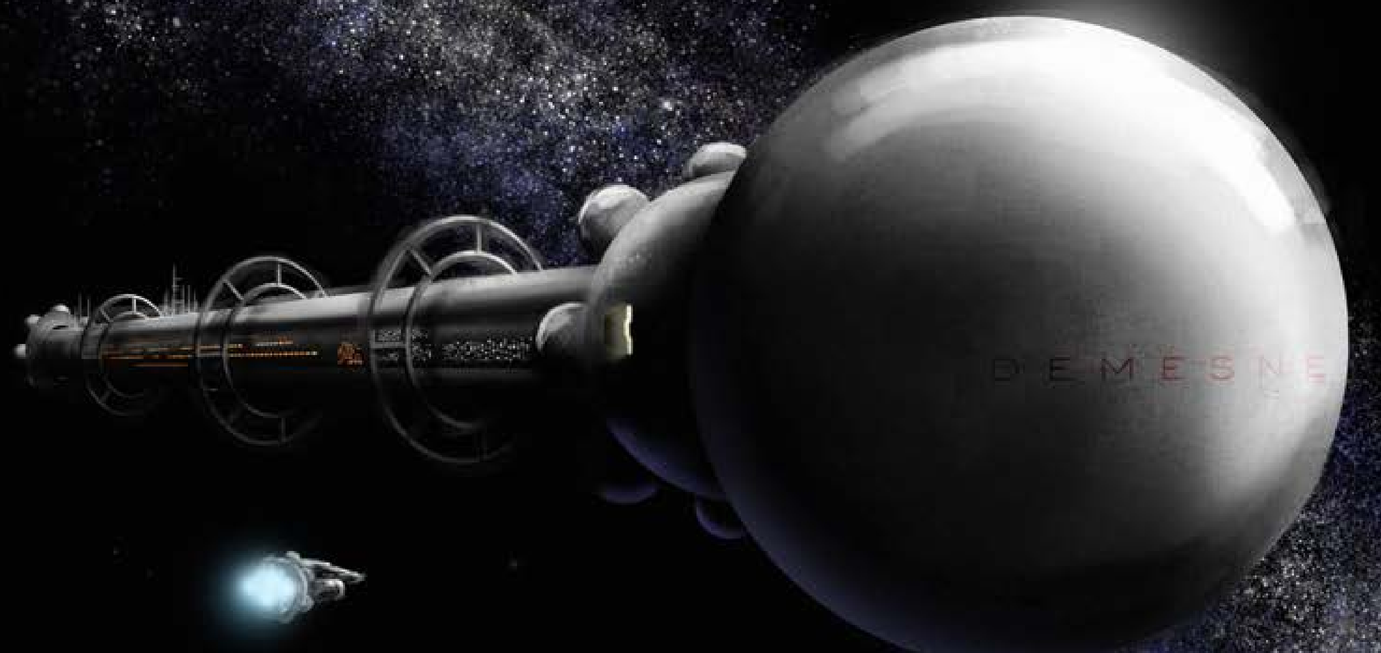


image: ©ALEX STORER

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» Robert G Kennedy III: President i4is USA - robert.kennedy@i4is.org
» Rob Swinney: Education Director - rob.swinney@i4is.org
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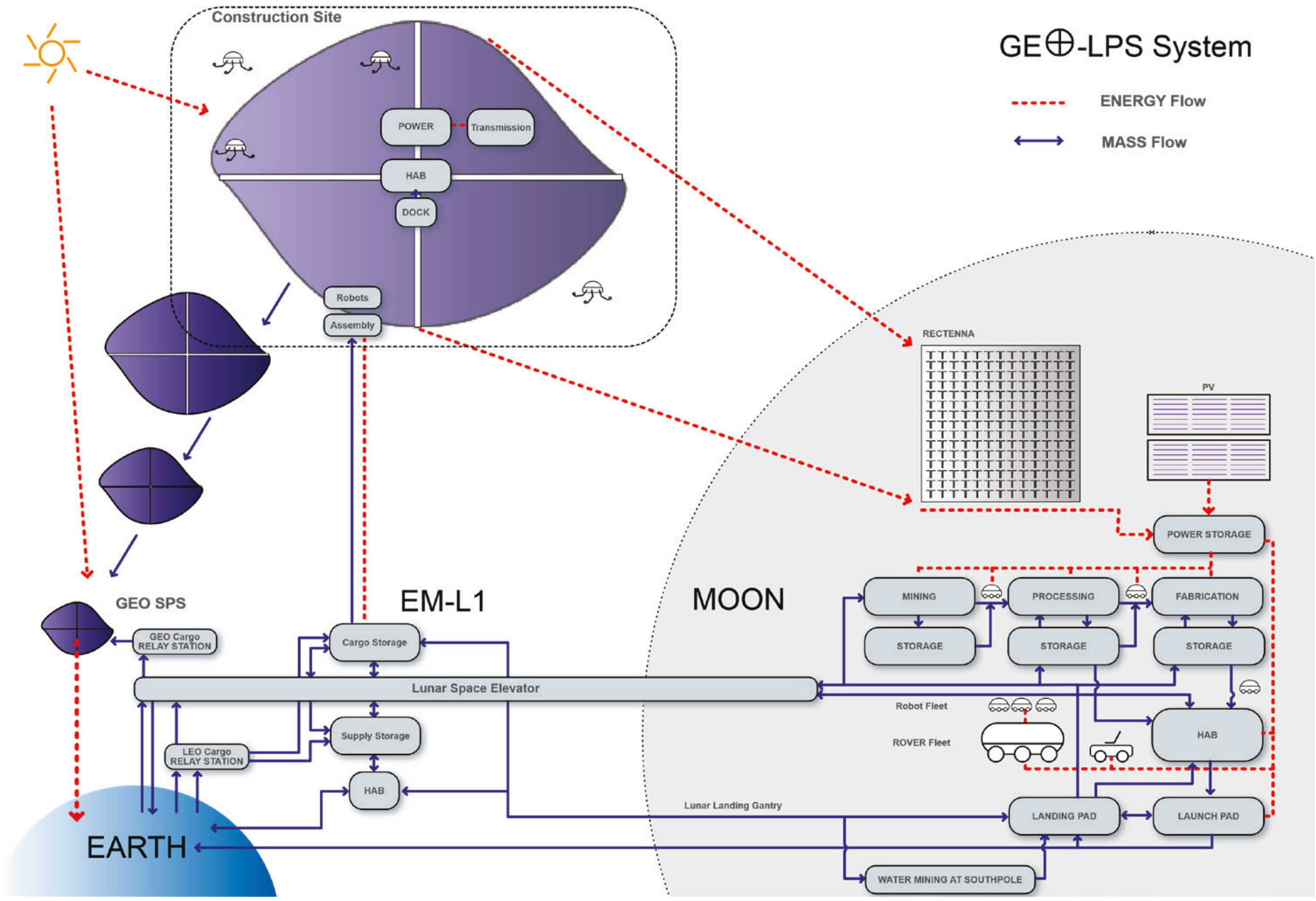
John I Davies reports on recent developments in interstellar studies

GE Lunar Power Station

A recent announcement by ESA envisages an element of space infrastructure which could provide a founding element of the space based economy which is a natural precursor of substantial interstellar activity. The *GE Lunar Power Station*, Executive Summary explains - nebula.esa.int/content/ge%E2%8A%95-lunar-power-station .

The study was conducted by Astrostrom GmbH as part of renewed ESA interest in Space-Based Solar Power (SBSP). An earlier Frazer Nash study had estimated that Europe would need 54 1.44 GW solar power systems (SPS) delivering 70 GWatts of electrical power and a launch capacity of 2,491 metric tons. This looks like about 250 launches of the SpaceX Starshot vehicle or orders of magnitude more for smaller boosters. This new study envisages power for lunar operations with material for solar cells, amongst other components, manufacturer in-situ from lunar materials an launched to an Earth-Moon Lagrange point.

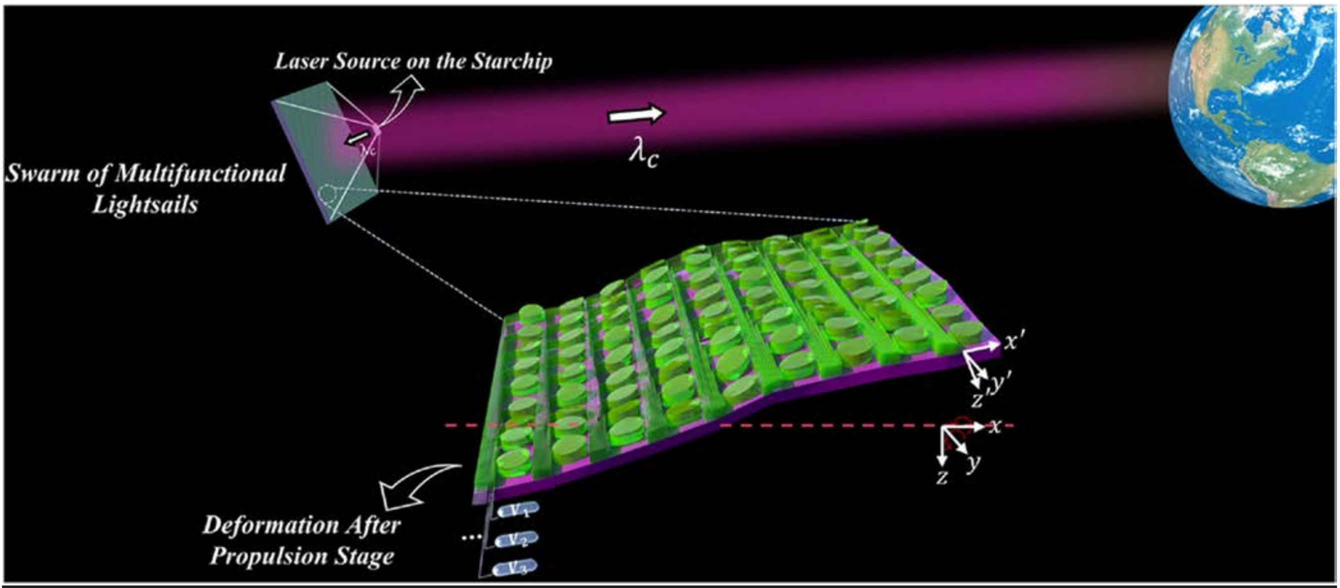
The intended system is well illustrated in the Executive Summary -



A single lunar power system would provide 1.5 MW of continuous power for initial lunar operations.
The Executive Summary provides a substantial vision of a future early step to a solar system economy and together with the potential Earth benefits of similar systems exhorts us - "The human spirit needs to believe in a future full of expectations, excitement, challenge, inspiration, and hope."

Distortion of a combined lightsail/downlink antenna for an interstellar probe

It has long been thought that the downlink antenna for an interstellar probe could re-use a large element of the propulsion system. The BIS Project Daedalus probe study suggested using the second stage fusion rocket nozzle as a microwave transmit antenna and, most recently, an i4is study for Breakthrough Starshot suggested that the whole disc of a lightweight probe should form both laser sail and transmit antenna. In *Active Metasurfaces for Non-Rigid Light Sail Interstellar Optical Communication* [1] researchers at Northeastern University, Boston, Mohammadrasoul Taghavi, Raana Sabri an Hossein Mosallaei, suggest that the force of propulsion on a non-rigid sail would lead to deformations affecting its performance. They propose a reflective metasurface with a high Q-factor (ie very narrow tunable optical bandwidth), an amplitude response approaching unity (the essential high reflectivity, not least to avoid destruction of the sail by the propelling photons), and a 2ϖ phase coverage (ie zero phase dependency).



The schematic depiction of the proposed gram-scale interstellar probe (not drawn to scale) aims to establish a relaying-based downlink communication channel. Each light sail consists of a multifunctional, all-dielectric nanophotonic platform that provides the required stable beam-riding stability and acts as a reflector antenna for the incident beam radiated by the payload in the front (Starchip). The magnified subfigure also illustrates a small array of communication unit cells that have undergone random geometrical variations during the propulsion stage..
Credit (image and caption): Taghavi et al, Figure 1

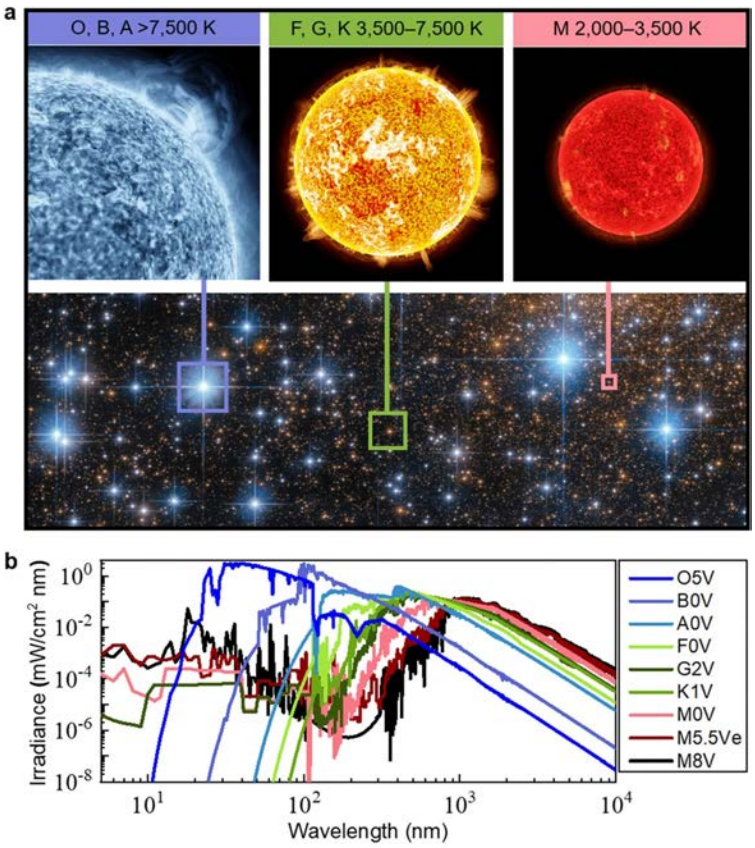
Ultrafast transfer to Mars

In *Ultrafast transfer of low-mass payloads to Mars and beyond using aerographite solar sails* (arxiv.org/abs/2308.16698) authors Julius Karlapp (Technische Universität Dresden), René Heller (Max Planck Institute for Solar System Research, Göttingen) and Martin Tajmar (Technische Universität Dresden) suggest a "feasible and worthy interstellar precursor mission" using solar sails made of the ultra-light material aerographite, known for its low density (0.18 kg/m^3) and high absorptivity (~1), enabling remarkable acceleration of payloads of up to 1 kg. They examine both direct outbound trajectories and sundiver launches. For example a direct outward Mars transfer yields 65 km/s in 26 days and a sundiver dive to 0.6 AU provides 148 km/s of escape velocity, reaching the heliopause in 4.2 yr. However they mention an unresolved question, the deceleration of the payload for a delivery rather than a flyby mission. Friction with the extended Martian atmosphere low gravity yield a relatively wide deceleration corridor and moderate heating rates compared to Earth and Venus.

[1] In the journal Advanced Theory and Simulations 10 October 2023 onlinelibrary.wiley.com/doi/10.1002/adts.202300359

Interstellar photovoltaics

A recent paper, *Interstellar photovoltaics*[1], Nora Schopp et al [2] considers the possibility of harvesting photons from different star types, including our closest neighbour star Proxima Centauri. The theoretical efficiency limits of single junction photovoltaic devices are calculated for different star types. The paper tells us that organic photovoltaics (OPVs) are the most lightweight solar technology and have the potential to be employed in weight-restricted space applications, including foreseeable interstellar missions. Photoconversion efficiencies (PCE) range from 47% for the hottest main sequence stars (subtype O5V) to 23% PCE for the coldest red dwarf types. The paper refers to the Breakthrough Starshot proposals where OPVs could deliver the required light weight while their photoactive layers are nanometer-thin films that can be deposited on thin plastic substrates and on curved surfaces.



Stellar types and their spectra.
a: Visually representative examples of O, B, A, F, G, K and M stellar types (hot to cold) within our galaxy.
b: Spectral distributions of stars ranging from O5V to M8V.
Credit (image and caption): Schopp et al

Light Sail Astrobiology Mission to Enceladus and Europa

In *A Light Sail Astrobiology Precursor Mission to Enceladus and Europa* (www.researchgate.net/publication/374153715_A_Light_Sail_Astrobiology_Precursor_Mission_to_Enceladus_and_Europa) Manasvi Lingam, Adam Hibberd and Andreas M Hein assess the feasibility of deploying laser sail technology in lieu of conventional chemical propulsion to instantiate precursor life-detection missions. They suggest that GigaWatt laser technology could accelerate a 100 kg probe to a speed of ~30 km/sec to reach Europa within 1-4 years and Enceladus within 3-6 years. The GigaWatt laser system could usefully be placed near either the Antarctic or Arctic Circles. They determine that the minimum encounter velocities with these moons (around 6 km/sec) may be nearly optimal for the detection of biomolecular building blocks (eg amino acids) in the plumes by means of a mass spectrometer akin to the SUrface Dust Analyzer onboard the Europa Clipper mission. They conclude that icy moons in the Solar System are potentially well-suited for exploration via the laser sail architecture approach, especially where low encounter speeds and/or multiple missions are desirable.

[1] September 2023, link.springer.com/article/10.1038/s41598-023-43224-5
[2] Researchers from University of California Santa Barbara (UCSB), Nazarbayev University, Kazakhstan, Fedkovych Chernivtsi National University, Ukraine, Adam Mickiewicz University, Poland, National University of Singapore, University of California Berkeley, CNRS, Université de Paris and The Hong Kong University of Science and Technology

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 October Issue.

An Interstellar Precursor Mission

Cornell's preprint server ARXIV published a paper by Julius Karlapp et al titled "Ultrafast transfer of low-mass payloads to Mars and beyond using aero graphite solar sails" on August 31, 2023. With interstellar mission concepts now being under study by various space agencies and institutions, a feasible and worthy interstellar precursor mission concept will be key to the success of the longshot. Hence this paper investigates interstellar-bound trajectories of solar sails made of the ultra-lightweight material aerographite. Due to its extremely low density and high absorptivity, a thin shell can pick up an enormous acceleration from solar irradiation. Payloads of up to 1 kg can be transported rapidly throughout the solar system.

