PRINCIPIUM

The Initiative and Institute for Interstellar Studies | Issue 39 | November 2022

SCIENTIA AD SIDERA | KNOWLEDGE TO THE STARS

Freedom in outer space
i4is Science Fiction Anthology
i4is at the Royal Institution
Interstellar News
Oumuamua - A Second Chance
IAC22: Interstellar Presentations
i4is 10th anniversary
The Journals

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EDITORIAL

Welcome to issue 39 of Principium, the quarterly magazine of i4is, the Initiative and Institute for Interstellar Studies. Our lead feature this time is Max Daniels' book review, *Freedom in outer spac*e, of the new book, *Interplanetary Liberty - Building Free Societies in the Cosmos*, Charles S Cockell, which considers how we might govern ourselves beyond Earth. This will be an essential component of the solar system society we need as a precursor to any major interstellar endeavour.
The front cover image this time is a mosaic of early Principium covers to celebrate 10 years of i4is. More about this in *i4is 10th anniversary*. The rear cover image is an AI imagination of a solar sail. More about both covers in *Cover Images* inside the rear cover.
We have 16 pages of Interstellar News and 5 pages of our regular summary of relevant peer-reviewed papers in *The Journal of the British Interplanetary Society* (JBIS) and *Acta Astronautica*. We have '*Oumuamua - A Second Chance*: Adam Hibberd's personal account of his journey to and through his vital contribution to i4is Project Lyra. A major item this time is the first report - *IAC 2022: The Interstellar Presentations*. First reports of the interstellar themes at the biggest world space conference of the year, which took place in Paris in September. Other features are the announcement of our planned *i4is Science Fiction Anthology* and some photographic *Impressions of IAC22*.
As always we have the i4is members' page and our regular call to action, *Become an i4is member*.

The next issue, in February 2023, will include -
• A report on the summer 2021 and 2022 courses - Human Exploration of the Far Solar System and on to the Stars, delivered by i4is for the Limitless Space Institute (LSI) - is postponed from this issue.
• Second part of *IAC 2022: The Interstellar Presentations*.
• Search for an Alien Message to a Nearby Star: Rob Swinney
- all listed in *Next Issue* at the end of this one.

And if you would like to help in any part of ***Working towards the real Final Frontier*** then please take a look at this poster, full-size on page 10. There's lots to do!

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

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

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

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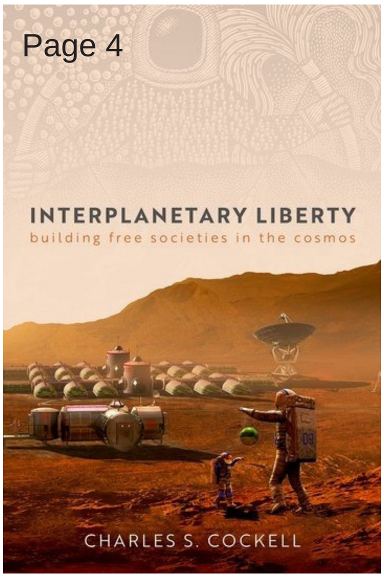

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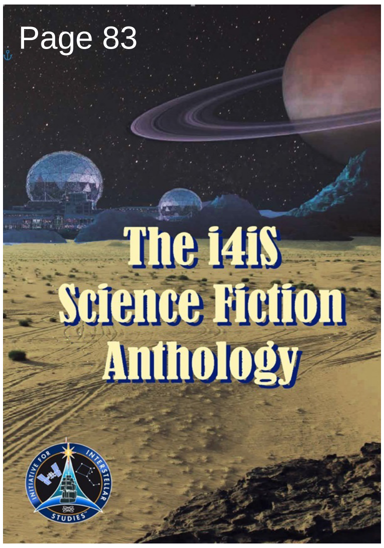

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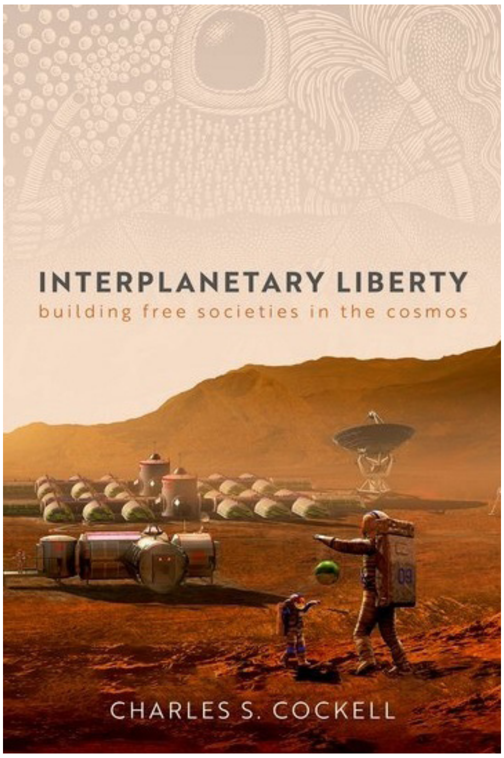
Book Review: Freedom in outer space

Max Daniels

Our lead feature this time is a review by regular Principium contributor Max Daniels of *Interplanetary Liberty: Building Free Societies in the Cosmos* [1]. Max reviews this new book discussing how we might build freedom in space. An essential component of the solar system society we need as a precursor to an interstellar human endeavour of significant scale and ultimately a galactic civilisation.



Professor Charles Cockell [2] is an astrobiologist and microbiologist, specialising in the study of life in extreme environments. He has worked previously at institutions including NASA and the British Antarctic Survey, and currently at the University of Edinburgh.

His scientific background informs his work on political philosophy, and these two fields meet in outer space, as seen in his writing on extra-terrestrial states and human liberty [3] and a comparison of liberty in the ancient and modern worlds and in outer space [4] .

Interplanetary Liberty considers the concept of liberty, or freedom, for those who will one day roam, settle and live in outer space. It is a speculative work – nobody lives there, yet – meaning it can look at a range of possible futures. He takes an appropriate route to a sensible answer, although I argue that there are sophistications and strands of thought that would enrich his study further, by focusing on spaces large and small.

[1] Oxford University Press (OUP), September 2022, 464 Pages. global.oup.com/academic/product/interplanetary-liberty-9780192866240?cc=us&lang=en&
[2] Professor C S Cockell, FRSE www.ph.ed.ac.uk/people/charles-cockell
[3] Charles Cockell, 2009: *Liberty and the Limits to the Extraterrestrial State*, Journal of the British Interplanetary Society, 62, pp. 139-157
[4] Charles Cockell, 2011, *Liberty across light years: The freedom of space settlers compared to that of the ancients and the moderns.* Journal of the British Interplanetary Society, 64, 287–88.

Democracy is difficult, including in space

The question that runs throughout the work is simple: will people in outer space be free, or not? He has two central arguments: that space is 'tyranny-prone' and likely to succumb to despotic regimes; and that humanity can avoid this, because we have the tools of art, education, and politics, and practical skills such as engineering and science.

I will argue that Cockell comes to appropriate conclusions. Reviewing speculation can prove tricky, but he has run through practical elements of society which would contribute to our understanding and implementation of liberty: welfare, justice, education, the building blocks of a free society, and the risk of tyranny and autocratic regimes. This is well thought through in logical ways, sensitive to arguments as to what extent liberty may exist in outer space from the past, present and, possibly, the future.

Where his analysis could be deepened is through a greater appreciation of the sophisticated ways in which freedom is exercised, fought over, and understood on Earth, and how this might play out in outer space. I will consider the concept of liberty, before seeing how it applied at different scales.

What is liberty?

Before exploring the work in depth, we need to understand what Cockell means by liberty and tyranny, in the context of outer space. He defines liberty, or freedom, as where, "individuals and groups... live free of undue coercion, domination, or interference from others in the extra-terrestrial environment" (p.9). Tyranny, on the other hand, is "in some sense merely the obverse of liberty" (p.22).

He describes his book as a work of 'speculative' political philosophy (p. xv), that looks to the future rather than dwelling in debates on liberty from the past. This is reasonable, in that it is not known when, where or how humans will live in outer space. As a political concept, though, I think it would be useful to draw from previous thought to guide our analysis.

He does refer to influential thinkers, although he perhaps could infuse their work into his own book more extensively. The 17th-century political philosopher Thomas Hobbes is clearly important to Cockell, forming both the frontispiece of Interplanetary Liberty and framing its opening chapter. Hobbes posited that individuals would rationally give up their freedoms to be under an authority, as otherwise there would not be order. The 'state', or government, in this case would be all-powerful [1].

This view was later challenged by writers such as John Locke, who placed greater emphasis on society as a concept, and government must uphold certain rights, such as property. Cockell agrees: "Private land ownership and property is essential for freedom" (p. 174). Others such as Algernon Sidney said that government should intervene in our lives to the least possible extent, while Jean-Jacques Rousseau in the 18th century wrote that by choosing to obey the law, we exercise our freedom, because politics is a necessary way of determining our interests as a collective.

The point of examining these old writings is two-fold. First, it provides the basis for an understanding of freedom when applied in outer space. Second, it shows that any speculation into possible political futures in space can benefit from their study. Looking at the western political tradition will inform how best to structure and critique political structures in outer space likely to have significant western involvement.

The importance of scale

The remit of Interplanetary Liberty is the 'bigger picture' question of freedom in outer space, as Cockell wishes to avoid dwelling on the details of what life might entail. This prevents us getting bogged down in mundane specifics, given there are so many uncertainties, including the state of technology.

Of course, a political culture is acted out every day. There is value in considering different scales: the effect of a settlement's rules on the lived experience of the individual and their resulting freedom, alongside the broader ideas that Cockell admirably considers. I will illustrate this through the example of movement.

Freedom of movement

One aspect of outer space that makes it tyranny-prone is that it is alien to humans, Cockell says. We are not adapted to live there, and so must devise clever ways of sustaining life. This includes the provision of vital resources such as food, water, and, especially, oxygen.

An authority who controls the supply of oxygen in an area also controls who lives, works, and moves through there. Power is exerted over that space:

[1] Alan Ryan, 2013: *On Politics*, London: Penguin www.penguin.co.uk/books/25400/on-politics-by-ryan-alan/9780140285185

who has access to each part of a station, your identity and what degree of 'citizenship' you might need, and what you must pay or do for that access. A space station's layout can also determine movement and how oxygen might be distributed, where architectural standards are a product of the culture and politics of their time [1].

Space stations will likely have a division between private quarters and public spaces. What is considered privacy and who decides this will be questions central to the experience of liberty for those living in these settlements. This has long been explored [Fig. 1], as freedom can be restricted overtly [2] or in muddier ways, particularly when it comes to ideas of justice, a concept that has been explored in the context of the "War on Terror" and western treatment of those they consider terrorists [3] .

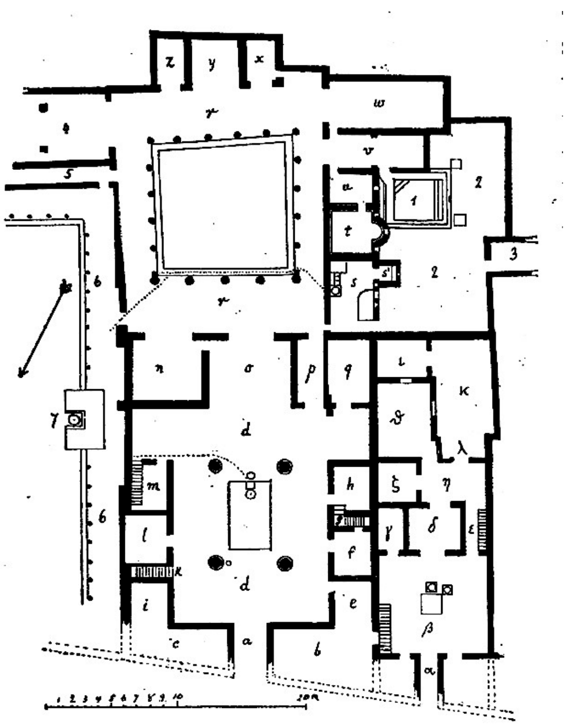


Fig. 146. — Plan of the house of the Silver Wedding.

a. Fauces.
d. Tetrastyle atrium.
n. Dining room.
o. Tablinum.
p. Andron.
r. Peristyle.
s. Kitchen.
t–v. Bath. (*v.* Apodyterium. *u.* Tepidarium. *t.* Caldarium.)
w. Summer dining room.
x, z. Sleeping rooms.
y. Exedra.
1. Open-air swimming tank, in a small garden (2).
3. Corridor leading to another house and to a side street.
4. Oecus.
6. Garden, partially excavated.
7. Open-air triclinium.
α–ι. Fauces, atrium, and other rooms of separate dwelling connected with the larger house.

Science, engineering, and justice

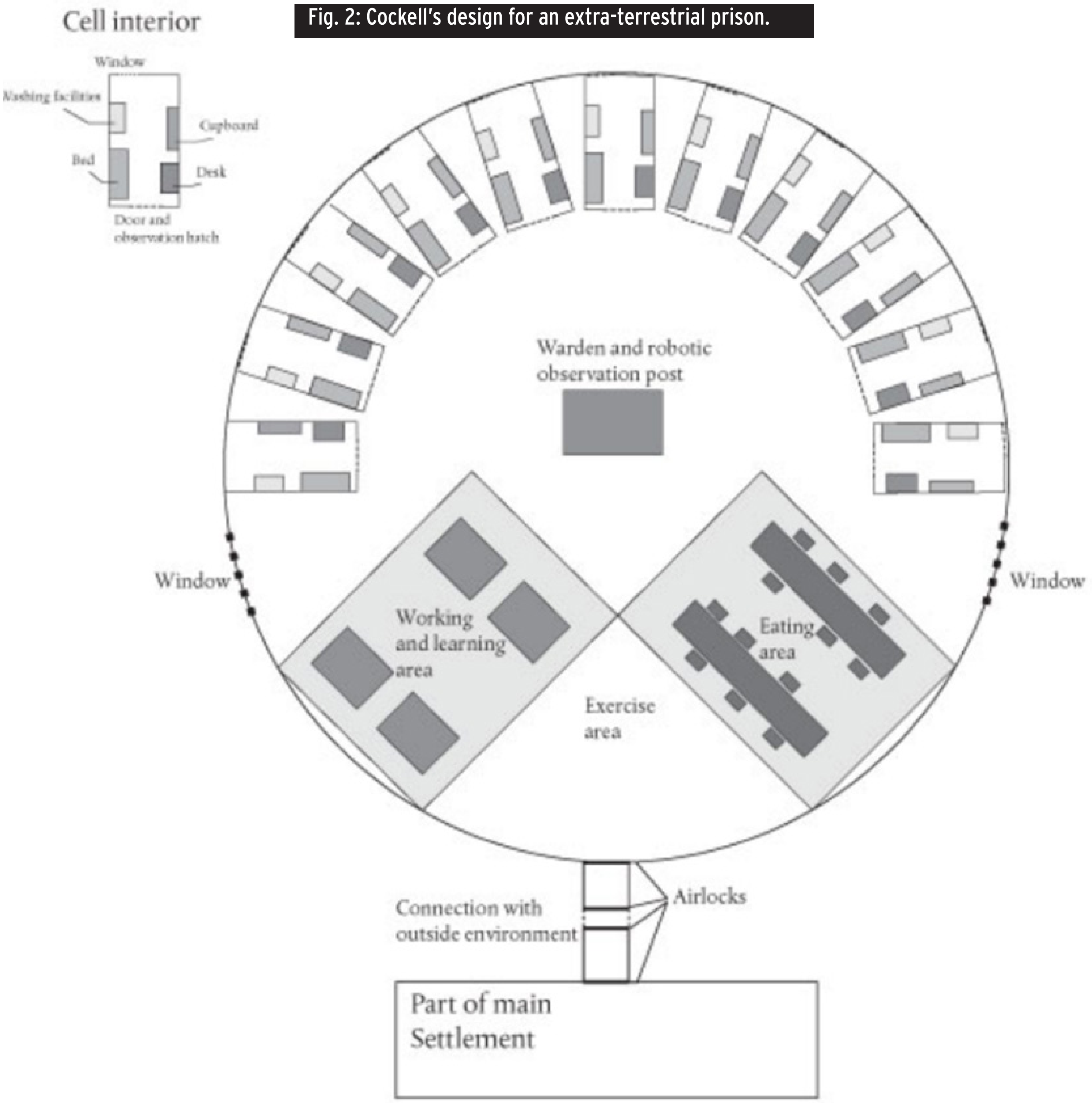
The relationship between physical space and liberty is addressed by Cockell in his chapter on "engineering liberty". Space stations can be designed with freedom in mind, such as by creating spaces where inhabitants can communicate discreetly. A novel idea is to make infrastructure secure enough to withstand a forceful uprising, such as by having strong enough walls so that a bullet-type strike would not cause decompression: the idea being that it would allow a society, in the vein of Locke, to remove unwanted regimes, or at least to make such actions a possibility.