This paper focuses on the potential of solar light sails to carry small payloads to Mars in short times, that is, weeks to months. Considering NASA's interest in putting humans on Mars, the paper believes that such a precursor mission would serve two purposes and hence be the most likely to be accepted and actually executed. The paper uses simulations to consider various launch scenarios from a polar orbit around Earth including direct outbound launches as well as Sun diver launches towards the Sun with subsequent outward acceleration. The paper also includes a trajectory analysis of such a spacecraft, and it could then easily be adapted to reach interstellar space in just 5.3 years. The full paper can be found here: arxiv.org/abs/2308.16698.

Interstellar Trajectories

On September 8th, 2023, the Journal of Spacecraft and Rockets published a paper by Larry Silverberg and Jeffrey W Eischen titled "Trajectory of a Spacecraft When It Passes by a Gravitational Body During Interstellar Travel." As we all know, interstellar missions that reach their destinations within a generation will require spacecraft that navigate across the cosmos at relativistic speeds. The planning for these missions will therefore be heavily based on simulation software that performs mission design tradeoff studies, energy and cost budgeting, astronavigation optimization, etc. In terms of the underlying physics, these codes will have to predict a spacecraft's relativistic trajectory as it passes by a gravitational source. This paper applies a new relativistic formulation of mechanics that can greatly simplify these predictions.

The paper first outlines the mechanics of such an interstellar mission, including how relativistic velocity and acceleration would be achieved. To this end, it develops geometric models of acceleration and velocity and derives a few governing equations. From these findings, the paper analyzes various relativistic orbital trajectories, including various interactions with a multitude of different gravitational bodies. It then discusses the various precautions and modifications that would have to be made to an interstellar probe to allow it to accomplish its mission despite some gravitational interaction. The full paper can be found here: www.mae.ncsu.edu/eischen/wp-content/uploads/sites/17/2023/09/LMS-JWE-JournalSpacecraftRocketsSept2023.pdf.

Diffractive Light and Solar Sails

On August 21st, 2023, Rochester Institute of Technology published a thesis by Prateek Ranjan Srivastava titled "Diffractive Light and Solar Sails." The thesis proposes using an elementary space variant diffractive film to design passively stable light sails propelled by laser radiation. It also explores the application of this concept to solar sails, enabling spiral trajectories and high orbital inclination angles at close solar orbits. It details the challenges of both approaches and provides a material analysis describing what composition would serve as the ideal light sail material.

The main focus of the thesis focus is on a 'bi-grating' light sail, designed for stable 'beam-riding' on a Gaussian laser beam. This concept aligns with the Breakthrough Starshot program, which aims to propel an ultra-lightweight sail to a nearby star at relativistic speeds. The paper also presents alternative light-sail designs –such as a conical mirror sail and spherical sail – but then explains why such designs are inferior to the bi-grating light sail. The paper analyzes stability conditions and evaluates 2D and 3D configurations of different light sail situations and designs. Leveraging advanced multi-objective optimization techniques, the thesis presents a solar sail with the highest force and lowest mass for maximum acceleration with a detailed mission concept and analysis. The full thesis can be found here: scholarworks.rit.edu/theses/11547/.

A photo of the Earth taken by NASA's Curiosity rover on 31 January 2014 from the surface of Mars using the left-eye camera of Curiosity's Mast Camera (Mastcam) to capture this scene about 80 minutes after sunset on the 529th Martian day, or sol, of the rover's work on Mars. No stars are seen in this photo because the Earth is shining brighter than any star in the Martian night sky. A human observer with normal vision, if standing on Mars, could easily see Earth and the moon as two distinct bright evening 'stars'. When Curiosity took the photo, Earth was about 99 million miles (160 million kilometers) away.
Credit (image and caption): NASA Jet Propulsion Laboratory-Caltech, Malin Space Science Systems and Texas A&M University.

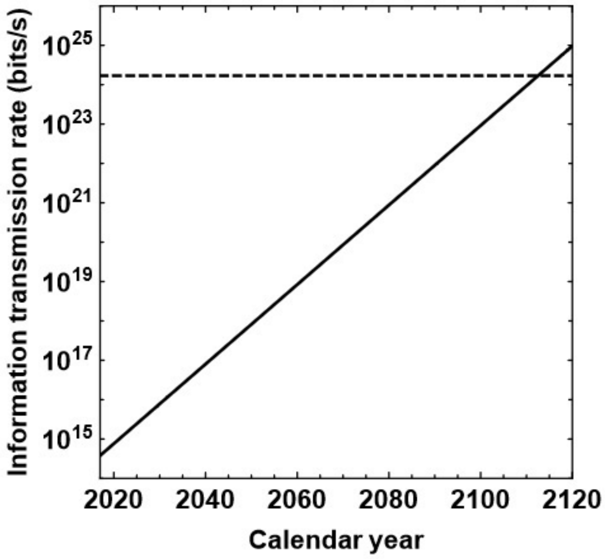
A "Paradox of Silence and Self-Awareness"?

In *Life in the Cosmos: Paradox of Silence and Self-Awareness* (arxiv.org/abs/2307.05507), Jonathan H Jiang (JPL), Avery M Minion (Rutgers Preparatory School, New Jersey), Stuart F Taylor (The SETI Institute) reflect on the paradoxical nature of our existence in a seemingly lifeless cosmos, the silence we encounter and the depths of our self-awareness. They challenge traditional definitions of life (especially in the context of AI). They suggest we have a profound responsibility as the only known life forms.
They suggest this silence is not discouraging but presents us with an opportunity for introspection into the very essence of our existence and the multifaceted nature of life itself.
As humanity embarks on an age of exploration, the question of whether we are alone in the universe remains unanswered. This comprehensive review reflects on the paradoxical nature of our existence in a seemingly lifeless cosmos, delving into the silence we encounter and the depths of our self-awareness. We embark on a journey that encompasses the search for life within our solar system, the mysteries of exoplanets, and the absence of technologically detectable life. Traditional definitions of life are challenged, especially in the context of artificial intelligence, as we strive to understand the complexities of existence. Contemplating our significance and insignificance in the vast cosmos, we grapple with the profound responsibility that accompanies being the only known life forms. Through introspection and contemplation, we capture the essence of our epoch -- an era defined by cosmic loneliness yet magnificent self-awareness. They ask an intriguing question in the context of the emergence of AI: Could these complex constructs of code and silicon, assuming they attain a degree of consciousness, be categorised as a nascent form of life?
The paper asks a lot of questions arising from the conjunction of our enormous responsibility as the only known sentient species and our apparent relative incognisance in the face of all this vastness.

Kardashev reconsidered?

A recent paper by Manasvi Lingam et al *Planetary Scale Information Transmission in the Biosphere and Technosphere: Limits and Evolution* [1] examines the total information transmission rate of the Earth biosphere and the corresponding technological rate. The biosphere sum is mainly prokaryote transmissions since the rest of us, the eukaryotes, single cells with a nucleus and multi-cellular life is three orders of magnitude less numerous. With some reservations they reach a global information transmission rate of Ip ~ $1.7*10^{24}$ bits per second. Technological information has been dominated by human to human and human to and from machine but machine to machine transmission is rising much more rapidly [2]. The paper shows that technological information transmission will probably (barring disasters) overtake the biosphere in less than a century.

An interesting conclusion is that "the Kardashev scale in astrobiology [3], which classifies putative technological species (including humans) based on their energy consumption rate (ie power), could be complemented by a scheme centered on the information transmission rate, or alternative measures of information content".



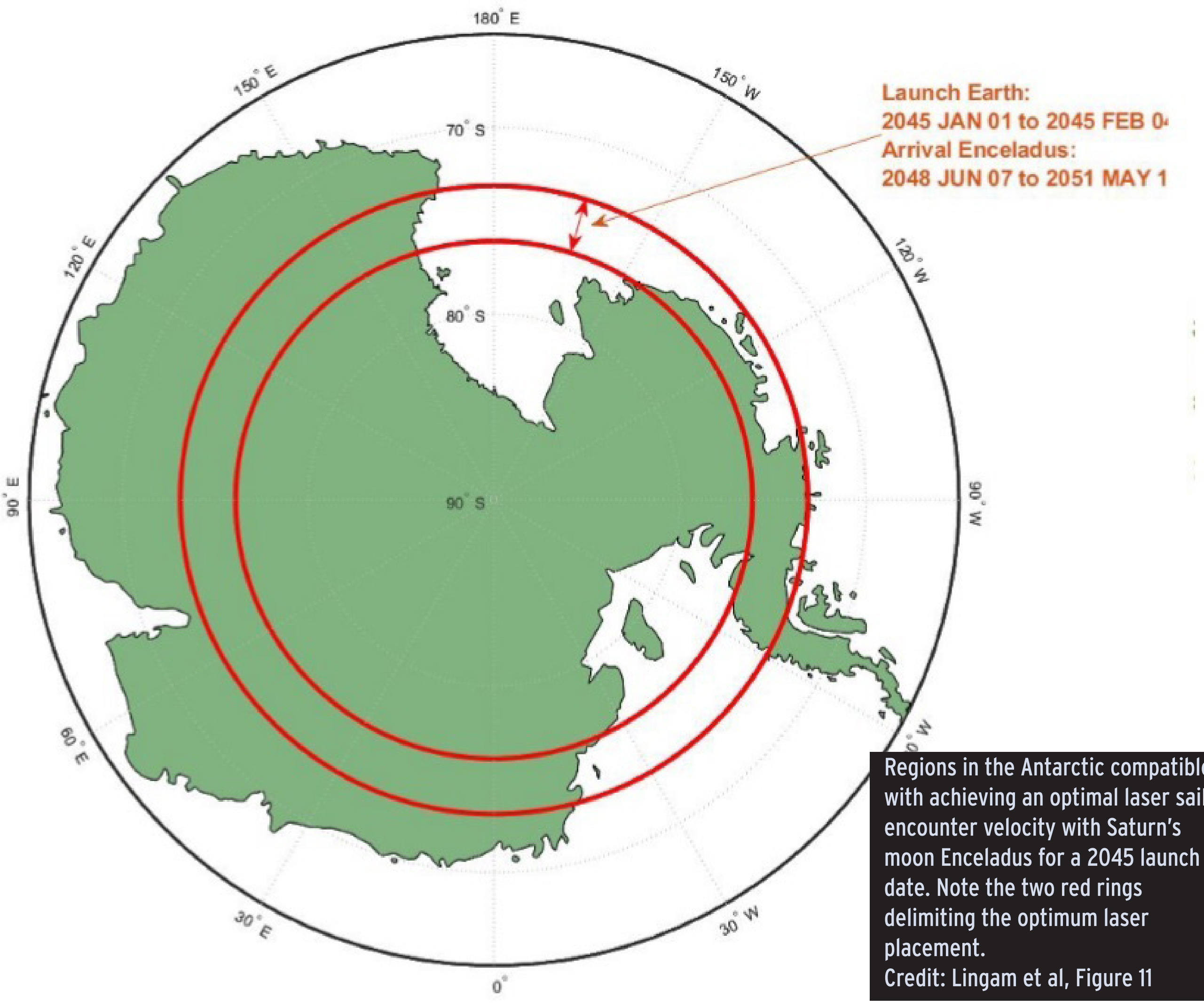
Information transmission rate associated with communication (in bits/s) as a function of the calendar year. The dashed line is the rate estimated for the biosphere (assuming it is roughly constant on short timescales) and the solid line signifies the rate for the technosphere. The growth is an exponential one based on an e-folding time of 4.3 years (the e-folding time is the doubling time divided by 0.693, the natural logarithm of 2).
Credit: Lingam et al Fig 1

Laser sailing to find life

In *A Light Sail Astrobiology Precursor Mission to Enceladus and Europa* [4], Andreas Hein and Adam Hibberd of i4is and Manasvi Lingam, Florida Institute of Technology, and old friend and colleague of i4is, suggest that deploying laser sail technology rather than conventional chemical propulsion would have advantages for precursor life-detection missions to the icy moons with subsurface oceans of liquid water in our own Solar System. Enceladus (orbiting Saturn) and Europa (orbiting Jupiter) emit plumes that seem accessible to in situ sampling. They suggest that gigawatt (GW) laser technology could accelerate a 100 kg probe to a speed of ~30 km/sec reaching Europa in 1-4 years and Enceladus in 3-6 years. It's worth recalling that Europa has a subsurface ocean containing more liquid water than all of Earth's oceans combined. The paper gives an extensive set of references to relevant existing research supporting these moons as perhaps our best chance of finding life within our Solar System. The paper uses Adam Hibberd's MATLAB code Optimum Interplanetary Trajectory Software (OITS) - much discussed in previous issues of Principium [5] - plus patched conics [6]. The team have derived launch site possibilities in Antarctica.

[1] www.mdpi.com/2075-1729/13/9/1850 Manasvi Lingam (Florida Institute of Technology and Institute for Fusion Studies, The University of Texas at Austin), Adam Frank (University of Rochester, New York) and Amedeo Balbi (Università di Roma "Tor Vergata")
[2] The paper cites the recent concept of the Internet of Things - commonplaces include your fridge ordering your food - but the internet itself produces massive volumes of machine to machine traffic. And do we include traffic generated by remote procedure calls and other remote application programming interfaces while ignoring communication within single systems?
[3] N S Kardashev *Transmission of Information by Extraterrestrial Civilizations*. Soviet Astronomy 1964, adsabs.harvard.edu/full/1964SvA.....8..217K7
[4] www.researchgate.net/publication/374153715_A_Light_Sail_Astrobiology_Precursor_Mission_to_Enceladus_and_Europa
[5] For example *Design of Interplanetary Missions to Jupiter Using Optimum Interplanetary Trajectory Software*, Hibberd, in Principium 36, February 2022 i4is.org/principium-30/
[6] en.wikipedia.org/wiki/Patched_conic_approximation

Antarctica: Laser Sail Launch Declinations in 2045 for Optimal Arrival at Enceladus



Regions in the Antarctic compatible with achieving an optimal laser sail encounter velocity with Saturn's moon Enceladus for a 2045 launch date. Note the two red rings delimiting the optimum laser placement.
Credit: Lingam et al, Figure 11

Like most previous missions to these moons, these would be flyby missions but the paper shows that several proven detection methods would be effective at the encounter velocities, a few km/sec, implied. In summary we can, within a couple of decades, come to know the actual and potential existence of life beyond Earth and in the Solar System.

Swarming Proxima Centauri: Optical Communications Over Interstellar Distances

The paper summarised in P41, our May issue, *News Feature: i4is delivers Communications Study to Breakthrough Starshot*, is now on open access on ResearchGate [1]. The paper, the result of substantial work by an i4is-centred team, presents a solution to the interstellar downlink challenge based on a swarm of disc-shaped probes, each with diameter 4 m and weighing about 1 gram. The work innovates in swarm architecture, launch cadence and velocity selection, probe materials, intra-swarm communications and precision of signal timing. For more about this the P41 article is at - i4is.org/wp-content/uploads/2023/05/News-Feature-i4is-delivers-Communications-Study-to-Breakthrough-Starshot-Principium41-23052291003-1.pdf.

[1] www.researchgate.net/publication/373833951_Swarming_Proxima_Centauri_Optical_Communications_Over_Interstellar_Distances

Magnetic Fusion Plasma Drive

In *Magnetic Fusion Plasma Drive* (arxiv.org/abs/2309.11524) Florian Neukart [1] presents the Magnetic Fusion Plasma Drive (MFPD) propulsion system. He discusses propulsion, plasma dynamics, and magnetic confinement in space. He suggests significant advantages of the MFPD system over existing technologies, particularly in fuel efficiency, thrust capabilities, and potential scalability. Challenges remain, but he believes the MFPD system represents a propulsion paradigm shift, potentially revolutionising our approach to space exploration.

The paper reviews all the other current reaction propulsion methods and moves on to the theory of the MFPD, specifically the deuterium/tritium reaction where it states that "This reaction releases 17.6 MeV (mega-electronvolts) of energy, predominantly carried away by the neutron" and later observes "The intense conditions within the MFPD system place substantial demands on the materials used: ....Neutron Damage: Fusion reactions, specifically those involving deuterium and tritium, emit high-energy neutrons. These neutrons can cause damage to materials, leading to potential system failures over time" but does not connect these two.

The deuterium/tritium reaction therefore looks like a bad example for the purpose. However Dr Neukart communicates -

> The choice to use a neutron-rich fusion reaction for our example calculation was primarily pedagogical and illustrative in nature. Given that the deuterium-tritium (D-T) fusion reaction is one of the most studied and understood reactions, it offers a clear and familiar basis upon which to elaborate the core principles and mechanics of our MFPD to the wider scientific community. This makes the paper accessible to a broad audience, including those who may not be intimately familiar with less common fusion reactions.
>
> Furthermore, the D-T reaction provides a useful benchmark against which we can measure and compare the performance of our drive. Given its relatively lower ignition temperature and higher cross-section, it serves as a good "starting point" for understanding fusion propulsion dynamics.
>
> That being said, our ultimate goal with the MFPD is to harness the potential of aneutronic reactions, specifically p-B^{11} (hydrogen nucleus-boron), which holds promise for space propulsion. The D-T example thus bridges traditional fusion research and the innovative paths we're pursuing with MFPD.

We'll be watching Dr Neukart's MFPD work with interest.

Why India signed the USA's Artemis Accords and why now?

First published in the magazine Room (room.eu.com) Gurbir Singh [2] asks - *Why India signed the USA's Artemis Accords and why now?* (astrotalkuk.org/why-india-signed-the-usas-artemis-accords-and-why-now/).

Artemis (www.nasa.gov/specials/artemis-accords/) is a US-centred set of accords centred around lunar exploitation but aimed to provide the basis for long term international guidelines as we extend our civilisation beyond Earth. Gurbir suggests that India has taken a pragmatic decision, balancing its commitment to the third world while judging that the US and its fellow Artemis signatories [3] look like the most appropriate group to join. Gurbir suggests that the Indian decision is entirely pragmatic but that it further separates Russia and China from this loose coalition of nations with space ambitions.