He also talks about the effect on liberty of more personal engineering. This includes parts of the human body, such as organs, and even the human mind. He concludes by saying that he cannot predict the implications, but that whatever happens liberty will remain an important topic. This is a weak conclusion, and strays away from the valuable analysis of the ways that engineering interacts with freedom.

Fig. 1: The separation of private and public spaces in Pompeii. Credit: wellcomecollection.org/works/d2ezh72h

[1] Michel Foucault, 1984: interview with Paul Rabinow, 'Space, Knowledge and Power', in The Foucault Reader, New York: Pantheon Books, pp. 239-256
[2] Jennifer Fluri, 2012: *Capitalising on bare life: sovereignty, exception, and gender politics*, Antipode, 44 (1), pp. 31-50.
[3] Giorgio Agamben, 1998: *Homo Sacer: Sovereign Power and Bare Life*, Stanford, CA: Stanford University Press

Fig. 2: Cockell's design for an extra-terrestrial prison.



Where liberty, space, and movement come together is in Cockell's discussion of justice. He outlines why individuals will commit crimes and the rights of suspects, arguing that the fair exercise of justice is essential to the functioning of a free society.

What is of particular relevance to my review is his take on the design of an extra-terrestrial prison, as a physical space that punishes via isolation, but also shields the convicted. As buildings, they have a role in restricting the prisoner's right to movement and other freedoms [Fig. 2]. He refers to an educational programme he led which engaged with Scottish inmates to design extra-terrestrial stations. This is enlightening, as it explores the function and purpose of prisons and the balance between redress and reform, which goes beyond a simple discussion of building design.

My main criticism here is that it is not inconceivable that an extra-terrestrial society would progress past prisons, which take up precious space and resources. They could use more humane or rehabilitative forms of punishment, or equally create more sinister restrictions on liberty. These could involve an architecture of surveillance, where individuals alter their behaviour based on a pre-emptive fear of punishment, or even through social norms [1] .

[1] Michel Foucault, 1976: *Society must be defended*, Lectures at the Collége de France, Picador: New York. Translated by David Macey. en.wikipedia.org/wiki/Foucault%27s_lectures_at_the_Coll%C3%A8ge_de_France#%22Society_Must_Be_Defended%22_(1975%E2%80%931976)

Moving outward and upward

At a larger scale, we can see that restrictions on movement in outer space exist today. The Artemis Accords [1] are a series of bilateral agreements between mostly western space powers and their allies which outline the use of 'safety zones'. These are areas around certain instruments or stations where others cannot operate [2]. It shows that terrestrial politics will, at least in the early days of space exploration, be crucial in determining extra-terrestrial freedom [3].
Politics is bound up in the use and applications of science in outer space. Cockell argues that science is an essential part of both contemporary life and our future life away from Earth, where pursuing scientific discourse is akin to the democratic process. The very nature of technology shows its centrality, where scientific solutions are needed to overcome challenges in space and maintain life there – as seen with the production of oxygen. I agree with Cockell in that if we consider larger scales, from settlements right up to the Solar System, scientific developments will increase our interdependence: if you build a faster rover, you can travel further [Fig. 3]. The analysis follows that this would weaken despotic regimes.

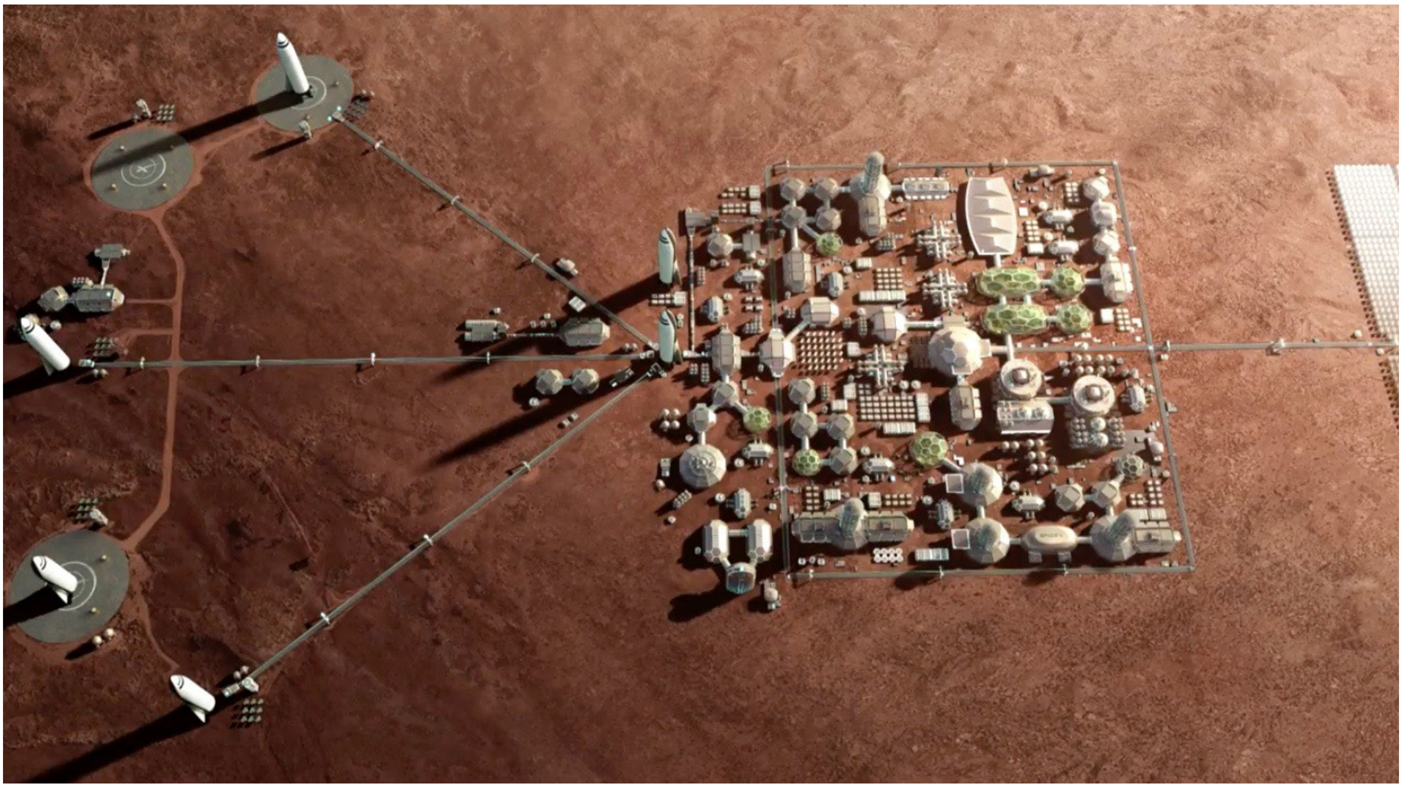


Fig. 3: Liberty needs to be considered at a range of scales, including settlements.
Credit: twitter.com/SpaceX/status/913634039545847808

[1] *The Artemis Accords - Principles for a Safe, Peaceful, and Prosperous Future* www.nasa.gov/specials/artemis-accords/index.html
See also Principium 32, February 2021, *The Artemis Accords: what comes after the Moon?*, Max Daniels i4is.org/wp-content/uploads/2021/06/The-Artemis-Accords-what-comes-after-the-Principium32-print-2102221659-opt.pdf
[2] *Imagining safety zones: Implications and open questions* www.thespacereview.com/article/3962/1
[3] *Regulating Design: The Practices of Architecture, Governance and Control*, Rob Imrie and Emma Street, journals.sagepub.com/doi/pdf/10.1177/0042098009346068

More than poles apart

Cockell claims that politics in Earth and in space, despite their geographical distance, will influence each other; where a tyranny on Earth might incentivise tyranny in space. It is remarkable that this could well be true: we hear calls today for governments to act well domestically so as not to inspire or give reasons to others to act badly. Distance will give us new perspectives [1], but surely being free in one will help us to be free in the other.