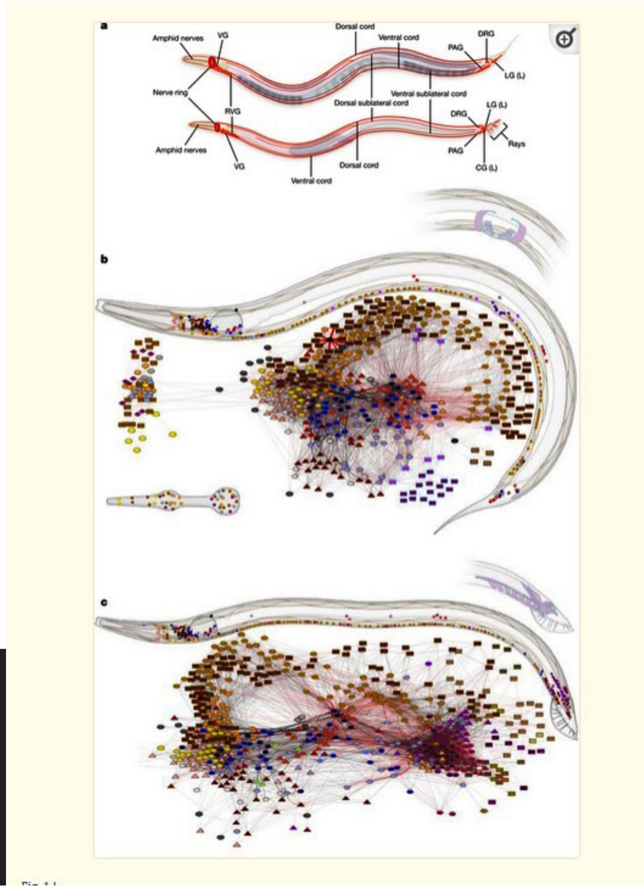
Principium first discussed the Artemis Accords in *The Artemis Accords: what comes after the Moon?* contributed by Max Daniels in Principium 32, February 2021 (i4is.org/principium-32/).

[1] Dr Florian Neukart is Chief Product Officer at Terra Quantum AG and Assistant Professor at Leiden University (Leiden Institute of Advanced Computer Science)
[2] Gurbir is the author of *The Indian Space Programme - India's Incredible Journey from the Third World To the First* (astrotalkuk.org/product/indian-space-programme-paperback)
[3] Signatories as of August 2023 are Argentina, Australia, Bahrain, Brazil, Canada, Colombia, Czech Republic, Ecuador, France, Germany, India, Israel, Italy, Japan, Luxembourg, Mexico, New Zealand, Nigeria, Poland, South Korea, Romania, Rwanda, Singapore, Spain, Saudi Arabia, Ukraine, United Arab Emirates, United Kingdom, United States.

Sleeper service to Mars (and beyond?)

In *Suspended Animation for Deep Space Flight* [1], Mauricio Girard, Daniel Barranco, Martina Canatelli-Mallat, Camila D Pasquini, José L Cordeiro and Rodolfo G Goya discuss Suspended animation (SA) and related techniques torpor, hypothermic suspended animation, emergency preservation and resuscitation (EPR), feasibility of reversible biological cryopreservation, vitrification and nanowarming. They report that the tiny organism caenorhabditis elegans (c elegans) has a nervous system which can be successfully cryopreserved and brought back to a functional condition by superfast freezing and thawing procedures, preserving the memory of trained specimens (though it's notable that c elegans has only hundreds of neurons).

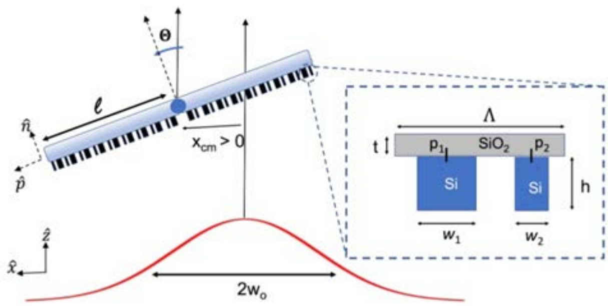
This looks like a useful review of SA and the technique has possible human applications to missions from months (eg Mars) to centuries (eg the nearest stars).



The C elegans adult nervous system, neuroanatomy and connectivity
(a) The major nerve tracts and ganglia (anterior to left) of adult hermaphrodite and adult male.
Neuroanatomy and network graphs
-Adult hermaphrodite (b) and
- adult male (c).
Credit: Cook et al, in Nature (2019) [2]

A bi-grating light sail for stable beam-riding

A PhD dissertation, *Diffractive Light and Solar Sails* (scholarworks.rit.edu/theses/11547/) by Prateek Ranjan Srivastava presented to the Rochester Institute of Technology, New York, describes a 'bi-grating' light sail, designed for stable beam-riding on a Gaussian laser beam. It analyses stability conditions and evaluates 2D and 3D configurations using a framework that optimises electromagnetic simulations. Such a light sail is designed to align with the Breakthrough Starshot programme. The analysis covers stability conditions and evaluates 2D and 3D configurations using MEEP (a software package for electromagnetic simulation). The work extends to the design and optimization of solar sails, maximising transverse force efficiency across a broad solar spectrum. The paper discusses the beam-riding problem and possible beam-riding configurations with implementations using a bi-grating beam-rider, an Axicon [3] beam-rider, metasurface beam-rider and a broadband diffractive solar sail - and suggests future work including a non-rigid sail, curved light sails, a spin-stabilized sail and achromatic liquid crystal gratings.



High contrast metasurface bi-grating configuration propelled by a Gaussian beam. The bi-grating is comprised of unit-cells with geometric parameters shown in the inset. p1,2 is measured from the center of the unit-cell.
Credit (image anf caption): Srivastava Figure 5.1

[1] www.researchgate.net/profile/Rodolfo-Goya/publication/372649407_SUSPENDED_ANIMATION_FOR_DEEP_SPACE_FLIGHT/links/64c1656bb9ed6874a546ebe6/SUSPENDED-ANIMATION-FOR-DEEP-SPACE-FLIGHT.pdf
[2] *Whole-animal connectomes of both Caenorhabditis elegans sexes* www.ncbi.nlm.nih.gov/pmc/articles/PMC6889226/, Fig. 1 - caption adapted from same source
[3] en.wikipedia.org/wiki/Axicon

Anti-matter propulsion feasible soon?

In *Quantification of Electron/Positron Pairs for Matter/Antimatter Propulsion: Experimental Results & Next Steps* [1] Mark Pickrell asserts that, based on early experimental results, it appears that the generation of sufficient quantities of electron/positron pairs by a high-energy laser, specifically for matter/antimatter propulsion, is now practicable. He cites E Liang, et al, *High e+/e- ratio dense pair creation with 10^{21} w•cm^{-2} laser irradiating solid targets*, E Liang et al [2], reporting that Dr Liang and others at Rice University and the Texas Petawatt Laser Facility determined that 10^{15} pairs per cubic centimetre are generated from bursts as short as 130 femtoseconds.

He proposes a laboratory setup for precise quantification and optimisation of electron/positron pair generation and presents calculations which suggest travel times of a few years to the nearest stars.

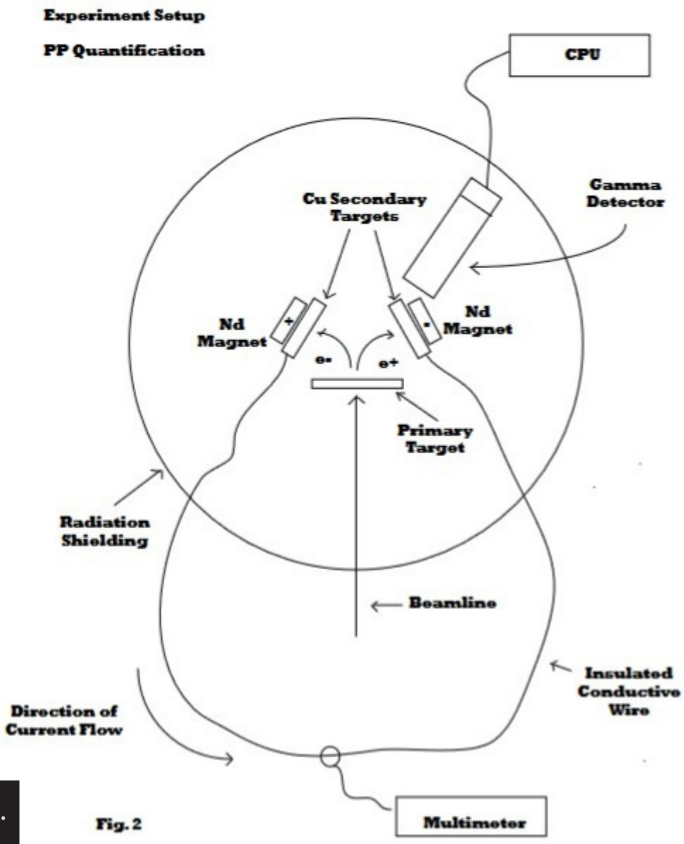


Fig. 2

Quantification/Optimization Experiment Setup. Credit: Pickrell Fig 5.

Don't shoot first!

In *An Assay on The Hobbesian Trap and Axioms of First Contact* [3], a philosopher at the University of Helsinki, Steven J Firth responds to claims made by Jebari and Olsson-Yaouzis [4] that the 'dominant thought' in the philosophy of language indicates that communication with ETI would not be possible, and that the resultant uncertainty forces us into the Hobbesian Trap [5] the proclivity to adopt pre-emptive military strategies as a function of mutual distrust and fear of imminent attack. He suggests that shared universal contexts, together with the potential existence of post-biological ETI, suggest that communication at a level sufficient to interpret basic dispositions (which he calls the level of 'performative function') may be possible. He attempts to refute the assumption that ETI would necessarily adopt a game theoretical rationality, critiques the notion that ETI would choose a risk-dominant strategy rather than a payoff-dominant strategy, repudiate the claim that communication with ETI would not be possible, and show how the Hobbesian equivalence principle is violated in a proximal first-contact situation.

All of these have echoes elsewhere including the Dark Forest scenario (referenced above), mutual assured destruction in the cold war and even the cowboy fiction idea of the "Mexican standoff".

Firth suggests fourteen axioms of first contact such as an axiom of incarnation - that while it is theoretically possible for ETI to exist in some alternative dimension, ETI need to be interpretable in order to be relevant to humanity.

Firth's axioms provide an interesting way of approaching the strategic problems of communication at first contact,

[1] Presented at the 2023 AIAA Ascend Conference, Las Vegas, www.researchgate.net/publication/374581514_Quantification_of_ElectronPositron_Pairs_for_MatterAntimatter_Propulsion_Experimental_Results_Next_Steps
[2] Nature Scientific Reports, 2015 www.nature.com/articles/srep13968
[3] Space Policy, September 2023, www.sciencedirect.com/science/article/pii/S0265964623000486
[4] *A Game of Stars: Active SETI, radical translation and the Hobbesian trap,* Karim Jebari & Niklas Olsson-Yaouzis (Institute for Futures Studies, Stockholm & Stockholm University), Futures, Volume 101, August 2018, no open access found
[5] See also *Cassidy Cobbs - Bioscientist - Part 2* in Principium 30, August 2020 and *The Dark Forest Rule: One Solution to the Fermi Paradox*, Chao Yu and Jiajun Liu, JBIS V68 #5/6, May/Jun 2015

Optimising capture trajectories at Alpha Centauri

The 6th International Symposium on Space Sailing took place 5 – 9 June 2023, New York (www.citytech.cuny.edu/isss2023/). An item of particular interest to Principium readers was *Optimization of Photon-sail Trajectories to Alpha Centauri Using Evolutionary Neurocontrol*, Dachwald et al [1]. They reported a Primary Goal - To find the optimal steering strategy for a photonic sail to get captured into the Alpha-Centauri system after a minimum-time transfer from Earth- and a Secondary Goal - To investigate transfer trajectories between the Alpha-Centauri stars and orbit-raising manoeuvres to explore the habitable zones of the stars. They attacked the problem using a reversal of the capture manoeuvre starting from an escape trajectory and using machine learning to arrive at the reverse, a capture trajectory. They looked at four potential sail materials Kapton, gold foil, Composite graphene-based and Graphene. They concluded that the laser acceleration and the solar (ie target star photon) sail requirements were so incompatible that a fly-though, as proposed by Breakthrough Starshot was the only feasible approach in the short term, If an ultra-light solar sail material becomes available in future then it might be best to discard the laser sail on arrival and deploy a separate solar sail to achieve capture.

Svarog - a sundiver to the heliopause

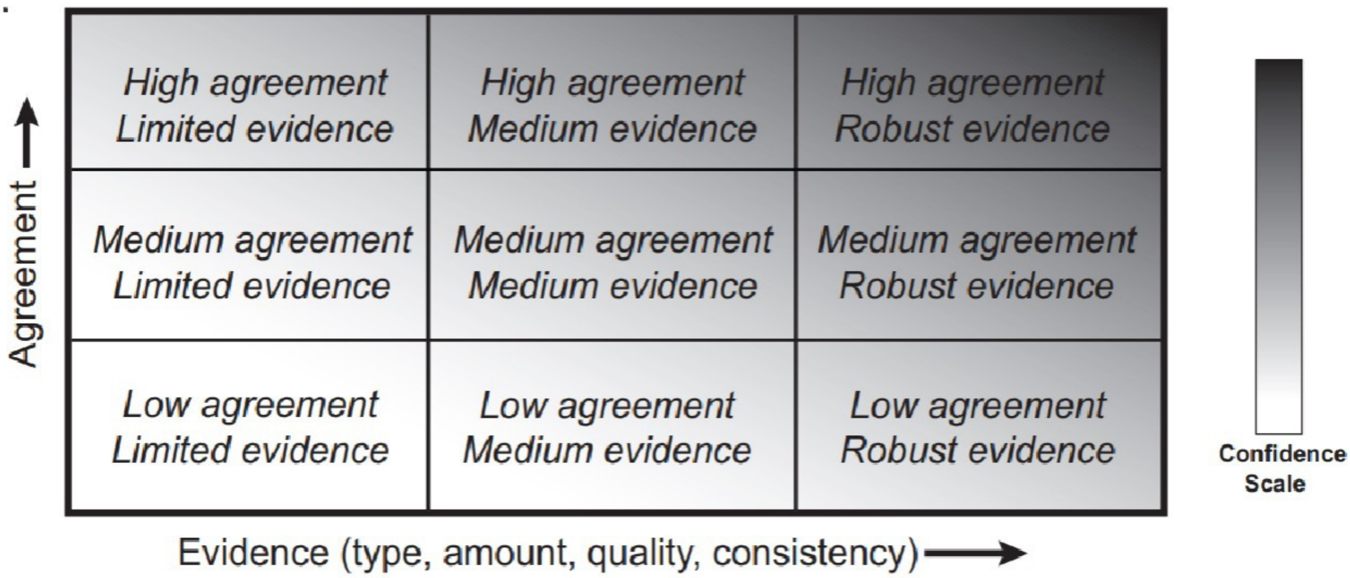
At the 6th International Symposium on Space Sailing (see previous article) Gil Barbosa Ribeiro, Debdut Sengupta and Beatriz Soriano Tortosa reported *Svarog - Research for an Early-Stage Development of the First Interstellar CubeSat Powered by Solar Sailing Technology* (www.citytech.cuny.edu/isss2023/docs/presentations/05_June_5_Fil.pdf). This is a multi-year project at Imperial College London to push forward solar sailing technology and demonstrate low cost interstellar travel accessible to student projects. The immediate aim is to construct a craft that will reach the heliopause (assumed at 123 AU from the Sun) within 100 years from launch by using solar sail technology. This would also be a technology denominator aiming to test the trajectory of the craft and validate it against theoretical models visual confirmation of sail deployment and carry a payload representing human ingenuity. The team have already looked at probe configuration, sail deployment (using a vacuum chamber), structural mechanics, tracking challenges and environmental modelling (thermal control).

Their current goal is to define accurate technical requirements for the mission plus numerical stability analysis of solar sail dynamics, improvement of their non-dimensional analysis of structural mechanics, model of communication for validation of link budget testing of electronics in a radiation environment and further development of boom deployment prototypes for testing and analysis.

"Is this the real life?" [2]

In *Confidence of Life Detection: The Problem of Unconceived Alternatives* [3] Professor Peter Vickers et al ask - If we find an apparent biosignature how certain can we be that we have genuinely found life? This must depend upon the extent to which we have explored the relevant possibility space. They recommend that the astrobiology community should follow a thoroughly time-tested framework, the uncertainty assessment approach adopted by the Intergovernmental Panel on Climate Change (IPCC). They start from philosophy of science, citing in particular the work of P Kyle Stanford (faculty.sites.uci.edu/pkylestanford/) the ‘problem of unconceived alternatives’. The worry is that we tend to jump too quickly from ‘There is no known abiotic explanation of φ’ to ‘φ is probably caused by life’ mentioning a number of false positives which have already arisen. Only when we have explored a particular type of alleged biosignature for decades without finding a plausible abiotic explanation should we be "very excited". They argue that astrobiology is still a young science, and research into ‘abiotic mimics’ of biosignatures is in its infancy. They apply the prior probability approach of Thomas Bayes and move on to recommend a specific approach, that of the IPCC, while also suggesting the NfoLD/NExSS framework.

[1] Bernd Dachwald (FH Aachen), Frederic Schoutetens (TU Delft, now DLR) and Jeannette Heiligers (TU Delft) www.citytech.cuny.edu/isss2023/docs/presentations/23_June_7_Dachwald.pdf
[2] With apologies to Freddie Mercury (Farrokh Bulsara)
[3] Peter Vickers, Christopher Cowie, Catherine Gillen, Cyrille Jeancolas (all Durham University), Lynn J Rothschild (NASA Ames) and Sean McMahon (University of Edinburgh) in Astrobiology, 2023 durham-repository.worktribe.com/output/1176163/



The IPCC uncertainty language framework: The X-axis corresponds to the degree of robustness of the evidence for a claim (assessed by a working group), and the Y-axis represents the extent of agreement of the scientific community regarding the same claim. From Mastrandrea et al [1] with permission.
Credit(image and caption): Vickers et al, Fig 5

They work through a past case of an apparent biosignature to demonstrate their own recommended test framework. They conclude by recommending three ways forward -

- Their own test framework for analysing possible biosignatures.
- A search for much more data on abiotic mimics.
- That astrobiologists making biosignature judgements should factor in considerations that are best described as historic, philosophical, or sociological.

Give us back our (Mars) atmosphere!

The Earth's magnetosphere helps protect the planet from the potential sterilizing effects of cosmic rays and also helps retain the atmosphere, which would otherwise by stripped by large solar storms as they pass over the planet. Mars currently does not have the protection of a planetary magnetic field. In this article researchers from Rutherford Appleton Laboratory (UK), NASA, Princeton University and University of Strathclyde aim to create one [2].

Their optimum solution is to create an artificial charged particle ring (similar to the Earth's Van Allen belts), around the planet possibly formed by ejecting matter from one of the moons of Mars (as forms the Jupiter-Io plasma torus), but using electromagnetic and plasma waves to drive a net current in the ring(s) that results in an overall magnetic field. They point out that one of the first goals of terraforming Mars will be to increase the atmospheric pressure above the Armstrong Limit (6.3 kPa [3]), a threshold that removes the requirements of having to wear a full-body pressure suit, although oxygen will still be needed.