The links between Earth and the heavens are also expressed through art, Cockell finds. It can uplift those living in alien worlds; art in space would inspire art on Earth; and artists can imagine futures where we find new ways to be free. He is right in that art transcends distance, tying Earth and space close together. Something of this sort is seen today when Antarctic research programmes invite artists to visit their scientific bases (Fig. 4).

Cockell is ambitious from the outset in his book, and should be applauded. He has sought an understanding of liberty far into the future and far away from our world, and given it a well-balanced evaluation. There are areas where his analysis could be deepened, such as in relation to spatial awareness, distance, and different scales. This applies outwards – to the scale of entire settlements and even between planets, including Earth – and downwards – to the individual, and what freedom means to their own person. His examples of art, engineering, science, and education are practical, and make it an enlightening and accessible read. I look forward to where his insights travel next.

Fig. 4: Artists bring Antarctica to the rest of the world, just as art will bridge the distance between planets. Credit: GRID-Arendal/ Peter Prokosch www.grida.no/resources/1382

[1] *The Conquest of Space and the Stature of Man*. Hannah Arendt. www.thenewatlantis.com/publications/the-conquest-of-space-and-the-stature-of-man

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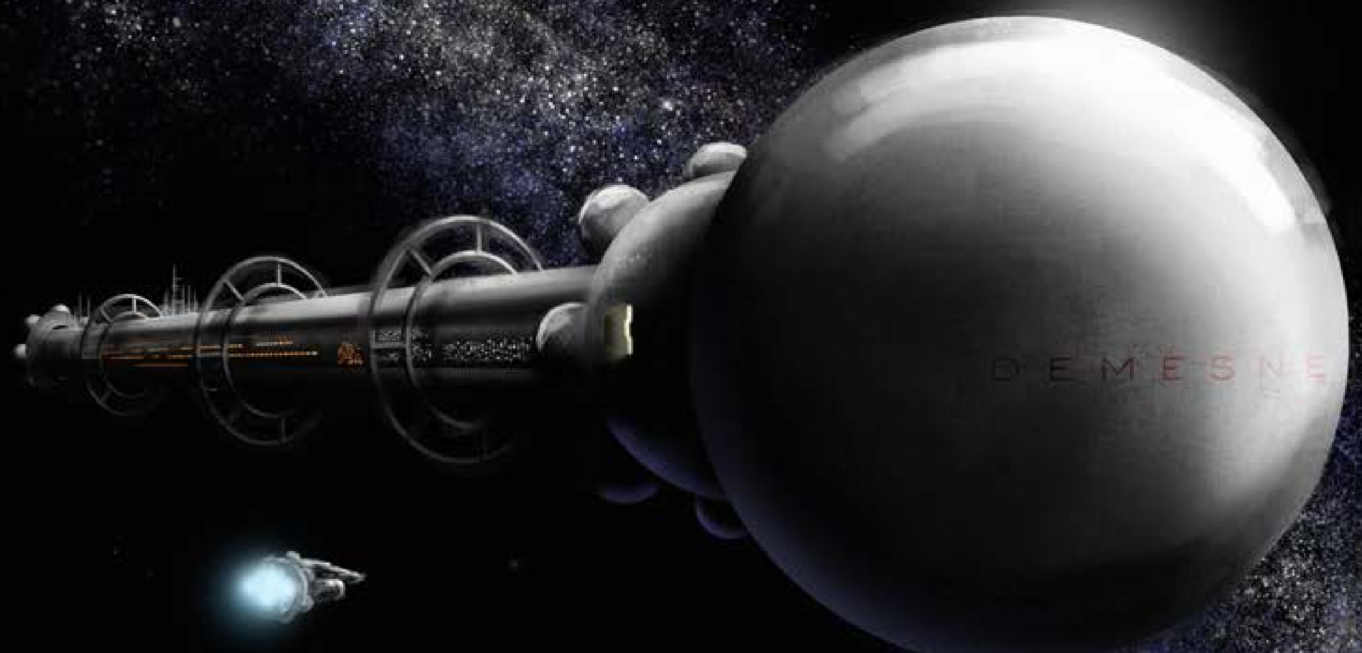

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John I Davies reports on recent developments in interstellar studies

Tarantula Nebula (NIRCam Image) "The NASA James Webb Space Telescope, developed in partnership with ESA and CSA, is operated by AURA's Space Telescope Science Institute." Credit: Space Telescope Science Institute

Webb's Tarantula

Occasionally we are distracted by the sheer staggeringness of what observational astronomers can achieve and we temporarily put aside our central objective, getting there, to goggle at the sheer gobsmacking wonder of what is out there. This recent image from the James Webb telescope is a case in point. Just a small clip above.

For the whole thing go to -
/webbtelescope.org/contents/media/images/2022/041/01GA76MYFN0FMKNRHGCAGGYCVQ
- and pick the 124 or 140 MB image. And, for those minded to calculate, here's an ESA video zoom -
www.youtube.com/watch?v=mnalsMi1jg0
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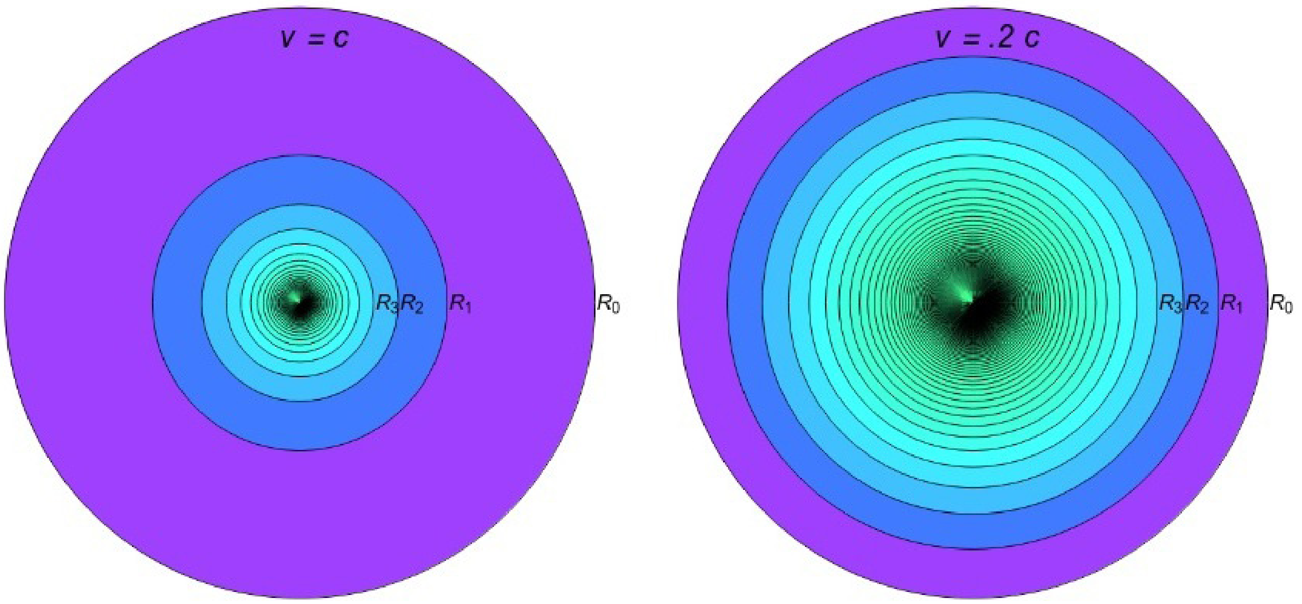
Credit: USPS. https://about.usps.com/newsroom/national-releases/2022/0726ma-usps-celebrates-james-webb-space-telescope.htm

Limit to cosmological communication

In *A causal limit to communication within an expanding cosmological civilization*, S Jay Olson of Boise State University, Idaho (arxiv.org/abs/2208.07871) suggests that a civilisation embarking on high-speed intergalactic expansion will have communication between remote galaxies in the civilisation limited by an extreme time delay, due to the distance involved, calling this a "causal horizon". The paper suggests that possible conversation with the home galaxy depends on expansion speed. So space settlements "beyond the horizon" in an expanding cosmic civilisation (ECC) can never be observed by the initiating home galaxy.