[1] Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties (www.ipcc.ch/working-group/wg1/ November 13, 2019)
[2] *How to create an artificial magnetosphere for Mars*, Ruth A Bamford, Barry J Kellett, James L Green, Chuanfei Dong, Vladimir Airapetian, Bob Bingham; Acta Astronautica, Volume 190, January 2022 and arxiv.org/abs/2111.06887
[3] 6.3 kiloPascals is about 6% of normal Earth atmospheric pressure which is about 43 KPa. It's worth noting that the peak of Mount Everest has about 33% of normal Earth atmospheric pressure.

High altitude gear - Everest versus the first pressurised altitude suit

Tenzing Norgay and Edmund Hillary after successfully completing the first ascent of Mount Everest, 29 May 1953 , note the oxygen bottles and masks.
Credit: Wikipedia and "Tenzing Norgay Trekking"

The Bristol 138 pressure suit worn by 1938 altitude record holder [1].
Credit: RAF Museum, Cosford UK

A direct quotation from the paper best explains their perspective -

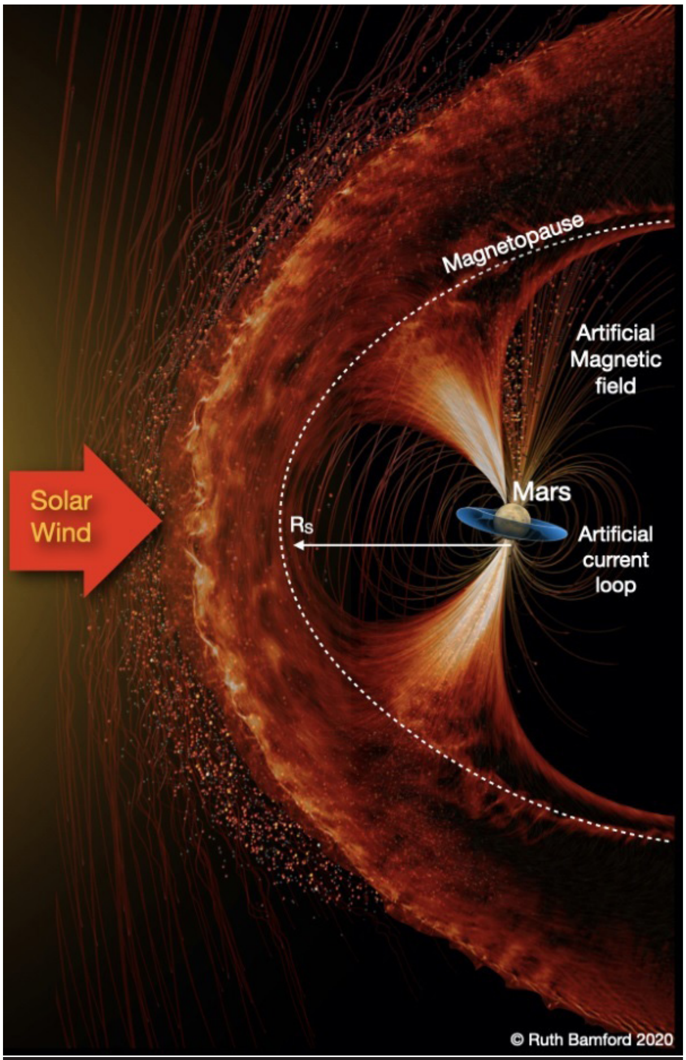
> The assumption is made here that there is a desire to create a magnetic field similar to that of a natural magnetized planet like the Earth and then follow how this could be done from a purely fundamental perspective. This issue, of creating an artificial structure at unprecedented scale, has not been considered in a peer-reviewed journal before. The calculations of power, resources and other relevant parameters are all deliberately made only to first order, as higher precision figures would be meaningless without a comparable level of precision for the engineering. This can be undertaken later.

They consider these technologies for implementation-

- re-starting the planet's iron core
- using solid state permanent magnets in either continuous loop or a series of discrete magnets
- the use of solid state superconductors
- a plasma current loop similar to a current driven plasma torus of an artificial plasmasphere

[1] web.archive.org/web/20160306213859/http://www.rafmuseum.org.uk/blog/research-development-collection-at-cosford/

They evaluate the plasma current loop option - They assume the development of successful nuclear fusion reactors as an efficient energy generation option.
They conclude that the intensity of magnetic field at the magnetopause needed to disrupt the solar wind, is not very much less than the field of a typical fridge magnet at ~5 mT. However the magnetic field over a minimum of 37 million square kilometres (the radius of Mars is RM ~3,400 km + ~100 km atmosphere) means the total energy stored in such a magnetic field is of the order of 10^{17} joules and this is excluding the energy needed to ramp the magnetic field up given the inductive properties of the surrounding media.
They summarise "No individual solution comes without vast technical challenges, many of which go beyond what can be described here. The primary challenge is not the intensity of magnetic field needed but the size of the required spatial dimensions."



An artistic impression of magnetosphere around Mars formed by a magnetic dipole field from an artificial ring or loop of electrical current circulating around the planet. The approximate point at which the pressures balance is the stand-off distance R_S Credit (image and caption): Ruth A Bamford Figure 1

Multilayer sails for ultralight spacecraft

In *Multilayers for directed energy accelerated lightsails* [1] Giovanni Santi (Università di Padova) et al assume a scalable, modular directed energy source with emission at 1064 nm, used to accelerate a spacecraft up to a target velocity of 0.2c. They point out that during acceleration the spacecraft will experience a longer wavelength than was initially emitted (in effect, red shift as observed in the recession of the galaxies).
They suggest two options to deal with this

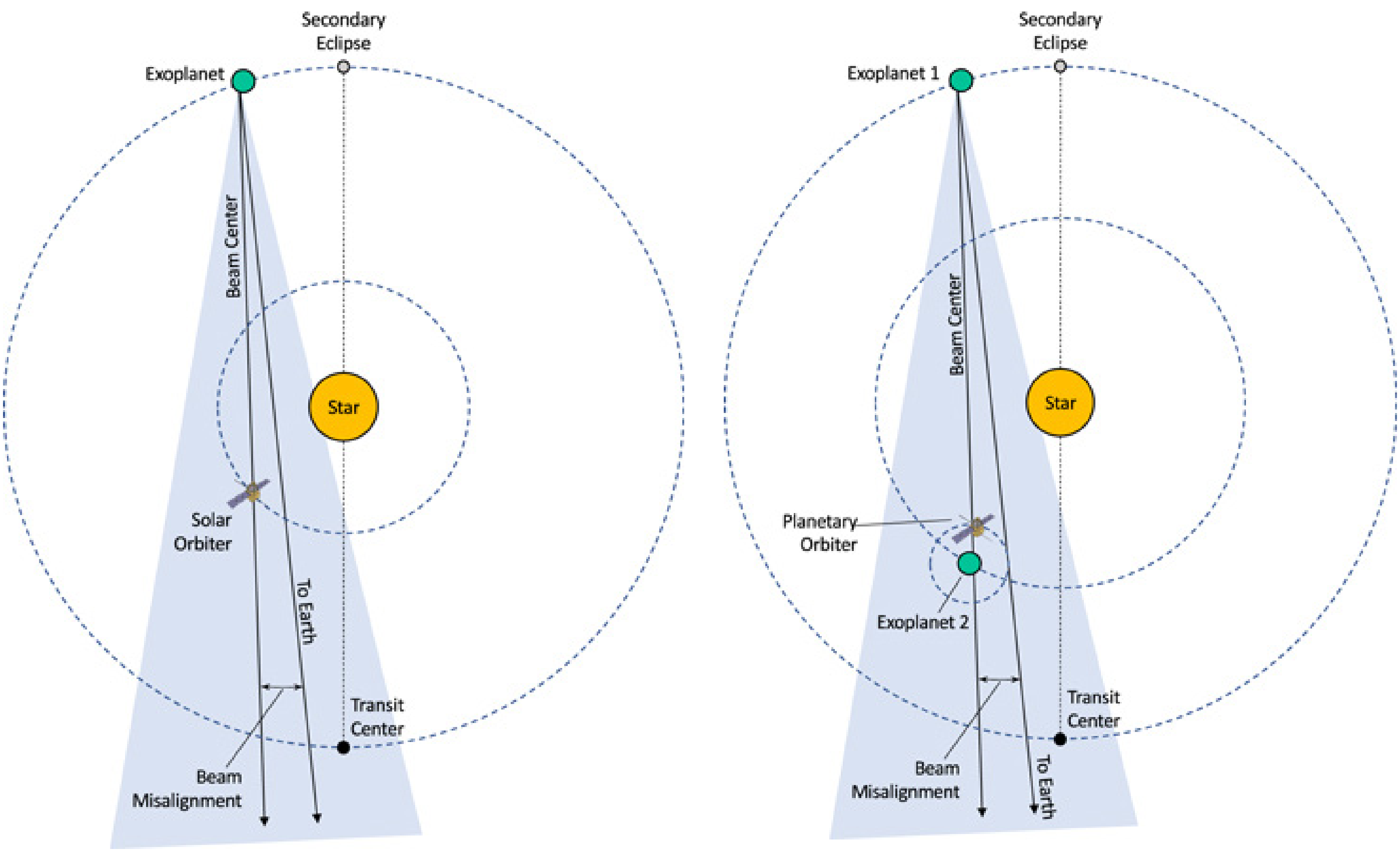
- shorten the emission wavelength as the spacecraft speeds up (so that the received wavelength at the spacecraft is constant)
- use a broadband reflecting sail to accommodate a modest or perhaps large dynamic range of received wavelengths.

They examine the latter in detail including the effect that beam spot size will also increase as the spacecraft recedes from the beamer. As reflecting materials they consider the properties of silicon, Magnesium fluoride, Silicon carbide, Silicon dioxide, Aluminium oxide and Titanium dioxide. They discuss issues in detail including thermal stability of the lightsail and fabrication challenges. They conclude that thin-film multilayers in the sub-micrometric scale could be valuable for low mass direct energy accelerated lightsails and end "The engineering process is fundamental to obtain proper optical characteristics, thus reducing the absorption of the lightsail in the Doppler-shifted wavelength of the laser in order to allow the use of high-power laser up to 100 GW." and remark that "The use of a longer wavelength laser source could expand the choice of potential materials having the required optical characteristics."

[1] Communications Materials, April 2022 https://www.nature.com/articles/s43246-022-00240-8

Detecting ETIs like us

In *Detecting Technosignatures from Earth-scale Civilizations* [1] Reza Ashtari of the Johns Hopkins University Applied Physics Laboratory (JHU-APL) looks into the possibility of detecting civilisations like our own by their electromagnetic emissions. He points out that the beams of satellite communications and interplanetary radar transmissions are tracked, so deep space communications and interplanetary radar operations use large, tracked antennas with kilowatts to megawatts of power pointed toward predetermined fixed points in space, so detection is not limited by the planet's rotation. If detected by the transit method "the interplanetary communications and radio activity of Earth-scale civilizations will only be visible during secondary eclipses (ie, superior conjunctions) and planet-planet occultation's (PPOs), unless intentionally directed at Earth".



Left: Geometry for observing interplanetary communications to a stellar orbiter before and after secondary eclipses.
Right: Geometry for observing interplanetary communications to a planetary orbiter before and after interplanetary conjunctions.
Note this configuration also applies for observing interplanetary radar. Credit (image and caption): Ashtari Figures 2 & 3

Looking at the geometry of the situation he suggests that transmissions to solar observer probes, like the Parker Solar Probe, make it particularly easy to observe. He suggests a number of known exoplanets as suitable for this sort of observation, of which three in the Trappist-1 system are the closest, at 41 light years.
Ashtari suggests applying an aggressive set of values for the Drake equation [2].

[1] The Astrophysical Journal, Volume 957, October 2023 https://iopscience.iop.org/article/10.3847/1538-4357/acf56c
[2] The Drake equation is -

$$N=R\times f_p\times n_e\times f_l\times f_i\times f_c\times L$$

N is the number of Earth-scale civilizations (Kardashev Type 0.7 or greater) in our Galaxy; **R** is the rate of star formation in our Galaxy; $\mathbf{f_p}$ is the fraction of stars with planets; $\mathbf{n_e}$ is the number of planets in each system that **can** support life; $\mathbf{f_l}$ is the fraction of those planets that **do** support life; $\mathbf{f_i}$ is the fraction of life-harbouring planets that develop intelligent life; $\mathbf{f_c}$ is the fraction of intelligent life that develops deep space communication capability; and **L** is the length of time for which communications exist.

Ashtari suggests these values -

Variable	Value	Unit	Description
R	2	stars/yr	Rate of star formation in our galaxy
f_p	0.7	...	Fraction of stars with planets
n_e	0.1	...	Number of planets that can support life, per star with planets
f_l	0.2	...	Fraction of planets that support life
f_i	0.2	...	Fraction of life-harbouring planets that develop intelligent life
f_c	1.0	...	Fraction of intelligent life that develops deep space communications capability
L	150	yr	Length of time for which such communications exist

- and estimates there to be only two Earth-scale civilizations in the Milky Way Galaxy. So for the foreseeable future, narrowband technosignatures are likely to be more prevalent and detectable from civilizations more advanced than Kardashev Type ~0.7 scale civilizations, like Earth.
Atari concludes we need to look for a much smarter ETI than ourselves!

Capturing every last photon of information

In *Scaling waveguide-integrated superconducting nanowire single-photon detector solutions to large numbers of independent optical channels* [1] Matthias Häuβler (University of Münster) et al show how a scalable number of waveguide-integrated superconducting nanowire single-photon detectors can be interfaced with independent fibre optic channels on the same chip.
In the interstellar context single-photon detectors are a vital tool in extracting the most usable bandwidth from a downlink signal originating on chip-scale probes four or more light years away. Such detectors are not new [2] but Häuβler et al offer new capabilities demonstrated in a plug-and-play detector package hosted in a compact and portable closed-cycle cryostat providing cryogenic signal amplification for up to 64 channels. They claim additional scalability especially suited for quantum communication and single-photon counting applications.

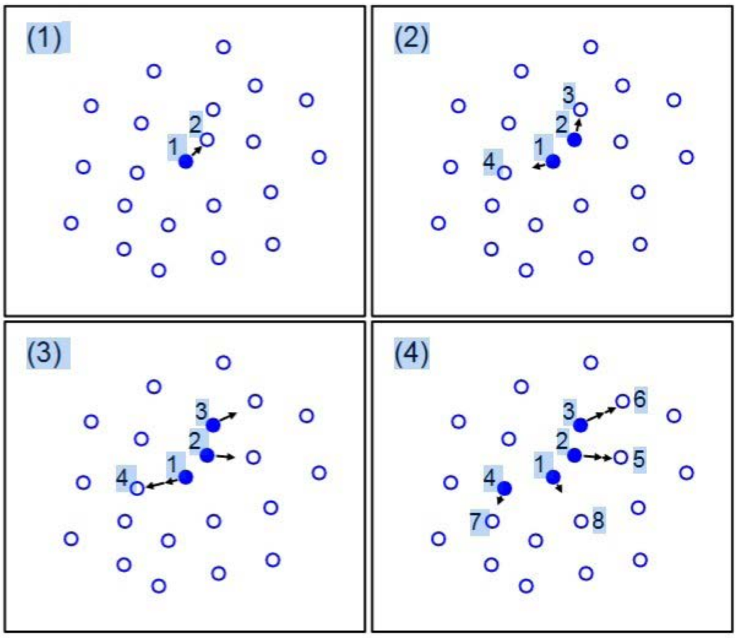
Percolation of 'Civilisation'

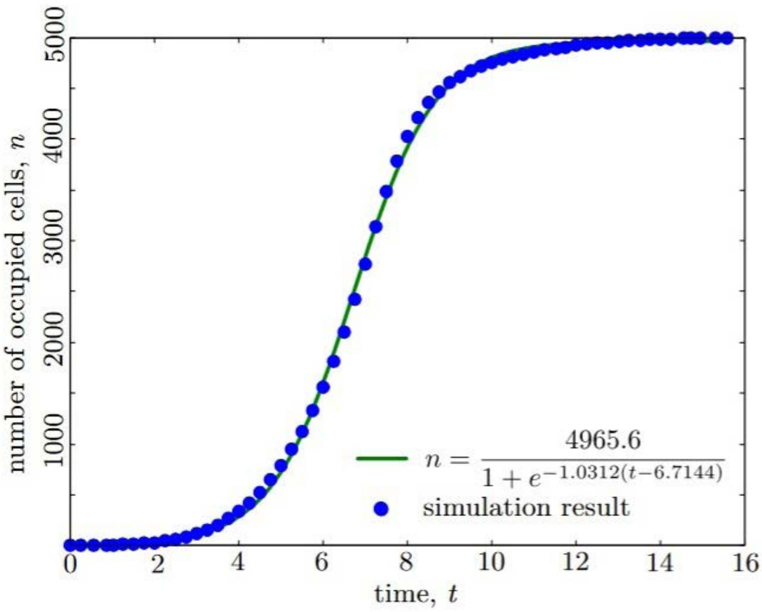
In *Percolation of 'Civilisation' in a Homogeneous Isotropic Universe* (arxiv.org/abs/2309.06575) Allan L Alinea and Cedrix Jake C Jadrin (University of the Philippines Los Baños) study how the cosmic evolution of the universe affects the spread of civilisations. They consider the total colonisation time for three types of universes, static, dark energy-dominated, and matter-dominated. Alinea and Jadrin have built simulations of these three types. They find

- A static universe: They set up a spherical 3D matrix of cells, assign random distances between them, choose a speed and run the simulation - see first image below. Unlike the superficially similar Game of Life (en.wikipedia.org/wiki/Conway%27s_Game_of_Life) cells never die. The result is an S curve following that of the Logistic Growth Model (en.wikipedia.org/wiki/Logistic_function) - see second image below.
- A dark energy-dominated universe: an exponentially expanding spacetime driven by a constant dark energy with a constant Hubble parameter (**en.wikipedia.org/wiki/Hubble%27s_law)**. The static universe model is modified so that distances between cells are increasing according to the Hubble parameter. So it takes longer time to colonise a given space but again follows the S curve of the Logistic Growth Model. But for large values of the Hubble parameter the growth of the universe outruns colonisation and parts of the unverse are never colonised. The limiting travel velocity is the velocity of light, c, which is the maximum speed which can be chosen, which leads to a "Hubble horizon" beyond which we cannot expand.

[1] In *Review of Scientific Instruments* January 2023 pubs.aip.org/aip/rsi/article-abstract/94/1/013103/2872162
Open publication at www.researchgate.net/profile/Carsten-Schuck-2/publication/366911713_Scaling_waveguide-integrated_superconducting_nanowire_single-photon_detector_solutions_to_large_numbers_of_independent_optical_channels/links/63c16fb9d9fb5967c2d33280/Scaling-waveguide-integrated-superconducting-nanowire-single-photon-detector-solutions-to-large-numbers-of-independent-optical-channels.pdf
[2] en.wikipedia.org/wiki/Superconducting_nanowire_single-photon_detector **and** en.wikipedia.org/wiki/Transition-edge_sensor

• A matter-dominated universe: Here the square of Hubble parameter is proportional to the reciprocal of the cube of the scale factor of the universe [1] and the expansion curve remains the familiar S shape. Here there is still a sort of Hubble horizon but it expands and the expansion rate relative to its centre is equal to c! The result is that all the cells in the model are eventually occupied.





TOP: Simplified illustration for the occupation of cells or 'planets' in a static universe. The centremost cell is occupied first and 'life' or 'civilisation' propagates towards neighbouring cells following the order (1) → (2) → (3) → (4)
Credit (image and caption): Alinea and Jadrin Figure 1.

BOTTOM: Behaviour of the number of cells occupied with time in a static universe, for N = 5000 cells and 500 trials.
Credit (image and caption): Alinea and Jadrin Figure 2

The authors suggest a number of areas for further study including factors involving planet habitability, death or survival rate of civilisations, and multiple starting civilisations.

[1] en.wikipedia.org/wiki/Friedmann%E2%80%93Lema%C3%AEtre%E2%80%93Robertson%E2%80%93Walker_metric

i4is at the Royal Institution

2023 - our fourth year

John Davies

The i4is Education team delivered our Skateboards to Starships summer schools to the Royal Institution for the fourth time 15-17 August 2023. We look forward to delivering them next year in addition to the long established 12-16 and 16-18 summer schools. The 12-16 day was oversubscribed so the RI offered a second day which was also well attended. This year we also published our presentations on the i4is website - i4is.org/skateboards-to-starships.

The i4is team this year was Rob Swinney (i4is Director of Education), Satinder Shergill and John Davies (schools lead for i4is Education) brilliantly assisted by Kajol Mistry from KCL Space, the Kings College London student space society (www.kclspace.com).

Here are some pictures Satinder took (with one exception) from the event. Note that we don't show 12-16 students faces for safeguarding reasons.

Rob Swinney presenting to the first 12-16 group on the first day of Skateboards to Starships 2023, 15 August - in the magnificent library of the Royal Institution.

Rob is on the right, John is on the left.

Kajol Mistry (right) and Richard Marshall (left) helping two groups of 16-18 students working on a knotty problem.

John Davies telling the 16-18 group how big the Starshot laser sail would be (actually its at least twice that size).

Two student teams setting up the balloon rocket experiment. The team at the rear is nearly ready to go with their balloon inflated. The team at the front is just walking their fishing line to the other end. Kajol Mistry watches both teams.

Satinder explains to the 16-18 students how the astronomical unit (AU) helps us to understand the size of the Solar System - but we need light-years or parsecs to deal with interstellar distances.

Credit: John Davies

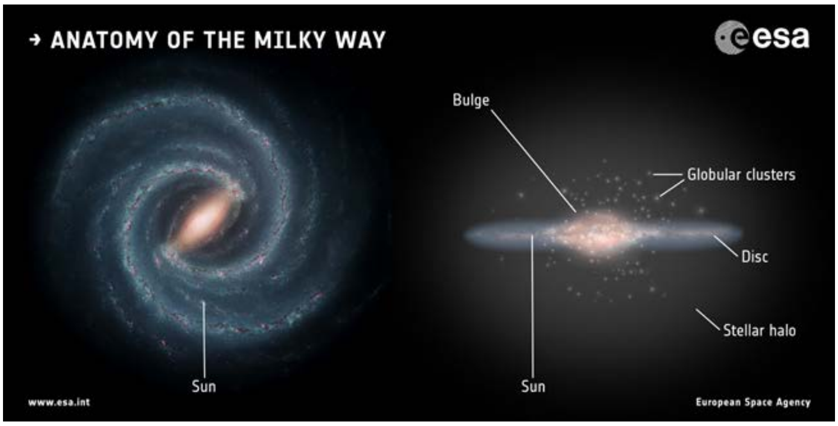
Our thanks to the RI team who supported us throughout and especially Richard Marshall (supervisor and part of the on-the-day team), Marie-Claire Hawthorne (Summer Workshops Administrative Assistant) and Peter Gallivan (Family Programme Manager at the RI now Outreach Support Manager at Kings College London).

The planned extension to two primary school generations, ages 7-8 and 9-11, was cancelled at the request of the Royal Institution but they aim to invite us back to deliver these. All revenue from the Summer Schools goes to the Royal Institution minus modest expenses.

Natural Geo-engineering of the early Earth

John I Davies

This article is based on work by Dr Phil Sutton at The University of Lincoln, UK. We summarise work by Dr Sutton with an international group of researchers which suggests that our planet has been significantly formed by its changing environment as it passes through the galaxy in its approximate 200 million year orbit of the galaxy.



In *Did transit through the galactic spiral arms seed crust production on the early Earth?* Kirkland et al [1] researchers analysed the isotopic composition of zircon grains from the North Atlantic and Pilbara cratons (cratons are the geologically stable portions of Earth's tectonic plates). They found a ~170–200-million-year frequency in both cratons that matches the transit of the solar system through the galactic spiral arms, where the density of stars is high. They suggest a corresponding enhanced rate of Earth bombardment by comets, the larger of which would have initiated crustal nuclei production (modification of molecular structure) via impact-driven decompression melting of the Earth's mantle (the material, the majority of Earth's mass, upon which the tectonic plates rest). They examined other periodicities in Earth's history but found best correlation with passage through the galactic spiral arms.

Dr Sutton finds it interesting to think of some processes in geology as having an extra-terrestrial origin but this has been controversial. The authors wrote *Scientists have traced Earth's path through the galaxy via tiny crystals found in the crust* [2] explaining the rhythm of crust production on Earth and reporting that these planetary cycles are approximately 200 million years. They observe that galactic spiral arms orbit at 210 kilometres per second, while the Sun orbits the galaxy at 240 km/sec so that the spiral arms act as a periodic, though very sparse, "traffic jam". The gravitational effects on objects of various sizes especially affect those most weakly bound to the Sun, those in the Oort cloud. Most objects impacting Earth travel at averaging 15 km/sec. But comets ejected from the Oort cloud arrive at an average 52 km/sec.

[1] Geology, 2022, eprints.lincoln.ac.uk/id/eprint/50578/
[2] theconversation.com/scientists-have-traced-earths-path-through-the-galaxy-via-tiny-crystals-found-in-the-crust-188158

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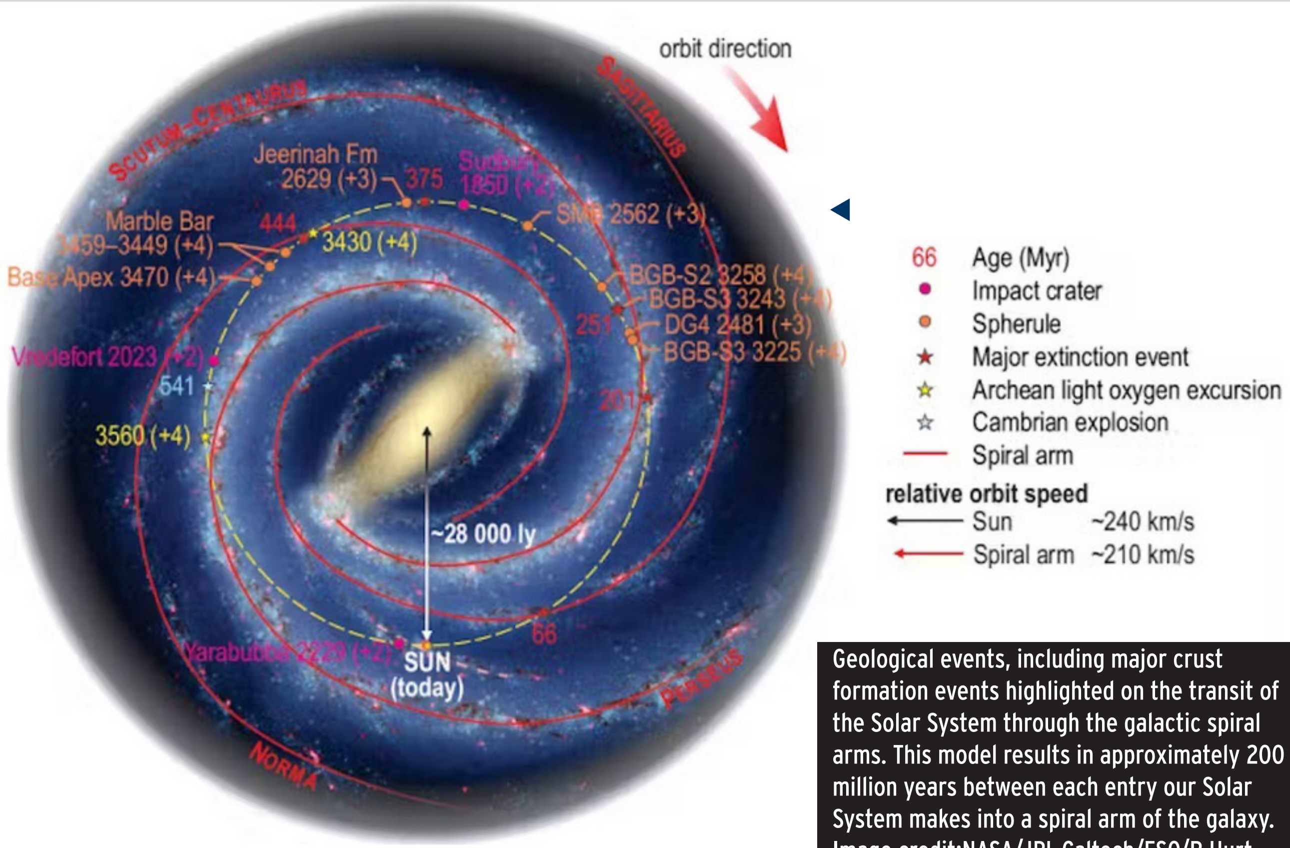


Geological events, including major crust formation events highlighted on the transit of the Solar System through the galactic spiral arms. This model results in approximately 200 million years between each entry our Solar System makes into a spiral arm of the galaxy. Image credit:NASA/JPL-Caltech/ESO/R Hurt (background image)

The controversies appear in a series of interviews with members of the research team

• Space.com "Earth's perilous journey through the Milky Way's spiral may shape the planet's geology" Sept 6, 2022

• Interesting Engineering "Scientists fire tiny laser beams at zircon crystals to reveal Earth's galactic companion" Sep 23, 2022

Including a link to Dr Sutton's video explanation -

YouTube: https://youtu.be/MZrnTJ6YDQ

• Scientific American "The Milky Way’s Spiral Arms May Have Carved Earth’s Continents" September 30, 2022 - quoting both support and opposition for the idea.

• Forbes "Milky Way’s Spiral Arms Incredibly Triggered Earth’s Continent Formation" Aug 26, 2022

These include the possibility that the periodic mass species extinctions the Earth has experienced may have this cycle as one possible cause.

Dr Phil Sutton is a lecturer in Astrophysics at the University of Lincoln, UK. He graduated in Physics with Astrophysics from Nottingham Trent University in 2006. He took his PhD in Astrophysics at Loughborough University in 2015. As a lecturer in the Lincoln School of Mathematics and Physics at the University of Lincoln, Dr Sutton is member of a team founded in 2014 researching in fundamental and applied mathematics and physics, ranging from pure mathematics to applied nano-science at the interface between biology, chemistry, physics, and mathematics. His primary research field is Computational Physics.

He is the author of *Implications of the Gaia Mission for Future Interstellar Travel*, in Principium 23, November 2018 (i4is.org/principium-23/) and *What Do We Really Know About The Outer Solar System?*, in Principium 28, February 2020 (i4is.org/principium-28/).

IAC 2023: The Interstellar Presentations. Part 1

Edited by John I Davies

Introduction

This year the International Astronautical Federation held the 2023 International Astronautical Congress in Baku, Azerbaijan, 2-6 October. Here is our initial report on items which are likely to be of special interest to Principium readers. Some are explicitly interstellar in topic but others are important in contributing to our interstellar goal including innovations in propulsion, exploitation of resources in space, deep space communication and control, enhanced and economical access to space, etc.
This is the first of two reports on the Congress. The second will be in our next issue, Principium 44, in February 2023. Our reporters here are Parnika Singh and John 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
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

D4,4,3,x79329	High-Speed Scientific Spacecraft Launches with Commercial Launch Vehicles	Dr Ralph L McNutt, Jr	Johns Hopkins University	USA

IAF Abstract: iafastro.directory/iac/paper/id/79329/abstract-pdf/IAC-23,D4,4,3,x79329.brief.pdf
IAF Cited Paper: iafastro.directory/iac/proceedings/IAC-23/IAC-23/D4/4/manuscripts/IAC-23,D4,4,3,x79329.pdf
IAF Cited Presentation/Video: iafastro.directory/iac/proceedings/IAC-23/IAC-23/D4/4/presentations/IAC-23,D4,4,3,x79329.show.pptx
Open Paper: None found
Reported By: Parnika Singh

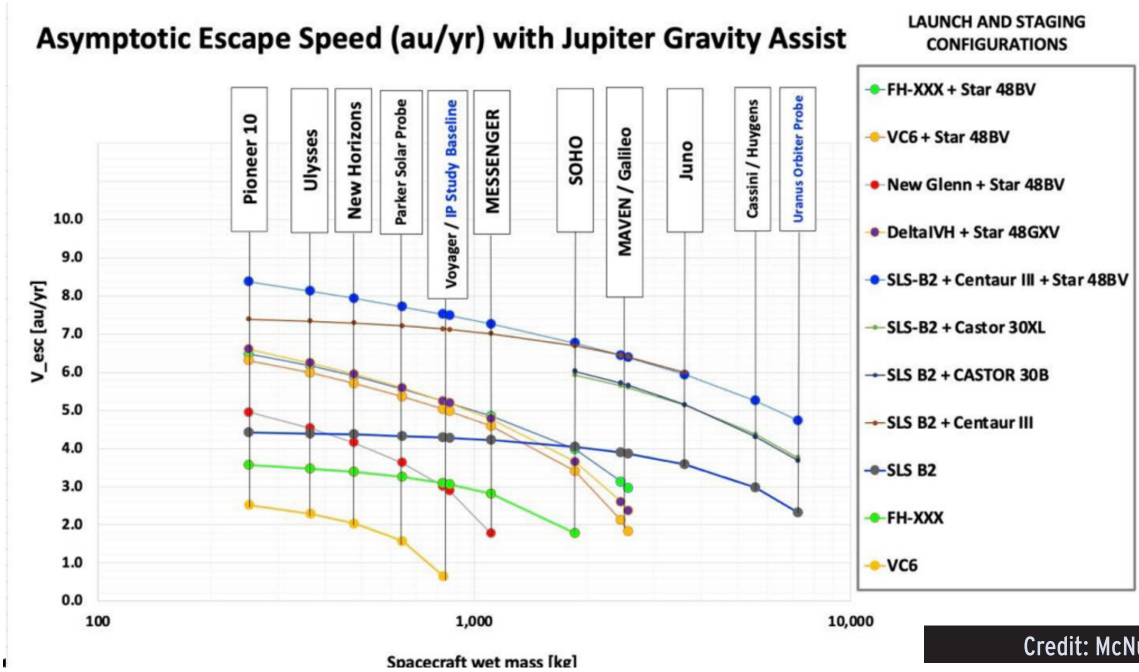
Reaching the outer solar system and interstellar space beyond has always been challenging due to the long distances and long travel times. But over time, various innovations have brought us closer to this goal. Dr McNutt discusses these innovations, beginning with the Space Race and Apollo missions, which led to the development of various new rocket technologies for dedicated space usage, such as the Saturn V rockets. The author then discusses subsequent advancements that followed after Apollo and built of its teachings, leading to Mars exploration probes as well as long-distance probes such as Voyager 1 and 2 and Cassini.

It considers new commercial launch vehicles, such as the Falcon Heavy from SpaceX and New Glenn from Blue Origin. Dr McNutt then discusses the application of these commercial launch vehicles to launch a dedicated interstellar probe – different from the Voyager probes where interstellar data was just a bonus. Dr McNutt identifies 3 possible commercial launch vehicle candidates: the Falcon Heavy (expendable), Vulcan V6, and New Glenn. It estimates their performance for launching a Voyager-like interstellar probe with six basic assumptions:

1. STAR-48BV is based on the Parker Solar Probe upper stage for all vehicles.
2. 3-sigma guidance reserves.
3. Two payload fairing doors.
4. Payload mass greater than 700 kg (1,543 lbm) may require mission-unique accommodations, resulting in cost and/or performance impacts.
5. Instantaneous launch attempt. Finite window accommodations may significantly reduce performance for missions with inertially fixed targets.
6. The performance shown is applicable for declinations between 28.5 deg. and -28.5 deg.

The Falcon Heavy has the best performance, but it could be improved upon as outlined later on in the paper through the addition of alternative stages. The paper provides a comparison of various commercial launch vehicles and stage combinations, shown below.

The paper briefly mentions commercial launch vehicle options currently under development, such as the Starship Super Heavy.



Credit: McNutt

◀

D4,4,7,x75821	Interstellar Exploration: from Science Fiction to Actual Technology	Prof Giancarlo Genta	Politecnico di Torino	Italy

IAF abstract: iafastro.directory/iac/proceedings/IAC-23/data/abstract.pdf/IAC-23,D4,4,7,x75821.brief.pdf
IAF cited paper: iafastro.directory/iac/proceedings/IAC-23/IAC-23/D4/4/manuscripts/IAC-23,D4,4,7,x75821.pdf
IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-23/IAC-23/D4/4/presentations/IAC-23,D4,4,7,x75821.show.ppt
Open paper: none found
Reported by: John I Davies

Prof Genta begins by enumerating the types of mission which might be the subject of fiction - from tiny flyby probes to generation ships and perhaps FTL. He defines stories using the evidently feasible technologies as "hard" science fiction and those based on more speculative technologies as perhaps fantasy. An interesting topic they touch on is interstellar commerce citing *The Economics of Interstellar Commerce*, Warren Salomon, [1], 1996. and a JBIS 1980 paper, *Comparison of reproducing and non-reproducing starprobe strategies for galactic exploration*, Francisco Valdes & Robert A Freitas Jr [2]. Most of the paper is a survey of fiction and feasibility.