Motivated by resource utilisation a wave of colonisation expands at high speed in all directions, saturating every galaxy along the way in an expanding sphere. The paper suggests a general internal property of an ECC – a fundamental limit to communication, imposed by causality. The quantity of interest to us here is the degree of conversation that is possible between a colony and the home galaxy of the ECC. This can be measured by the number of sequential, back-and-forth signals that are possible before the "end of time" thus dividing the ECC into spatial regions, corresponding to different numbers of possible conversations. The net effect is that faster expansion leads to greater isolation. The paper sums this up "For a very high expansion speed, close to v = c [the speed of light], the large majority of the final ECC volume corresponds to the n = 0 region, where colonies can send no signal at all back to the home galaxy. For lower expansion speeds, the relative size of the n = 0 region is smaller."



The relative size of communication regions for v = 1c and v = 0.2c, with the final domain scaled to equal size, for comparison. High expansion velocity means that far more of the final domain exists beyond R1, and will never be able to signal the home galaxy.

Credit: Olson

The paper cites the book by Bostrom [1] describing how cosmic expansion could be initiated by a superintelligence suggesting that even if a superintelligence's final goals only concerned what happened within some particular small volume of space, such as the space occupied by its original home planet, it would still have instrumental reasons to harvest the resources of the cosmos beyond but would still limit its final sphere of expansion.

[1] Nick Bostrom, *Superintelligence: Paths, dangers, strategies*, Oxford University Press, 2014. See also *Sending ourselves to the stars?* Principium 12 & 13, February and May 2016.

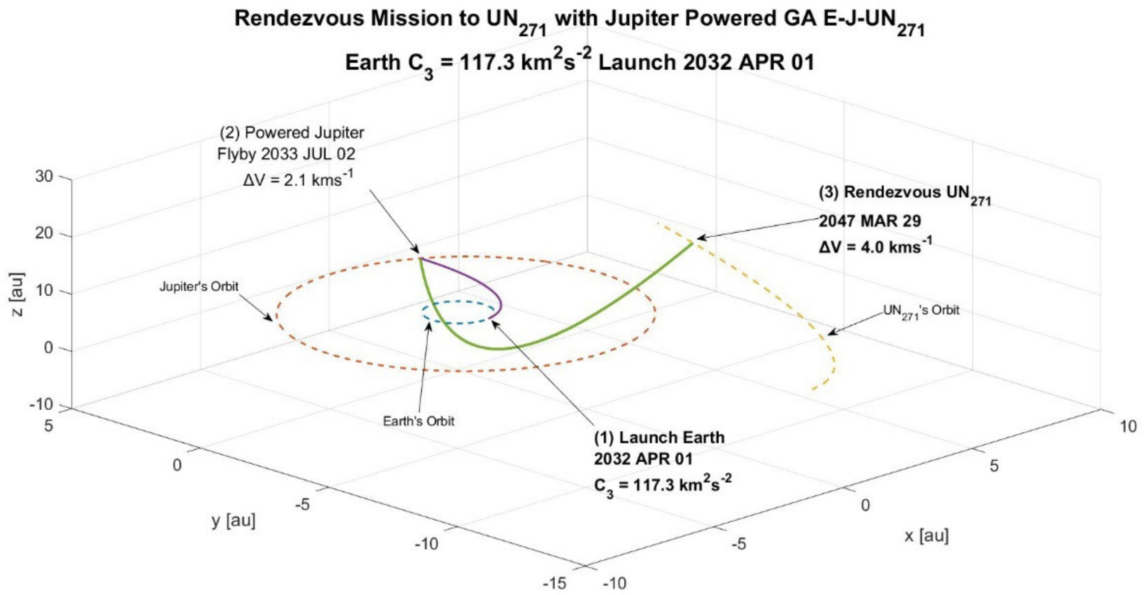


Figure 11. Rendezvous with UN271, Example Mission with Jupiter GA
Credit (image and caption): Hibberd/Eubanks

Missions to Comet C/2014 UN271

Comet Bernardinelli/Bernstein, C/2014 UN271, was discovered very early in its journey inwards from the Oort Cloud. UN271 was more than 29 astronomical units (AU) away or about the same distance as the furthest recognised planet, Neptune (with apologies to Pluto for its downgrading to "minor planet") but it's coming in almost perpendicular to the ecliptic plane so it will plunge through, reach perihelion in 2031 at about 10 AU (about as far out as Saturn) and will then head back through the ecliptic roughly where it came from. UN271 is also big; Its comet nucleus is around 140 km across.

The i4is Project Lyra team proposed a mission to it last year, discussed in *News Feature: Mission to 2014 UN271 using OITS,* Principium 34, August 2021. In a new paper the team advocate *Analysis of Low ΔV Spacecraft Missions to Oort Cloud Comet C/2014 UN271,* Adam Hibberd, T Marshall Eubanks (arxiv.org/abs/2210.05190). The team describe various methods for reaching UN271 during the period around its perihelion and ecliptic plane passage, with both flyby and rendezvous options; exploiting direct transfers (see image above), Jupiter powered gravitational assists (GA) or alternatively a series of GAs of the inner planets. They have found viable flyby and rendezvous trajectories, especially using the NASA Space Launch System (SLS) as the launch vehicle.

Argus Optical Array

The Argus Optical Array will be an all-sky, arcsecond-resolution, 5 m class telescope which builds a simultaneously high-cadence and deep survey by observing the entire sky all night. The 55 GPix array, currently being prototyped, will consist of 900 telescopes covering 20% of the entire sky, each with a very-low-noise CMOS detector enabling sub-second cadences. Providing depths of 23-24 magnitudes by trading off relatively small apertures for very long co-added exposure times - just as amateur astrophotographers do to deliver the "big telescope" pictures beloved of astronomy magazines. The objective is to enable highly sensitive searches for high-speed transients, fast-radio-burst counterparts, gravitational-wave counterparts, exoplanet microlensing events, occultations by distant solar system bodies, and other phenomena. See *The Argus Optical Array: a 55GPix large telescope surveying 20% of the entire sky every second* (baas.aas.org/pub/2022n6i409p05/release/1) for more details.

To coordinate inputs from 900 telescopes it will use the *Argus Array Hierarchical Data Processing System*, as its instrument control and analysis pipeline [1]. It will use standard commercial X86 computers to distil the raw 11 Tbps data rate into transient alerts, full-resolution image segments around selected targets at 30-second cadence, and

[1] *The sky at one terabit per second: Architecture and implementation of the Argus Array Hierarchical Data Processing System,* Hank Corbett et al, University of North Carolina at Chapel Hill, arxiv.org/abs/2207.14304

full-resolution co-adds of the entire field of view at 15+-min cadences.

The science goals are detailed in *Low-Cost Access to the Deep, High-Cadence Sky: the Argus Optical Array*, Law et al (arxiv.org/abs/2107.00664) and those of specific interstellar interest include -

• Covering the entire sky with a cadence hundreds of times faster than any other deep sky survey
• Spotting interstellar asteroids
• Exoplanet occultation of stars

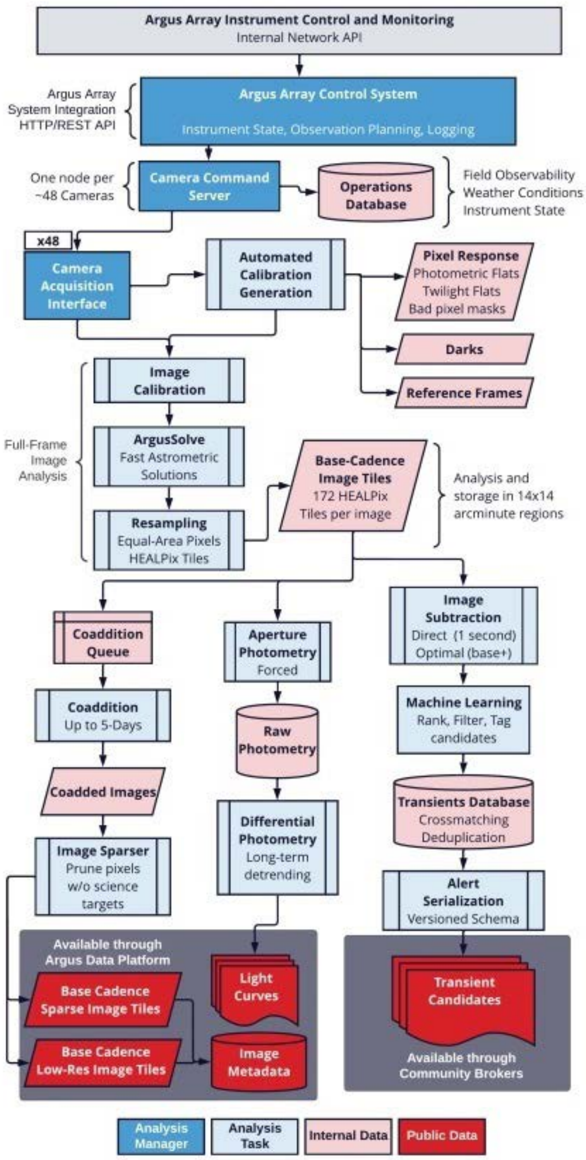


Figure 1. Pipeline components, processes, and data products for the Argus Optical Array. Credit (image and caption): Corbett et al

Can We Fly to Planet 9?