Mentioning reproducing probes, Von Neumann machines, he refers to several SF stories, for example by Arthur C Clarke, Fred Saberhagen, Theodore Sturgeon and Greg Benford. Giancarlo Genta has also written SF on this theme.

Of course the distances involved naturally lead to the idea of worldships (called space arks or generation ships by this author) and hibernation. In the latter case Prof Genta asserts that they "require advances in AI since all maintenance and navigation tasks must be entrusted to machine" but does not mention periods of on-watch and hibernation which are illustrated in a 2016 SF film he cites earlier, *Passengers* [3] in the paper.

Much of the paper is devoted to the highly variable feasibility of various forms of faster than light (FTL) travel. Interestingly he quotes Gene Roddenberry's "warp factor" equation from *Star Trek* -

$$w_f = \sqrt[3]{\frac{v}{c}} ,$$

- though he gives no citation and this equation would make warp factor 8, most often used when great haste was required in the original series would be - $w_f = \sqrt{(v/c)}$ thus $v/c = w_f^{\,2} = 8^2 = 64$ times c, and warp factors would leave to simply squares of the integers [4]. Though there seems to some uncertainty about this [5].

He mentions early 20th century predictions of the impossibility of space travel and the adoption of similar arguments now offered about the impossibility of interstellar travel but concludes conservatively "For now, we can just enjoy tales about FTL journeys and proceed with the exploration of the solar system and the first attempts to go beyond it using realistic technologies."

[1] The final chapter of the book *Islands in the Sky: Bold New Ideas for Colonizing Space*, edited by Stanley Schmidt and Robert Zubrin. New York Wiley
[2] www.rfreitas.com/Astro/ComparisonReproNov1980.htm
[3] en.wikipedia.org/wiki/Passengers_(2016_film)
[4]

Warp factor	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Multiple of c	*c*	*4c*	*9c*	*16c*	*25c*	*36c*	*49c*	*64c*

[5] en.wikipedia.org/wiki/Technology_in_Star_Trek#Warp_speeds https://memory-alpha.fandom.com/wiki/Warp_factor

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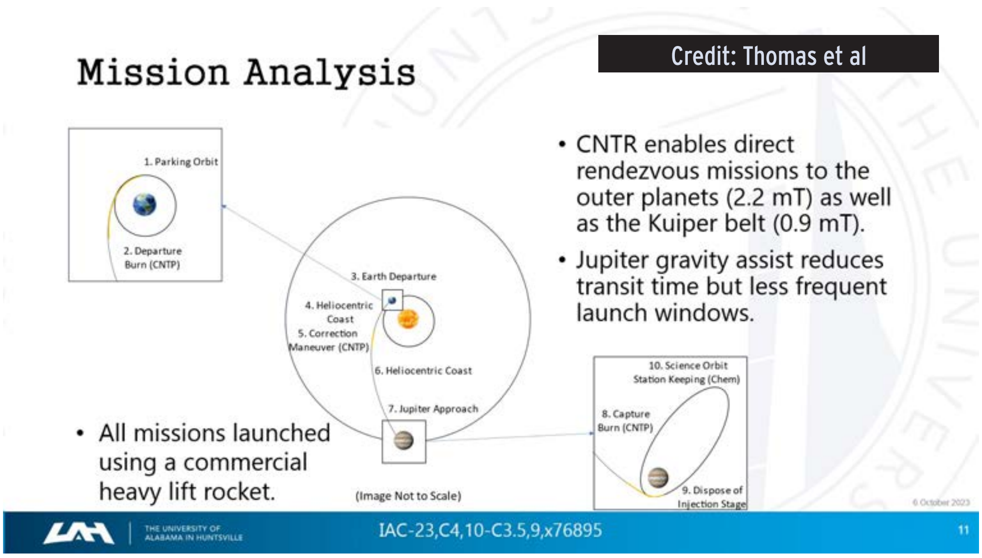
C3.5,9,x76895	Research Progress toward Engineering Feasibility of the Centrifugal Nuclear Thermal Rocket	Dr Dale Thomas	University of Alabama in Huntsville	United States

IAF Abstract: https://iafastro.directory/iac/proceedings/IAC-23/data/abstract.pdf/IAC-23,C4,10-C3.5,9,x76895.brief.pdf
IAF Cited Paper: https://iafastro.directory/iac/proceedings/IAC-23/IAC-23/C4/10-C3.5/manuscripts/IAC-23,C4,10-C3.5,9,x76895.pdf
IAF Cited Presentation/Video: https://iafastro.directory/iac/proceedings/IAC-23/IAC-23/C4/10-C3.5/presentations/IAC-23,C4,10-C3.5,9,x76895.show.pptx
Open Paper: None found
Reported By: Parnika Singh

The Centrifugal Nuclear Thermal Rocket (CNTR) is a Nuclear Thermal Propulsion (NTP) concept designed to heat propellant directly by the reactor fuel. In this paper, Dr Dale Thomas explains the differences between CNTR and traditional NTP designs, the main one being that instead of using traditional solid fuel elements, the CNTR uses liquid fuel with the liquid contained in rotating cylinders by centrifugal force.

Dr Thomas also discusses the various engineering challenges involved with realizing the CNTR concept, such as ensuring adequate heat transfer, controlling reactivity, sourcing materials that can withstand the high heat of the combustion chamber, and much more. With all these challenges explained, the paper shifts into a discussion of the current research progress on CNTR. The research efforts presently underway to address the foundational challenges fall broadly into two categories – (i) analysis & modelling of neutronics, heat transfer, and fluid dynamics, and (ii) experimentation to correlate the analytical models. The analysis and modelling efforts underway are providing insight into the neutronics to generate the necessary heat, the heat transfer between the liquid uranium and the gaseous hydrogen, and the dynamics associated with the rotational cylinders where all this action is taking place. The experimentation focuses initially on the development of experimental apparatus and subsequent use of the apparatus to confirm model predictions or reveal a lack of correspondence thereof such that the phenomena can be further researched, understood, and addressed. The paper provides a closer dive into a few research areas of particular interest, namely optimizing the neutronics design, heat transfer, bubble dynamics, and modelling the CNTR engine.

The paper closes with a consideration of the various missions CNTR technology would allow us to pursue. A CNTR has the potential to support direct rendezvous missions to the outer planets as well as the Kuiper belt. Analyses have estimated its maximum potential performance as high as 1,800 s specific impulse. The paper extends these analyses to show that direct trajectory rendezvous missions to both gas giants and ice giants are feasible with a CNTR. These missions deliver 2,200 kg of payload dry mass to a high eccentricity polar orbit around the destination, beginning in medium Earth orbit after a single launch of a commercial heavy-lift launch vehicle. Clearly, CNTR provides a host of new opportunities.



C4,10-C3.5,8,x77652	Development of a high power Nuclear Electric Propulsion System for interplanetary missions	Mr Vlad-George Tirila	University of Southampton	UK

IAF Abstract: iafastro.directory/iac/proceedings/IAC-23/data/abstract.pdf/IAC-23,C4,10-C3.5,8,x77652.brief.pdf
IAF Cited Paper: iafastro.directory/iac/proceedings/IAC-23/IAC-23/C4/10-C3.5/manuscripts/IAC-23,C4,10-C3.5,8,x77652.pdf
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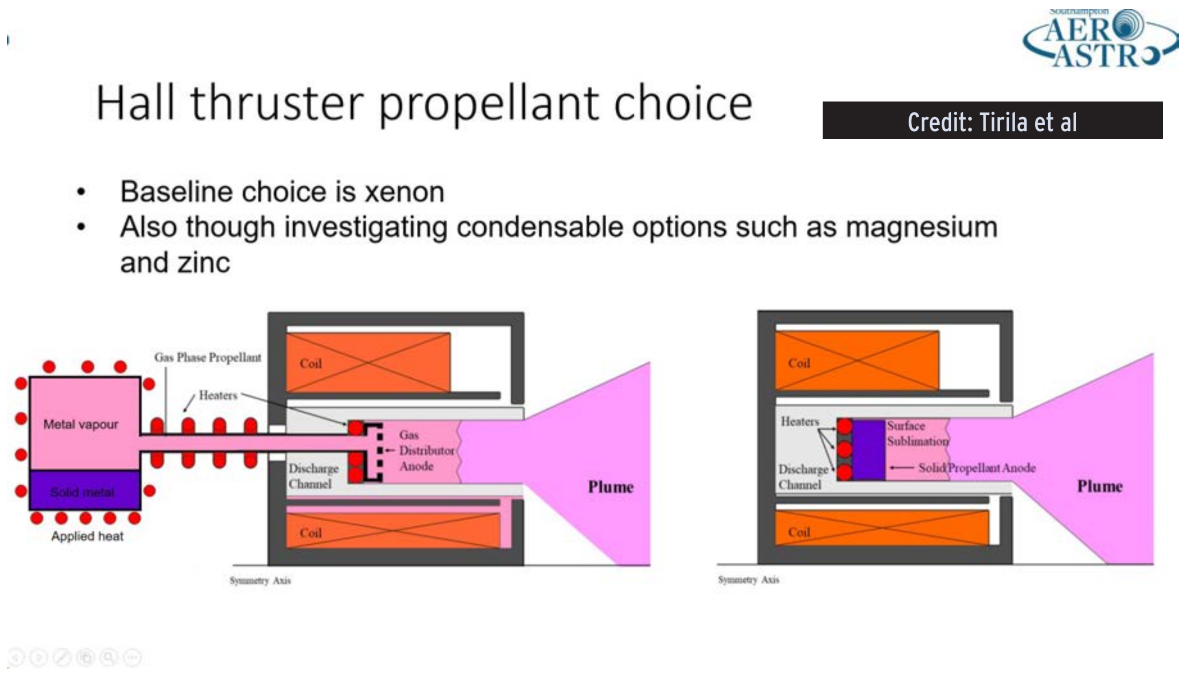
Open Paper: None found
Reported By: Parnika Singh

There is a renewed interest in the development of nuclear fission power sources for space applications. With the large growth in the space sector, missions requiring nuclear fission reactors are again being considered, as demonstrated by NASA planning to fly a prototype nuclear thermal propulsion system in 2025. This paper by Mr Vlad-George Tirila explores the creation of probes that combine nuclear propulsion technology with electric propulsion. In such a probe, a nuclear fission power system would be used to operate a high-power electric propulsion system (ie an ion thruster) that drives the spacecraft towards a distant target.

Although this idea may seem very novel, Mr Tirila explains that nuclear power systems for such applications have been studied for over 70 years across the world. The paper provides a historical overview of notable experiments and projects that paved the way for nuclear propulsion and electric propulsion technologies to be what they are today.

Mr Tirila then outlines the diverse applications of a nuclear electric propulsion system. These include manned missions to Mars, landing a probe onto the moon of a gas giant, and a robotic exploration of the far reaches of our solar system. The paper outlines the different requirements for each of these missions such as their power needs and payload mass. It explains the various launch and orbital trajectories for each mission.

However, all of these designs would share the same basic nuclear reactor and ion thruster. The design of the nuclear reactor is described in detail, including the choice of ceramic-coated uranium fuel kernels, zirconium hydrate for a neutron moderator, and Stirling engine-based heat conversion systems. The design of the ion thruster is also described. A Hall thruster is chosen for its high specific impulse, modelled after the M11k Hall thruster – the most powerful to be produced in the UK to date.



C4,10-C3.5,1,x80575	KEYNOTE: Nuclear Thermal Propulsion - Progress and Potential	Dr Dale Thomas	University of Alabama in Huntsville	United States

IAF Abstract: iafastro.directory/iac/proceedings/IAC-23/data/abstract.pdf/IAC-23,C4,10-C3.5,1,x80575.brief.pdf
IAF Cited Paper: iafastro.directory/iac/proceedings/IAC-23/IAC-23/C4/10-C3.5/manuscripts/IAC-23,C4,10-C3.5,1,x80575.pdf
IAF Cited Presentation/Video: iafastro.directory/iac/proceedings/IAC-23/IAC-23/C4/10-C3.5/presentations/IAC-23,C4,10-C3.5,1,x80575.show.pptx
Open Paper: None found
Reported By: Parnika Singh

Nuclear Thermal Propulsion (NTP) is one of the oldest alternative propulsion systems. However, due to significant restrictions on nuclear technology, development has been fairly slow. This paper by Dr Dale Thomas discusses the current research and development efforts underway within the United States on NTP, with a particular focus on the Demonstration Rocket for Agile Cislunar Operations (DRACO) project, a joint effort of the United States Defense Advanced Projects Agency (DARPA) and NASA

Dr Thomas first provides an overview of the lengthy history of NTP in the USA, starting with its foundations in 1946, when both North American Aviation and the Douglas Aircraft Company issued reports describing concepts and projected performance of NTR concepts. The paper also discusses the Rover/NERVA program of 1955 and the SNTP program of 1987 and their various achievements and findings on NTP. It makes note of notable research papers on NTP and their findings as well. Dr Thomas specifically focuses on the result of the optimal fuel for an NTP reactor, low-enriched uranium, which performed much better than other fuels during experimentation.

Dr Thomas then discusses DRACO specifically, with its goal of demonstrating a nuclear thermal rocket in orbit. Created by the US Department of Defense, DRACO will be the first NTP reactor to incorporate high-assay low-enriched uranium fuel. additionally, DRACO will demonstrate various engine modes through remote engine control, including start-up to full power, steady-state operation, shutdown, spacecraft maintenance, and restart.

DRACO has been planned in 3 phases, the first of which was completed in late 2022 and involved the designing of the nuclear reactor and operations system. Phase 2 will involve a cold flow test of the rocket engine without nuclear fuel. Phase 2 is expected to take 24 months and include a complete preliminary and detailed design of the demonstration as well as construction and experimental validation of the flight engine. Phase 3 will involve assembly of the fueled NTR with the stage, and environmental testing. Ultimately, Phase 3 will include the launch and in-orbit demonstration of the NTP engine at full power and full thrust, with the mission planned for 2027.

NASA has declared it will partner with DARPA to execute the next two phases, especially when it comes to testing the technology which NASA has greater experience with. NASA has also worked to create safety guidelines for DRACO, allaying concerns about the dangers of nuclear technology.

Dr Thomas ends with a brief discussion on the possible applications of NTP technology and other experimental nuclear space developments. Only time will tell if DRACO truly succeeds or not.

BIS Symposium brings Project Icarus to a close

Patrick J Mahon

Patrick J Mahon reports on a one-day meeting which discussed the final conclusions of the Starship Design Study

Images in this report are by GEIR ENGENE/BIS (Geir) [1] and John I Davies (JID).

Rob Swinney opens the proceedings. Credit: JID

On 30 September, our friends at the British Interplanetary Society (BIS) hosted a symposium to discuss the final conclusions of 'Project Icarus – son of Daedalus'. Icarus is a theoretical design study for a fusion-powered uncrewed interstellar probe, capable of decelerating a 150-tonne scientific payload into orbit around our nearest star, Alpha Centauri, within 100 years of launch [2].

The symposium marked the end of Project Icarus, which was launched at another BIS symposium on 30 September 2009, exactly 14 years earlier [3]. The purpose of Project Icarus was to revisit and update the conclusions of Project Daedalus – the BIS study which produced the first credible design for an interstellar spacecraft back in 1978 [4] – in the light of over 30 years of scientific and engineering advances.

Project Icarus was co-founded by Kelvin Long and Richard Obousy as a collaboration between BIS and the Tau Zero Foundation. Many of i4is's activists and friends were involved, including Rob Swinney, Andreas Hein, Richard Osborne, Michel Lamontagne and Robert Freeland II.

[1]/www.flickr.com/photos/bis-space/sets/72177720311656386/
[2] R W Swinney, R M Freeland II & M Lamontagne (2020), *Project Icarus: Designing a Fusion Powered Interstellar Probe*, Acta Futura 12, 4-59, (in Acta Futura 12, Interstellar Exploration www.esa.int/gsp/ACT/acta_futura/issue12/) presented at ESTEC Noordwijk 2019 and reported by Andreas Hein, *News Feature: Interstellar Workshop of the European Space Agency* in Principium 26, August 2019
[3] K F Long, R K Obousy, A C Tziolas et al (2009), *Project Icarus: Son of Daedalus – Flying Closer to Another Star*, JBIS 62, 403–416. arxiv.org/abs/1005.3833
[4] A Bond & A Martin (1978), *Project Daedalus – The Final Report on the BIS Starship Study*, JBIS

One key difference between Daedalus and Icarus was that the former study adopted the technically much simpler approach of a fly-by of the destination star system. However, conscious that flying through a star system at an appreciable percentage of the speed of light would severely limit the amount of time available for collecting scientific data, Project Icarus included a requirement to decelerate the spacecraft into orbit around the destination star, enabling a far longer timescale for data collection.

While Project Daedalus delivered a single spaceship design, Project Icarus produced multiple competing concepts. The symposium provided an opportunity to consider the project in its totality. It was co-chaired by i4is's Rob Swinney and by Professor Ian Crawford of Birkbeck University of London, and included ten presentations.

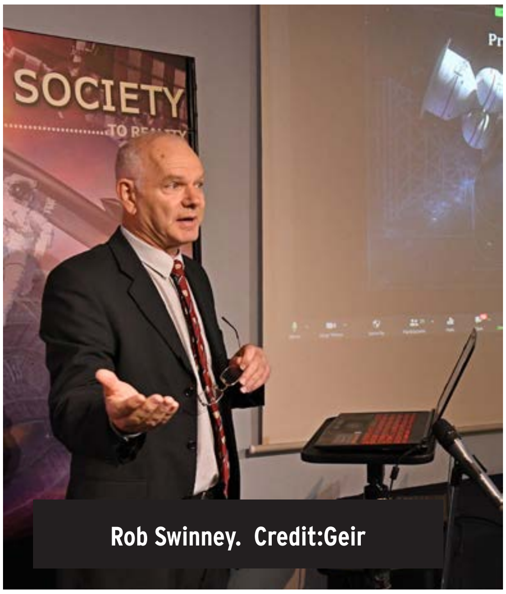
Kelvin Long (co-founder of Project Icarus and i4is, and now Director of the Interstellar Research Centre) presented first, explaining the background to Project Icarus, summarising what Project Daedalus had achieved in the 1970s, and how Project Icarus was intended to build upon it.