A new paper by i4is team members and colleagues asks *Can We Fly to Planet 9?,* Adam Hibberd, Manasvi Lingam, Andreas M Hein (arxiv.org/abs/2208.10207).

Planet 9 is a hypothetical object in the outer Solar system, which is as yet undiscovered. It has been speculated that it may be a terrestrial planet or gas/ice giant, or perhaps even a primordial black hole (or dark matter condensate). State-of-the-art models indicate that the semimajor axis of Planet 9 is about 400 astronomical units (AU), about 20 times the distance to Uranus. If the location of Planet 9 were to be confirmed and pinpointed in the future, this object constitutes an interesting target for a future space mission to characterize it further. The team describe mission architectures to reach Planet 9 based on a combination of chemical propulsion and flyby manoeuvres, as well as more advanced options (with a ~100 kg spacecraft payload) such as nuclear thermal propulsion (NTP) and laser sails. The ensuing mission duration for solid chemical propellant ranges from 45 years to 75 years, depending on the distance from the Sun for the Solar Oberth manoeuvre. NTP can achieve flight times of about 40 years with only a Jupiter Oberth manoeuvre whereas, in contrast, laser sails might deliver timescales as little as 7 years. We conclude that Planet 9 is close to the transition point where chemical propulsion approaches its performance limits, and alternative advanced propulsion systems (eg NTP and laser sails) apparently become more attractive.

Could we see extragalactic transmitters?

In *Constraints on extragalactic transmitters via Breakthrough Listen* (arxiv.org/abs/2209.08147), Professor Mike Garrett and A P V Siemion [1] observe that SETI surveys traditionally ignore the fact that they are sensitive to many background objects, in addition to the foreground target star. Since the Breakthrough Listen Initiative has embarked on a comprehensive SETI survey of nearby stars in the Milky Way that is vastly superior to previous efforts as measured by a wide range of different metrics we need to better appreciate and exploit the presence of extragalactic objects in the field of view.

[1] respectively - Jodrell Bank, University of Manchester + Leiden Observatory, Leiden University and Berkeley SETI Research Center, UC Berkeley + SETI Institute, Mountain View.

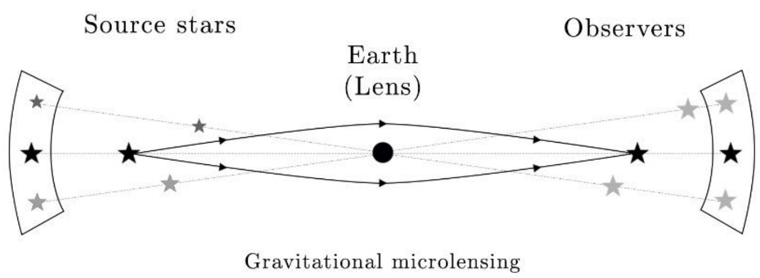
For this paper, the Aladin sky atlas and the NASA/IPAC Extragalactic Database (NED) were employed to make a rudimentary census of extragalactic objects that were serendipitously observed with the 100-m Greenbank telescope observing at 1.1-1.9 GHz. For 469 target fields (assuming a FWHM (full width at half maximum (en.wikipedia.org/wiki/Full_width_at_half_maximum) radial field-of-view of 4.2 arcminute, NED identified a grand total of 143,024 extragalactic objects, including various astrophysical exotica eg active galactic nuclei (AGN) of various types, radio galaxies, interacting galaxies, and one confirmed gravitational lens system. Several nearby galaxies, galaxy groups and galaxy clusters were identified, permitting the parameter space probed by SETI surveys to be significantly extended. This places constraints on the luminosity function of potential extraterrestrial transmitters assuming it follows a simple power law and that limits on the prevalence of very powerful extraterrestrial transmitters associated with these vast stellar systems are also determined. It is demonstrated that the recent Breakthrough Listen Initiative, and indeed many previous SETI radio surveys, place stronger limits on the prevalence of extraterrestrial intelligence in the distant Universe than is often fully appreciated.

"To see oursels as ithers see us!"

In *To a Louse*, Robert Burns mediated on our inability to "To see ourselves as others see us". In *Earth through the looking glass: how frequently are we detected by other civilisations through photometric microlensing?*, Suphapolthaworn et al [1], a team from Hokkaido University (Thailand), Jodrell Bank, University of Manchester and University Bourgogne Franche Comté attempt that feat in the context of SETI.

They observe that microlensing is proving to be one of the best techniques to detect distant, low-mass planets around the most common stars in the Galaxy and, in principle, Earth's microlensing signal could offer the chance for other technological civilisations to find the Earth across Galactic distances. They consider the photometric microlensing signal of Earth to other potential technological civilisations and call the regions of our Galaxy from which Earth's photometric microlensing signal is most readily observable as the "Earth Microlensing Zone" (EMZ). The EMZ can be thought of as the microlensing analogue of the Earth Transit Zone (ETZ) from where observers see Earth transit the Sun. Just as for the ETZ, the EMZ could represent a game-theoretic Schelling point [2] for targeted searches for extra-terrestrial intelligence (SETI) [3]. They use the Gaia DR2 catalogue with apparent magnitude less than 20 (recall that celestial magnitudes are inverted, the Sun has an apparent magnitude of ~27 and Proxima Centauri is about 11) to generate Earth microlensing probability and detection rate maps to other observers. Our Solar system is a multi-planet system but they suggest that Earth's photometric microlensing signature is almost always well approximated by a binary lens assumption. Nevertheless they find that the Earth is in fact well-hidden to observers with technology comparable to our own. Even if observers are located around every Gaia DR2 star with apparent magnitude <20, they expect photometric microlensing signatures from the Earth to be observable on average only tens per year by any of them.
So to others we are a hard-to-find exoplanet and it's hard to see how we can better achieve Burns' objective. See also "Search for an Alien Message to a Nearby Star" later in this section.

Figure 3. An illustration of a gravitational microlensing event and observer-source pairings for this study. Credit (image and caption): Suphapolthaworn et al



[1] S Suphapolthaworn, S Awiphan, T Chatchadanoraset, E Kerins, D Specht, N Nakharutai, S Komonjinda and A C Robin, Monthly Notices of the Royal Astronomical Society, V515 #4, October 2022 arxiv.org/abs/2206.09820
[2] A default choice in the psychology of games en.wikipedia.org/wiki/Focal_point_(game_theory)
[3] Note the parallel between this and a treffpunkt, watering-hole or poste-restante, in *AMiTe Treffpunkt - A proposal for communication between Kardashev Type IIb civilisations,* David F Gahan in Principium 32 February 2021

Perhaps galaxy migrants are choosy?