Kelvin Long gives us the project aims. Credit: Geir

Adam Crowl (Team Leader for Project Icarus' Main Propulsion Module) spoke next, remotely via Zoom from Brisbane Australia, providing a technical review of Project Daedalus, and discussing some of the technical criticisms of the design that have emerged since it was published. He noted that some, but not all, of these were subsequently addressed by the Daedalus team [1].

Adam Crowl gives a technical overview. With BIS CEO Simon Feast(far left) and Ian Crawford. Credit: JID

[1] A Bond & A Martin (1986), *Project Daedalus Reviewed*, JBIS 39, 385-390.



Rob Swinney. Credit:Geir

Rob Swinney (Icarus Project Leader and Deputy Executive Director of i4is) outlined the key goals of Project Icarus, and described the way that the project was initiated, setting up a Project Icarus Study Group which split the work into 20 modules, to be researched in 10 phases over 5 years. Swinney summarised the early work on multiple different spacecraft concepts and designs, including precursor missions intended to provide proof of concept while exploring the interstellar medium between Earth and Alpha Centauri.

He outlined the multiple challenges that the project faced, when new organisations such as Icarus Interstellar, the 100 Year Starship initiative and i4is were set up. While these provided a welcome expansion in the number of people engaged in interstellar studies, they also diverted the attention of key Project Icarus personnel to other activities, slowing down progress. As a result, Swinney became the Project Leader in 2013, tasked with refocusing project activities. The result was a design competition, followed by a workshop, which encouraged several teams to develop their competing spacecraft designs in more detail. These included Pegasus, Firefly, Ghost, UDD (named after its proposed fuel, Ultra Dense Deuterium) and Zeus. Of these, although Ghost had been the favourite at the time of the competition the Firefly design was the one which was ultimately elaborated most comprehensively. With steady progress, more work was completed on the first two designs, as discussed below. This extended the project beyond the originally planned five years

Following coffee, Kelvin Long presented his Pegasus design, which had evolved through several name changes (originally Resolution, then Endeavour). Long's approach was the closest to the Daedalus design, primarily an evolution of the Inertial Confinement Fusion (ICF) propulsion approach, and attempting to directly address the technical criticisms of it. (In ICF, powerful lasers are focused onto tiny pellets of fuel, heating and compressing them sufficiently to initiate nuclear fusion.) Resolution refined that design. He had written Fortran code to model the design of the ICF fuel pellets, with the aim of finding a solution that overcame the plasma instabilities that typically interfered with the ignition of the fuel, and thus would enable successful fusion propulsion.

Discussion continued over an excellent buffet lunch, before Robert Freeland II (Deputy Project Leader for Project Icarus, and Team Leader for Icarus Firefly) presented the Firefly design. This resulted from a re-consideration of alternative approaches to creating a workable fusion engine. The Firefly team chose Z-pinch fusion, a method originally researched between the 1930s and 1950s, before doubts about its viability led to it being sidelined for four decades. New research in the late 1990s which overcame some of those difficulties, revived interest, including at NASA, which led to its selection for Firefly.

Another key decision was the choice of fusion fuel. The Firefly team chose Deuterium-Deuterium, rather than Deuterium-Helium 3, as used in the Daedalus design, because the Helium 3, proposed to be mined from the atmosphere of Jupiter, was thought unlikely to be available to the right timescale. A major consequence of this fuel choice is that a high proportion of the fusion products are uncharged, so can't be focused into an effective exhaust stream. This energy is wasted, but trying to shield the vehicle against these escaping high energy fusion products simply creates more radiation. So the best solution is to create a long, thin vehicle with minimal shielding, with many of the unusable fusion products escaping into space.

The initial design work on Firefly took place between 2013 and 2015 [1] [2], but it has evolved further since, with Freeland outlining the specifications of the 2023 version, Firefly Mark VI. He concluded by noting that although Firefly is a design for an uncrewed vehicle, the BIS SPACE project has considered the potential value of this approach for larger, interplanetary crewed spacecraft.

[1] RM Freeland II & M Lamontagne (2015), *Firefly Icarus: An unmanned interstellar probe using Z-pinch fusion propulsion*, JBIS 68, 68-80.

[2].See PJ Mahon (2018), *Reaching the Stars in a Century using Fusion Propulsion: A Review Paper based on the 'Firefly Icarus' Design'*, Principium 22, 3-13 i4is.org/reaching-the-stars-in-a-century-using-fusion-propulsion.

Robert Freeland presents the Icarus Firefly (and other Icarus designs) downlink issues. See *Project Icarus: Communications Data Link Designs between Icarus and Earth and between Icarus spacecraft*, Peter Milne, Robert Freeland and Michel Lamontagne JBIS, V69, 2016. Also *The Icarus Firefly Downlink* in Principium 36, February 2022 i4is.org/issue-36-february-2022. Credit: Geir

The next presenter, zooming in from Canada, was Michel Lamontagne, who explored the vital issue for any fusion-powered spacecraft of heat dissipation via radiators. This is a particularly critical challenge for the Firefly design, which produces a lot of Bremsstrahlung radiation. Lamontagne explained the heat loads that result, and how the Firefly radiator design deals with this. He also summarised how this issue could be tackled on the other Icarus spacecraft designs.

Richard Osborne gave a presentation dealing with three issues common to all of the spacecraft designs: power generation and management, payload technologies, and the infrastructure needed to support the successful launch of an Icarus spacecraft to Alpha Centauri. In all three areas, Osborne noted how much progress had been made in the now forty-five years since Project Daedalus concluded, whilst recognising that some challenges remained.

Richard Osborne explains power generation and management, payload technologies, and infrastructure. Credit: Geir

Professor Ian Crawford discussed the scientific case for sending a probe, rather than relying solely on solar system-based telescopes. He considered the science that could most usefully be done on the way to Alpha Centauri, such as studying the interstellar medium, and also once decelerated into the destination star system, where in-situ studies of the target stars, planetary science and astrobiology would all be a high priority. He then proposed a package of scientific instruments that would deliver a strong science return whilst fitting within the 150-tonne payload constraint. See Prof Crawford's 2016 paper [1] for further details.

Prof Crawford proposes an astrobiology instrument package for the Icarus probe. Note Terry Regan's magnificent Daedalus model below the screen. Credit: JID

As the day drew towards a close, Rob Swinney reviewed the outcomes from Project Icarus against the initial terms of reference, concluding that the project had been largely successful on its own terms, meeting almost all of its own goals, as well as helping to increase individual and organisational activity in the area of interstellar exploration significantly since 2009.

The final discussion of the day was initiated by science fiction writer, Project Icarus team member and BIS Fellow Stephen Baxter, via zoom. He had been involved since the beginning and felt that although Project Icarus had delivered well on a technical level, it had perhaps not been as successful as Project Daedalus in achieving cut-through to wider society, beyond the immediate community of spaceflight aficionados. That was perhaps something that could be addressed, now that the project had concluded.

Physicist and SF writer Stephen Baxter deivers his thoughts on Project Icarus. Credit: Geir

[1] I A Crawford, *Project Icarus: Preliminary Thoughts on the Selection of Probes and Instruments for an Icarus-Style Interstellar Mission*, JBIS 69, 4-10. core.ac.uk/reader/42136030.

The resulting discussion was both animated and constructive, bringing forward several ideas for ways to bring Project Icarus to a broader audience.

Lively Q&A took place after each presentation. Here Robert Kennedy III makes a point supported by the i4is swarming downlink paper recently published. Credit: Geir

A large contingent of remote participants engaged with the symposium. Here Rob Swinney surveys them and BIS CEO Simon Feast sets things up. Credit: Geir

A group of the presenters after the presentation. Left to right: Kelvin Long, Robert Freeland, Rob Swinney and Richard Osborne - with Terry Regan to the right. Credit: Geir

After the day's formal proceedings had concluded, BIS CEO Simon Feast was kind enough to take several members of the Project Icarus team up to the BIS library, where he showed them a number of original technical drawings made for Project Daedalus, including some which did not appear in the Project Daedalus final report. It was fascinating to find out that, 45 years later, Project Daedalus still had some secrets to reveal!

The Symposium was extremely successful, and draws Project Icarus to a close after 14 years. However, a final report and further technical papers are due to appear in future issues of JBIS, and will be reported on in Principium as they appear.

A shorter version of this report, *Reach for the Stars,* ***appeared in the December 2023 issue of the BIS magazine Spaceflight.***

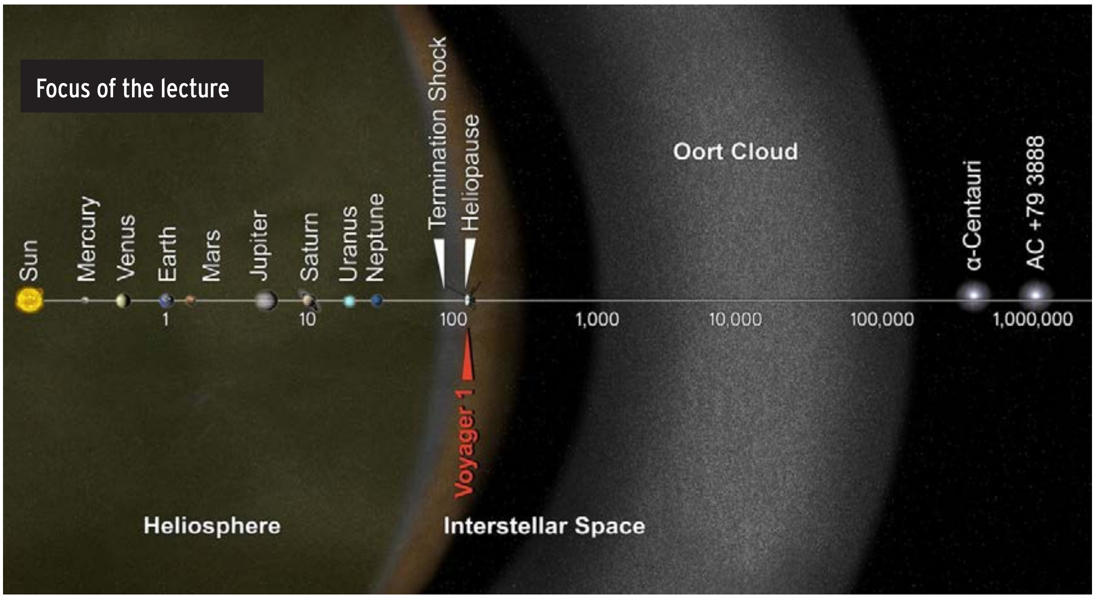
A group after the symposium. Participants and speakers (from left to right) John Davies, Robert Kennedy III, Robert Freeland, Amy Hlebak, Alistair Scott. Dave Lally, Griffith Ingram, Kelvin Long, Rob Swinney, Richard Osborne, Richard Blogg, Les Shoulder, Patrick Mahon, Simon Feast. Terry Regan. Most of us then adjourned to the *Riverside* pub. Credit: Geir

Interstellar Studies - Inspiring the next generation

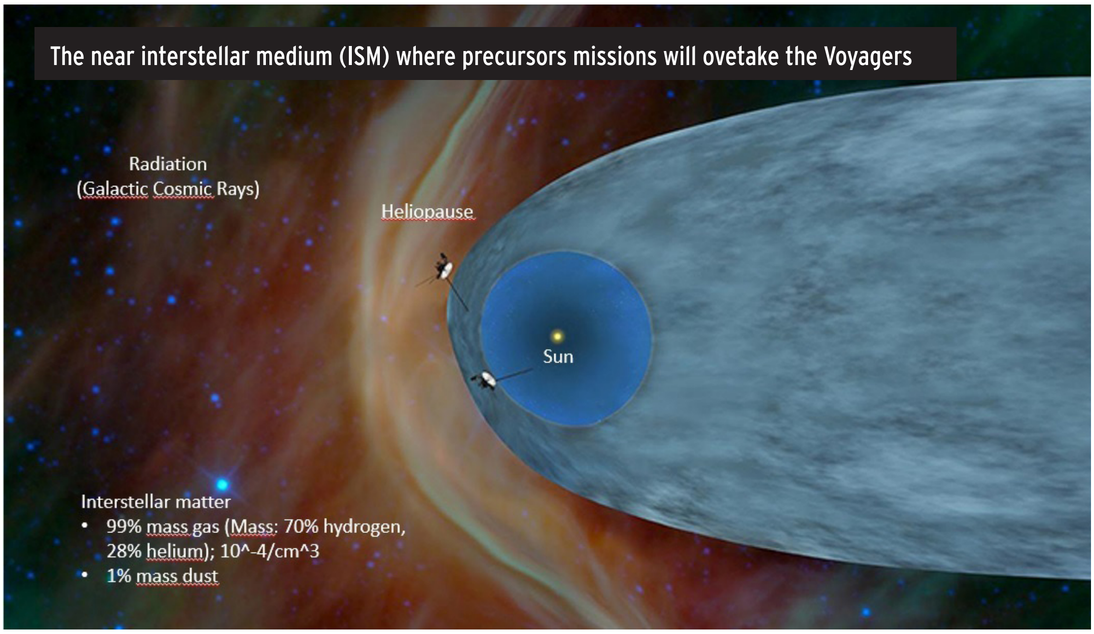
John Davies

On 20 July this year our Executive Director, Andreas M Hein, gave a lecture on interstellar travel at the Technical University of Munich's Ottobrunn campus to about 45 students of the aerospace engineering MSc cohort. He has shared his presentation and some images of the event with Principium.

Andreas's learning objectives were to enable the students to know the characteristics of interstellar space, the various objects that populate interstellar space, the potential technologies for (precursor) interstellar exploration, the manoeuvres for precursor interstellar exploration, the different modes of crewed interstellar transport and how to design a simple crewed interstellar mission. He introduced his team at the University of Luxembourg.



He looked at missions to interstellar objects (ISOs) including the SunDiver light sail technology for chasing and catching them. He moved on to ISO possibilities on Earth, ISO missions using laser sails and interstellar precursor missions including to nomadic planets known to exist between stellar systems.



True interstellar missions are much more technically demanding given the distances involved. He concentrated on propulsion techniques including both fusion and antimatter. Breakthrough Starshot offers a relatively near term means to access to nearby systems so Andreas examined the challenges in some detail. For human interstellar missions the time required means that revolutionary approaches will be required using generation ships, sleeper ships, conveyance of embryos or even emulated humans via advanced artificial intelligence.

This presentation addressed the generation about to enter both research and development and both are vital to our endeavour. But we also engage undergraduate and school students. If you are working with any of these rising generations then please get in touch with us. Rob Swinney (rob.swinney@i4is.org) is the contact for universities, both undergraduate and postgraduate, John Davies (john.davies@i4is,org) is the contact for all school generations from primary onwards.

The Journals

John I Davies

Here we list recent interstellar-related papers in the **Journal of the British Interplanetary Society (JBIS)**, published since the 1930s.

Acta Astronautica (ActaA), the commercial journal published by Elsevier, with the endorsement of the International Academy of Astronautics.

JBIS

Four issues of JBIS (online) April, May June and July 2023, have appeared since the report in our last issue, P42 (up to JBIS V76 #3 March 2023). Later issues are in print but not yet online.

Title (open publication)	**Author**	**Affiliation**
Abstract/Précis/Highlights		

JBIS VOLUME 76 2023 NO.4 APRIL		
Advanced Electric Propulsion Concepts for Fast Missions to the Outer Solar System and Beyond	**Angelo Genovese [1] & Nadim Maraqten**	Initiative for Interstellar Studies
Electric Propulsion (EP) comprises all types of space propulsion in which a certain amount of propellant is ionized and then accelerated by electric or magnetic fields, or both. This propulsion technology allows for much higher specific impulses (Isp > 2,000 s) than conventional chemical propulsion (Isp < 500 s), resulting in a major reduction of the propellant mass or a considerably higher final speed for a certain space mission. Hence, EP can enable very challenging space missions as DAWN has clearly shown. Furthermore, an EP system coupled with an advanced nuclear reactor could enable fast manned missions to Mars (one-way travel times less than 4 months). This propulsion technology can be scaled up to even higher specific impulses (Isp > 5,000s). However, the power needed for the same thrust is also increasing. An Oberth maneuver performed very close to the Sun could provide the additional power to a high-Isp Solar Electric Propulsion (SEP) system in order to reach the needed delta-v for challenging interstellar precursor missions. A breakthrough in power source specific mass is needed in order to enable missions with ultra-high specific impulses (> 10,000 s); this breakthrough could be realized having the power source not on-board, as with Laser-powered Electric Propulsion (LEP), where the needed power is beamed to the spacecraft from an external laser source. In this case the on-board power source is limited to a light-weight photovoltaic receiver/converter. The development of ultra-high Isp ion thrusters powered by an external laser source could enable the most challenging interstellar precursor missions up to the Oort Cloud and beyond. This paper gives an update on the status of these advanced propulsion concepts, and provides some examples of interstellar precursor missions enabled by advanced EP systems which could be launched before 2040.		

[1] Angelo is a member of the Board of Directors of the Initiative for Interstellar Studies

The Lagrange Sunshade: Its Effectiveness in Combating Global Warming and Its Application to Earth Defense from Asteroid Impacts, Beaming Solar Energy for Terrestrial Use, Propelling Interstellar Migration by Laser-Photon Sails and Its Technosignature	**Gregory M Matloff [1]**	New York City College of Technology, CUNY
One suggested method to partially mitigate the effects of global warming is the construction of a ~2,000 km dimension sunshade at or near the Sun-Earth Lagrange-1 (L1) Point. Opaque and transparent sunshades have been suggested for this application. Mass estimates are presented for both as well as a discussion of station-keeping issues. If constructed, such a megastructure would have additional applications. These include beaming energy to divert or destroy Earth-threatening Near Earth Asteroids (NEAs), space-based solar-energy production for terrestrial use, and energy beaming to accelerate laser-photon propelled starships engaged in interstellar migrations. Global warming may be a filter that an emerging galactic civilization might have to overcome. As such, technosignatures of extra-solar star-planet Lagrange sunshades might be detectable by extremely large telescopes. Larger Lagrange sunshades might also be constructed by a civilization inhabiting a planet circling an aging star since stellar luminosity increases with star age.		