In *Galactic settlement of low-mass stars as a resolution to the Fermi paradox*, Jacob Haqq-Misra and Thomas J Fauchez [1] (arxiv.org/abs/2210.10656) suggest that, though an expanding civilisation could rapidly spread through the galaxy, we should not necessarily expect extraterrestrial presence in the solar system. Not all stellar types may be equally useful for a long-lived civilisation. Perhaps low-mass stars, and K-dwarf [2] stars in particular, would be ideal migration locations for civilisations that originate in a G-dwarf [3] system. The authors use a modified form of the Drake Equation to show that expansion across all low-mass stars could be accomplished in 2 Gyr, including waiting time between expansion waves to allow for a close approach of a suitable destination star and only requiring travel distances about 0.3 light years (ly) to settle all M-dwarfs [4] and about 2 ly to settle all K-dwarfs. They suggest that interstellar expansion will prefer to migrate from a short-lived to a long-lived star and will thus primarily target low-mass systems in order to maximise the longevity of galactic settlement.

SETI: risk of perceived technology advantage

In *Geopolitical Implications of a Successful SETI Program*, (arxiv.org/abs/2209.15125), Jason T Wright (Penn State), Chelsea Haramia (Spring Hill College, Mobile. Alabama) and Gabriel Swiney (NASA and Harvard Law School) analyse recent work thinking through the potential geopolitical results of even minimal successful SETI by Kenneth Wisian (University of Texas at Austin, ex-USAF Major General) and John Traphagan (also University of Texas at Austin), [5] who concluded that there is a measurable risk of conflict over the perceived benefit of monopoly access to ETI communication channels. Given the likelihood that any civilisation we hear from is likely to have anywhere from hundreds to billions of years of technology development lead time on humanity, even the most seemingly trivial of resulting scientific knowledge, if wielded solely by one nation, might confer an enormous strategic advantage and that even the suspicion that this may be so would be highly destabilising

W&T reject the view that -

> "passive SETI is widely regarded as presenting little or no risk to humanity, apart from upsetting some people with incompatible world views".

Wright et al believe that Wisian and Traphagan (W&T) overestimate the necessity for a "realpolitik" approach believing that their approach is based on an overly narrow contact scenario. They conclude that the W&T recommendations are unlikely to work and may even precipitate the ills that they foresee. In response they recommend transparency and data sharing, further development of post-detection protocols, and better education of policymakers to prepare them for a contact scenario.

Without access to the full W&T paper this writer provisionally suspects that W&T may be right. It was certainly a view taken by cosmologist Sir Fred Hoyle, as dramatised in his 1957 novel *The Black Cloud* and his 1961 TV drama *A for Andromeda*.

Fred Hoyle (second left) as an undergraduate in Cambridge in the early 30s. Credit: St John's College, Cambridge

[1] respectively Blue Marble Space Institute of Science, Seattle and American University, Washington DC

[2] en.wikipedia.org/wiki/Stellar_classification#Class_K

[3] en.wikipedia.org/wiki/Stellar_classification#Class_G

[4] en.wikipedia.org/wiki/Stellar_classification#Class_M [5] Kenneth W Wisian and John W Traphagan., *The Search for Extraterrestrial Intelligence: A Realpolitik Consideration*. Space Policy, May 2020, summary: www.sciencedirect.com/science/article/abs/pii/S0265964620300199, no open paper

i4is Technical Director wins LSI award

Limitless Space Institute (LSI) has announced the 2nd biennial LSI Grants awards. Dr Andreas Hein's team at the University of Luxembourg won with -

Extremely Light-Weight Solar Sails for Fast Deep Space Missions (SEEDLING): Investigate viability of fabricating µm thick aerographite sheets; determine load capability; integrate into feasible sail-craft, University of Luxembourg.

The full set of award winners are at - www.prnewswire.com/news-releases/limitless-space-institute-announces-2nd-biennial-lsi-grants-awards-301617203.html.

Notably -

Direct Fusion Drive Based on Centrifugal Mirror Confinement, University of Maryland
Real Acceleration and Impulse Limits of Light-Sails, Delft University of Technology
The Path Forward: Directed Energy Phased Array (DEPA) Technology, UC Santa Barbara
Traversable Wormholes and Warp Drive: A Road To Interstellar Exploration, University of Bergamo [1]
The Casimir Torque Thruster, University of California, Davis
Navigating the atmosphere: Transferring terrestrial beamed energy to light-sail spacecraft, Australian National University.

The awards have additional support from Breakthrough Initiatives.

Identifying ISO Impact Craters

Samuel H C Cabot and Gregory Laughlin have considered how we might identify impact craters made by interstellar objects (ISOs) [2]. Gregory Laughlin has been interested in ISOs for many years, having co-authored numerous papers starting in 2017 (Google Scholar search; Laughlin interstellar). In this paper he and his colleague Samuel Cabot turn their attention to evidence for past ISOs concentrating on lunar impact craters as a long-preserved record. ISOs exhibit relatively high encounter velocities compared to asteroids and comets. They suggest that the melt volume within craters of a given diameter may be a potential means of identifying ISO craters, as faster impacts produce more melt but this is a challenging task since melt volume and high-pressure petrology, possible diagnostic features, would need in situ analysis of large volumes of material though this may be possible using images from the Lunar Reconnaissance Orbiter camera (LROC) ahead of in situ examination by robotic or human explorers.

ISO Accessibility and Mission Design

The subject of interception of interstellar objects (ISOs), pioneered by the i4is Project Lyra team, continues to attract interest. A team with lead author Benjamin P S Donitz from CalTech,of NASA Jet Propulsion Laboratory and the University of Hawaii at Manoa present *Interstellar Object Accessibility and Mission Design* (arxiv.org/abs/2210.14980) which discusses the accessibility of and mission design to ISOs with varying characteristics. This includes a discussion of state covariance estimation over the course of a cruise [3] handoffs from traditional navigation approaches to novel autonomous navigation for fast flyby regimes and overall recommendations about preparing for the future in situ exploration of these targets.

The team observe that lessons learned here also apply to the fast flyby of other small bodies including long-period comets and potentially hazardous asteroids, which also require a tactical response with similar characteristics. They also observe that though telescopic observations from Earth-based observatories and telescopes can provide valuable science, a dedicated spacecraft can acquire unique information through higher-resolution optical remote sensing and physical interrogation of the target which could resolve the shape, rotation properties, surface morphology, and composition of an asteroid-like ISO and mass spectroscopy can report the gas composition of a comet-like ISO. In addition, using an impactor at an asteroid-like ISO could also reveal fresh surface material to remove any effects of space weathering due to long exposure to interstellar space.

[1] Congratulations to Dr Remo Garratini, a long established friend and colleague of i4is. This has been his research area for many years. See, for example, Principium articles - *Traversable Wormholes and the Casimir Energy in Modified Gravity*, in our report *Wormholes Come to London, "Interstellar Wormholes: Physics and Practical Realisation" Part 2*, in Principium 10, August 2015 and *Wormhole-Stargates: Tunnelling Through The Cosmic Neighbourhood*, in the same issue and also his own article *Wormholes, Energy Conditions and Time Machines*, in Principium Issue 22, August 2018. There is also a report of *Casimir traversable Wormholes*, part of a report on the last *Foundations of Interstellar Studies Workshop* 2019, in Principium 26, August 2019.
[2] *Identifying Interstellar Object Impact Craters*, The Planetary Science Journal (American Astronomical Society) , Volume 3, Number 7 iopscience.iop.org/article/10.3847/PSJ/ac77e9/pdf.
[3] JPL's Mission Analysis, Operations, and Navigation Toolkit Environment was used to perform covariance analysis for spacecraft and ISO trajectory pairs.

Like the Project Lyra team they believe that key questions about the ISOs found so far remain open, and can only be addressed with a dedicated spacecraft flying out and obtaining close-up and in-situ measurements of the ISO's shape, properties, and composition.
Navigating to an ISO requires state determination of the object and trajectory correction to ensure a high-accuracy flyby (the team reject rendezvous as too challenging give the present "state of the art". They review current state of practice in autonomous navigation moving from "ground in the loop" (GITL) in mission cruise phase. An approach phase would last from ten to dozens of days before encounter until 24 hours from encounter, entering the terminal phase when knowledge of the encounter point is reduced to below about 100 km. They suggest optical navigation using onboard cameras.
The mission profile is summarised in a diagram.