Reliability Assessment of Nuclear Thermal Engine Configuration and Health Monitoring System	**Samantha B Rawlins & L Dale Thomas**	University of Alabama in Huntsville
Today's space nuclear technology programs are often confronted with two fundamental challenges early in the project life cycle: 1) development and testing will be more expensive than a non-nuclear alternative, and 2) the consequences of failure will be more severe. As a result, many space nuclear programs have been designed to minimize testing and maximize their probability of success: their reliability. The United States' Nuclear Engine for Rocket Vehicle Applications Program recognized these facts early on, and by 1961 the program's primary objective set safety and reliability as the overriding considerations. This focus on reliability greatly influenced the engine's design towards minimizing the possible number of catastrophic failures modes. As such, the final configuration heavily relied on duplicate components for redundancy, including duplicate turbopumps. Despite these efforts, at program cancellation in 1972, the non-nuclear subsystem only achieved a mission predicted reliability of 33%. Some of the most significant contributions to rocket engine reliability in the last 50 years have been from advancements in the Health Monitoring System (HMS). Through rigorous instrumentation and control an engine's HMS has the potential to convert over 90% of a system's catastrophic failure modes to a safe shutdown situation. Due to this, many modern rocket engine designs no longer require redundant components and can prioritize performance-enhancing configurations over those that inherently minimize failure modes. Unfortunately, a standard liquid rocket engine HMS will likely not be compatible with a nuclear rocket engine (NRE). The HMS for a liquid rocket engine most often prevents catastrophic failure by shutting off flow to the combustion chamber. This would not work for a NRE, as removing propellant flow to the reactor could result in reactor overheating and meltdown. Maintaining flow to the reactor is often essential for safe NRE operation, such that reliance on an advanced HMS system alone may not be sufficient. This work investigates the feasibility of an NRE HMS by comparing the HMS designs for liquid rocket engines and terrestrial nuclear power plants and evaluates the necessity for redundant components to maximize overall system reliability.		

[1] Professor Matloff is a member of the Advisory Board of the Initiative for Interstellar Studies

JBIS VOLUME 76 2023 NO.5 MAY		
The Settlement of Space: Economical and Logistical Drivers and Constraints	**Richard Soilleux et al [1]**	-
This work is part of the BIS SPACE technical project studying long term possibilities for an expansion of industrial civilisation on Earth and in space. This paper traces the potential development of space settlements through four 'generations', driven and constrained by various economic, physical, and cultural factors. To provide a context for later work, time scales and orders of magnitudes are estimated together with constraints and drivers for space settlement. Following papers will explore the technology of fast transits within the Solar System required to support the economic model and define a fleet of interplanetary craft, based on flow stabilized Z-pinch fusion engines.		

Fast Interplanetary Travel: a Literature Review	**Stephen Baxter**	-
The project to which this paper is a contribution is a prospectus for the integrated industrial development of the Solar System. Fast transit on an interplanetary scale is a prerequisite before such a development can be established. To facilitate this freedom of movement, this study has defined a suite of fast, large-scale interplanetary ships, achievable in the relatively near term. As background, the present paper is a review of the literature on the feasibility of fast, large-scale, nuclear-powered, cargo-carrying and/or crewed interplanetary craft, as explored historically from the development of atomic theory itself through to the application of modern fusion-technology high-performance propulsion systems. The study is part of the BIS SPACE (Study Project Advancing Colony Engineering) technical initiative.		

Optimization of Interplanetary Trajectory for Direct Fusion Drive Spacecraft	**Giancarlo Genta & Dario Riccobono**	Politecnico di Torino, International Academy of Astronautics
The Direct Fusion Drive (DFD) technology, which is being developed at present, will allow fast and affordable interplanetary travel. This is a result of the very high specific impulse and the low specific mass of DFD thrusters which outperform more conventional Nuclear Electric Propulsion (NEP), with which it shares the ability of providing a low (albeit higher than in the case of NEP) continuous thrust. It is well known that, to optimize the payload fraction, the thruster should operate in Variable Exhaust Velocity (VEV) mode and that the lower is the specific mass, the higher should be the maximum specific impulse the thruster can produce. A low thrust interplanetary travel, from the orbit around the starting planet to the orbit around the destination planet, can be considered as made of three parts: a first planetocentric phase, a second heliocentric phase and finally a third planetocentric phase; in all of them the trajectory is a sort of a spiral, but while in the first and third the spacecraft makes several (or even a large number) turns about the two planets, the second consists of a fraction of a turn about the Sun. In the first and last one the optimal specific impulse is not much variable and should remain quite low, while in the second one it must go through large variations, reaching a very high value at roughly midway between the planets. To show the potentialities of DFD, three typical fast missions are studied: to the Moon, to Mars and to Titan, showing that this propulsion device will allow humans to reach practically the whole solar system in a reasonable time.		

Jerome Pearson and Space Elevators	**David Raitt**	-
This paper discusses the contribution to space activities, specifically space elevators, by American aerospace engineer, Jerome Pearson. Following a brief introduction to placing objects in orbit via rocket and introducing a green alternative, the paper mentions two early pioneers of space elevators, followed by a short biography of a third — Jerome Pearson, who finally had his ideas published in 1975. His conceptual design for a space elevator is discussed in depth, together with his other ideas for lunar space elevators and his relationship with Arthur C. Clarke who was inspired by his work. A brief summary of what a space elevator is is included together with a summary of how advanced rockets and space elevators could work together to bring the anticipated massive tonnage requirements for future space projects to orbit and beyond.		

[1] Stephen Baxter, Michel Lamontagne, Robert M Freeland II,

JBIS VOLUME 76 2023 #7 JULY		
Special Issue: Future Directions for Space Elevators	-	-
All papers may be of interest as contributions to building a Solar System civilisation as a step to interstellar. *Building the Space Elevator Tether* - Dennis H Wright *Payload Design for the Space Elevator Climber* - Larry Bartoszek & Dennis H Wright *Innovation and Research for Space Elevators* - John M Knapman *Huge Fast Spacecraft Travelling Our Solar System* - Peter A Swan & Cathy W Swan *The Lunar Space Elevator: A Key Technology for Realising the Greater Earth* - Lunar Power Station (GE -LPS) - Arthur Woods, Andreas Vogler, Patrick Collins		

Acta Astronautica

Acta Astronautica papers are published online before print.

Title	Number+date	Author	Affiliation
Abstract/Précis/Highlights			
A sign in space: An interdisciplinary exploration of the potential reception of an extraterrestrial signal	Volume 212, November 2023	Daniela de Paulis et al	SETI Institute
A Sign in Space is an interdisciplinary project by media artist Daniela de Paulis, in collaboration with the Green Bank Observatory, the National Institute for Astrophysics, the SETI Institute and the European Space Agency. The project consists in transmitting a simulated extraterrestrial message as part of a live performance, using an ESA spacecraft as celestial source. The objective of the project is to involve the worldwide search for extraterrestrial intelligence (SETI) community, professionals from different fields and the broader public in the reception, decoding and interpretation of the message. This process will require global cooperation, bridging a conversation around the topics of SETI, space research and society, across multiple cultures and fields of expertise.			
Chasing nomadic worlds: A new class of deep space missions	Volume 212, November 2023	Manasvi Lingam, Andreas M Hein, T Marshall Eubanks	Florida Institute of Technology, University of Luxembourg, Space Initiatives Inc
Nomadic worlds, ie objects not gravitationally bound to any star(s), are of great interest to planetary science and astrobiology. They have garnered attention recently due to constraints derived from microlensing surveys and the recent discovery of interstellar planetesimals. In this paper, we roughly estimate the prevalence of nomadic worlds with radii of 100 km $\lesssim R \lesssim 10^4$ km. The cumulative number density $n_{>}(> R)$ appears to follow a heuristic power law given by $n_{>}\ \alpha\ R^{-3}$. Therefore, smaller objects are probably much more numerous than larger rocky nomadic planets, and statistically more likely to have members relatively close to the inner Solar system. Our results suggest that tens to hundreds of planet-sized nomadic worlds might populate the spherical volume centered on Earth and circumscribed by Proxima Centauri, and may thus comprise closer interstellar targets than any planets bound to stars. For the first time, we systematically analyze the feasibility of exploring these unbounded objects via deep space missions. We investigate what near-future propulsion systems could allow us to reach nomadic worlds of radius $>R$ in a 50-year flight timescale. Objects with $R \sim 100$ km are within the purview of multiple propulsion methods such as electric sails, laser electric propulsion, and solar sails. In contrast, nomadic worlds with $R \gtrsim 1000$ km are accessible by laser sails (and perhaps nuclear fusion), thereby underscoring their vast potential for deep space exploration. See also *Chasing Nomadic Worlds* in Principium 40 February 2023.			

BECOME AN i4is MEMBER

Let's 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?

"Provide ships or sails adapted to the heavenly breezes, and there will be some who will brave even that void," Johannes Kepler, letter to Galileo Galilei 1610.

The i4is membership scheme exists for anyone and everyone who wants to help us achieve an interstellar future. Your membership helps to fund our technical research and educational outreach projects. In return, members receive many exclusive benefits, including our program of educational talks, a monthly newsletter, preprints, and access to the members-only area of the website which contains exciting tools and new material added on a regular basis. If you are passionate about an interstellar future for humanity, joining our membership scheme is the perfect way for you to get more involved while also helping us take the vital early steps towards finally reaching the stars. To find out more, visit www.i4is.org/membership.
Try a Google Scholar search - i4is interstellar - for just a sample of our technical and scientific work.

If you like what you see in Principium, and want to help us do more, please consider becoming a member.

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To find out more and join, see *i4is.org/membership*

THE i4iS MEMBERS' PAGE

Parnika Singh and John I Davies

The i4is membership scheme exists for anyone and everyone who wants to help us achieve an interstellar future. Your membership helps to fund our technical research and educational outreach projects. In return, members receive many exclusive benefits, including our program of educational talks, a monthly newsletter, preprints, and access to the members-only area of the website which contains exciting tools and new material added on a regular basis. If you are passionate about an interstellar future for humanity, joining our membership scheme is the perfect way for you to get more involved while also helping us take the vital early steps towards finally reaching the stars. To find out more, visit www.i4is.org/membership.

Oumuamua Updates

Our team at i4is has been working with using SOHO's SWAN instrument to look at potential water outgassing from Oumuamua. The data had so far been overlooked. Their preliminary results indicate that no hydrogen-containing outgassing that would explain the acceleration was detected. If this is true, it rules out the hydrogen/water iceberg hypothesis. The nitrogen hypothesis remains possible, although it makes 1I very unusual. Using a simple force equation with mass flow x exhaust velocity x collimation degree which shows that to explain the acceleration by lower outgassing levels, 1I would have to be much lighter than existing comets. Hence no matter how you turn things, you end up with a highly unusual – and likely interstellar – object. Exciting news for sure!

i4is Science Fiction Book Club

I4is has a science fiction book club for readers and writers. We read and discuss stories that take the eyes above and beyond the horizon, tales that inspire minds and hearts to leap from here and now to tomorrow and elsewhere. We examine stories for both their readability and for what we can learn from them as writers. Due to the worldwide nature of the i4is membership, this book club is held once a month on Zoom, typically at 19.00 UK time on the second or third Thursday of the month.

In October the i4is SF Book Club members considered again 'The Road to Science Fiction Volume 3: From Heinlein to Here' edited by James Gunn, a collection of selected short stories from the 'Heinlein to Here' era. They read and discussed stories 12, Critical Factor by Hal Clement, and 13, Fondly Fahrenheit by Alfred Bester but were also open to more discussion/debate.

To join the club, please email bookclub@i4is.org for the link.

i4is Science Fiction Anthology

You will have seen from earlier Members' Newsletters that we are still looking for short stories for the upcoming "The i4is Science Fiction Anthology." To ensure a level playing field, submissions must be in Shunn's Modern Manuscript format, the widespread standard for fiction submissions. www.shunn.net/format/story (Make sure you click the Modern tab.) Further information is available – or just send submissions as email attachments – to the editors sarah.margree@i4is.org and jean.asselin@i4is.org

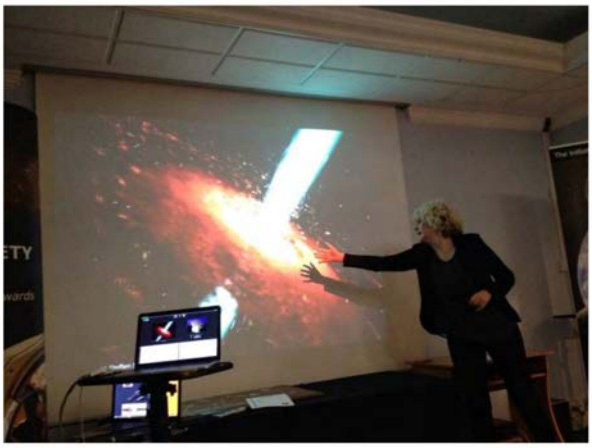
Getting More Actively Involved

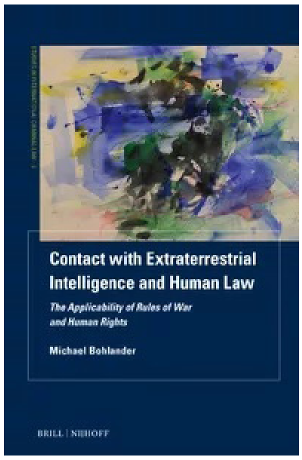
i4is is always looking for volunteers to help support humanity's venture onto the interstellar stage. If taking a more active role in our work is of interest to you, we'd love to hear from you! There are many different ways you can help us take our programs forwards, whether your skills are technical, 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.

Members' Newsletter

The i4is Members' Newsletter is an exclusive newsletter that keeps you up to date with the most compelling interstellar advances, research, and news. Since the last Principium issue, two member newsletters have been delivered, including coverage of a variety of different developments pertaining to interstellar travel. They included preprint access to a number of articles from this issue and news items - a Lightsail Precursor Mission to Enceladus and Europa, a Magnetic Fusion Plasma Drive, Reinforcing Light Sail Nanocraft, A Laser-Fusion Propulsion System and Antimatter Propulsion.

NEXT ISSUE





Left: Faster than light (FTL) travel
Silke Britzen and Remo Garattini at an i4is symposium - from P30, *Wormholes Come to London*, in 2014

Right: cover of *Contact with Extraterrestrial Intelligence and Human Law - The applicability of rules of war and human rights (brill.com)*

- **Current FTL thinking:** Dan Fries and Parnika Singh will deliver this somewhat postponed survey of the possibility of avoiding all those messy fusion rockets and tiny sailing craft for something closer to our younger imaginations from Dan Dare and Star Trek.
- **Book review: Contact with Extraterrestrial Intelligence and Human Law** An eminent academic lawyer, Professor Michael Bohlander of Durham University, has a new book - *Contact with Extraterrestrial Intelligence and Human Law - The applicability of rules of war and human rights* (brill.com/display/title/68174?language=en). Our friends in the Space Law group at KCL Space (www.kclspace.com/) will review.
- **More from IAC23 and IRG23:** We will have more reports of interstellar contributions at the 2023 IAF Congress and from the 2023 Interstellar Research Group symposium.
- **plus** Interstellar News and interstellar papers in The Journals.

COVER IMAGES

Our cover images for this issue look at our own Solar System both as it is and as how one small part of it might be if we build a big interstellar probe.

FRONT COVER

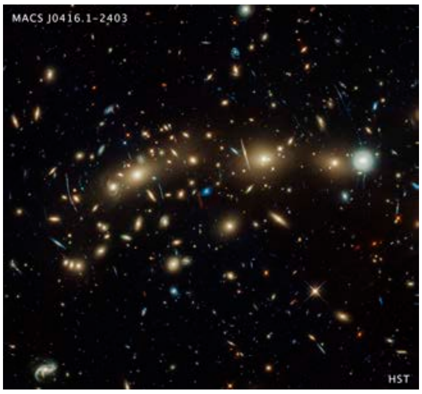
An experiment in "AI"

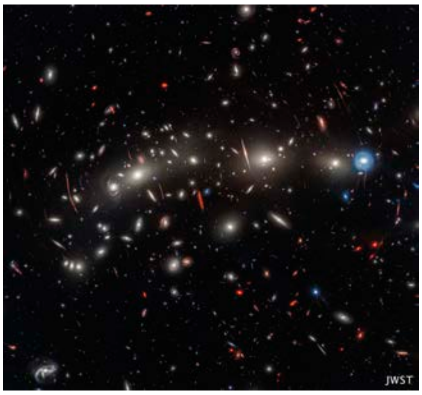
Our Colleague Marshall Eubanks has been experimenting with some current technology, a version of artificial intelligence. Marshall is the lead author of the i4is study for Breakthrough Starshot, *Swarming Proxima Centauri: Optical Communication Over Interstellar Distances* (arxiv.org/abs/2309.07061) as we reported in a News Feature in Principium 41, May 2023. So naturally his first experiments were based on this work.

He used Microsoft Image Creator with DALL-E version 3 (create.microsoft.com/en-us/learn/articles/how-to-image-prompts-dall-e-ai) with an input of - *Swarming Proxima Centauri: Optical Communications Over Interstellar Distances.*

The result looks good though the probes are not quite as our study team intended - and the probes would perhaps be better against a mainly stellar background with a planet as a large feature but not a dominant one. So in the image creation exam it might perhaps be 7 out of 10 for our current generation of AI? DALL-E is based on the ubiquitous ChatGPT - clever stuff but we are still a long way from Artificial General Intelligence (AGI) - more about this in the interstellar context in *Sending ourselves to the stars?* in Principium 12 (i4is.org/principium-12/) and 13 (i4is.org/principium-13/), 2016.

BACK COVER





Hubble and Webb Compared

The Space Telescope Science Institute (STScI) showed us how the veteran Hubble compares with its new relative, the James Webb Space Telescope. The images are at the top and bottom of the page with the division just about at the star which tops the Initiative for Interstellar Studies logo. On the back page the JWST image obscures the lower part of the Hubble image - somebody had to win to fit the A4 page!

The STScI explains "Both images feature hundreds of galaxies, however the Webb image shows galaxies that are invisible or only barely visible in the Hubble image. This is because Webb's infrared vision can detect galaxies too distant or dusty for Hubble to see. (Light from distant galaxies is redshifted due to the expansion of the universe.) The total exposure time for Webb was about 22 hours, compared to 122 hours of exposure time for the Hubble image."

webbtelescope.org/contents/media/images/2023/146/01HDHHRZ9KTFXH9Z94EDAYD9VE

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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: An experiment in "AI"
Credit: Marshall Eubanks
Back cover: Hubble and Webb compared
Credit: NASA, ESA, CSA, STScI

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.

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