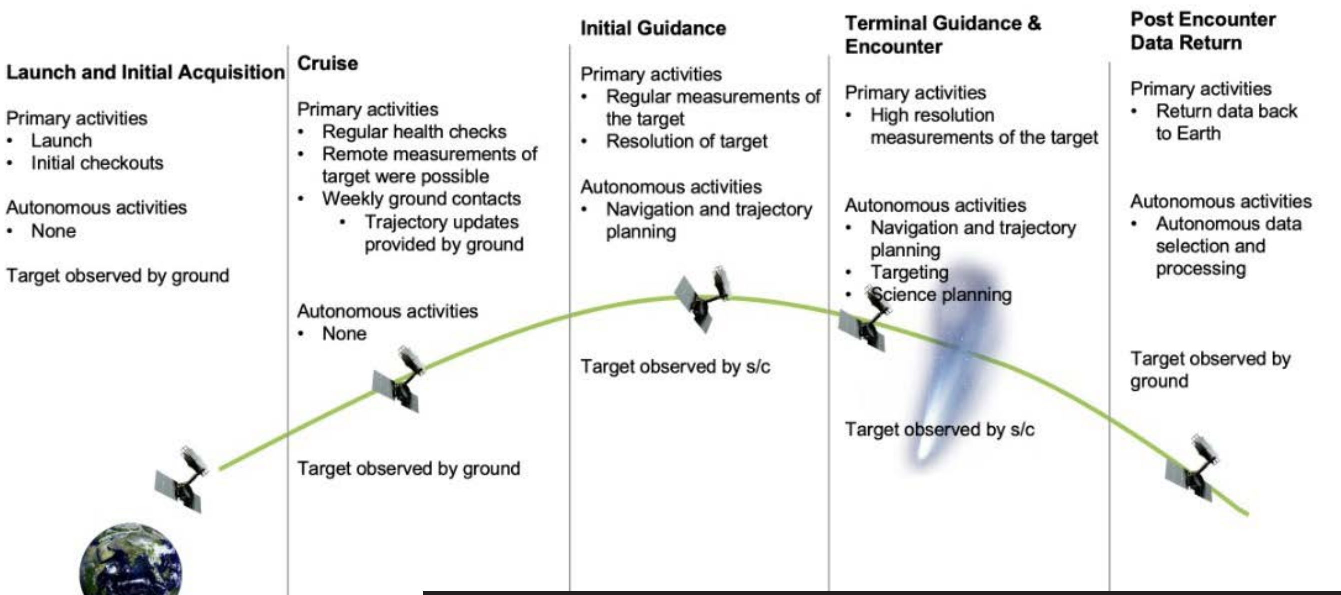


Figure 2: ISO Encounter Concept of Operations. Credit (image and caption): Donitz et al

The authors at Caltech and JPL collaborated to investigate Neural-Rendezvous "a novel deep learning-based Guidance & Control framework for encountering fast-moving targets, including ISOs, robustly, accurately, and autonomously in real-time even with the limited computational capacity of current spacecraft" and testing it for the mission using the JPL SmallSat Dynamics Testbed (SSDT), "a high-fidelity dynamics simulation that models realistic uncertainties and design variables involved in flying a spacecraft". They report performance 20-30 times better than existing autonomous navigation techniques. They suggest that both the initial mission profile and terminal guidance need significant additional refinement as the most significant next steps.

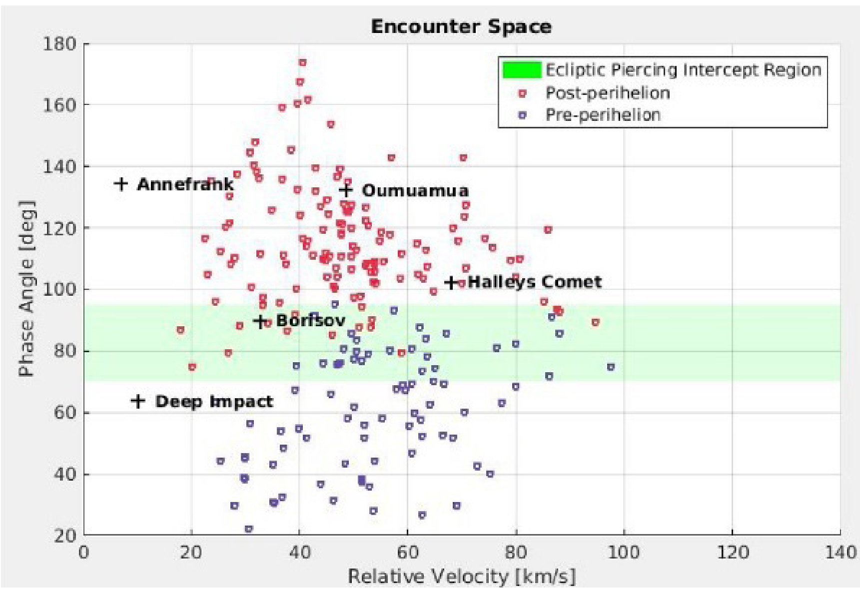


Figure 1: Most trajectories have relative velocities at >60 km/s and phase angles of >120°.
Credit (image & caption): Donitz et al

A personal view by your editor: The JPL/Caltech/U of Hawaii team make no distinction between 1I/'Oumuamua and 2I/Borisov despite the fact that 2I differs little from Solar System comets while 1I is unique in both form and behaviour (see numerous Project Lyra papers, other peer-reviewed research and Principium articles going back to the first Project Lyra paper within weeks of the discovery of 1I). This error is compounded by Figure 1 in the paper (see previous page), which the paper states "...shows the distribution of all ISO flyby cases with their relative velocity and phase angle" but shows Halley's comet and, presumably, other non-interstellar objects since there are several hundred objects shown in the diagram.
There is no need to invoke "Little Green Men" (LGMs) to suggest that 1I represents a science problem wholly unprecedented in its challenge and that therefore a chase mission grows in urgency as the months and years pass without any appearance of a similar object. If our ignorance remains in 10 years time then we will look increasingly myopic having allowed a unique and mysterious object to have passed beyond our reach.

Is Oumuamua perihelion date significant?

Some preliminary thinking about the trajectory of our first discovered ISO, 1I/'Oumuamua, in a recent piece by Adam Hibberd *Exploring 'Oumuamua's Perihelion Date* (i4is.org/exploring-oumuamuas-perihelion-date/). Adam reports he has "been mucking around with 'Oumuamua's orbit on my computer lately". Looking at the orbit parameters he asks "what happens if we keep all of 'Oumuamua's parameters fixed and just change the perihelion date and time?". Varying this parameter over a year around the observed perihelion date and graphing it against perigee distance (ie closest approach to Earth) he finds that the minimum perigee occurs very close to the observed perigee. Adam also tells me that this is an annual cycle so 1I would have been within a few days of closest perigee around that date each year. He's still thinking about this, and he has his own reservations already, but take at look at this blog entry and mull it over yourself.

Keith Cooper on the 'Oumuamua puzzle

In *Interstellar object Oumuamua still puzzling scientists 5 years after discovery* (www.space.com/oumuamua-discovery-solar-system-implications) Keith Cooper, our former editor, mulls the continuing mystery. Keith, for some years editor of *Astronomy Now* (astronomynow.com), has interviewed Greg Laughlin, an astronomer at Yale University [1] about the deepening 1I/'Oumuamua mystery. The principal topic is the hypothesis of the solar system "throw line". Laughlin and Caltech astronomer Konstantin Batygin coined the term to define where a giant planet is able to slingshot a small body with enough acceleration to achieve escape velocity from the gravitational pull from its star. The farther out the planet is, the easier this becomes because the star's gravity decreases with radial distance. In our solar system, according to Laughlin, the throw line is at about 372 million miles (about 600 million kilometres) from the Sun. Jupiter, Saturn, Uranus and Neptune are beyond our solar system throw line, and all could have ejected bodies into interstellar space but "hot Jupiters", commonly discovered exoplanets, are too close to their stars to do this. Laughlin still likes the idea that 'Oumuamua is a chunk of solid hydrogen ice since he suggests that it would explain all of 'Oumuamua's strange properties [2]. Cooper concludes by observing that further ISOs have failed to turn up as had been predicted by several astronomers. Laughlin said -

> "If objects like 'Oumuamua are discovered in short order by Rubin-LSST, then that's pointing to a large population of Neptune-like planets. But if it finds no such objects, then the degree to which 'Oumuamua was unusual will become more and more pronounced."

All this uncertainty underlines the importance of preparations to examine 'Oumuamua closely by the only possible means, a mission to it. I4is Project Lyra pioneered such planning within weeks of the discovery of this first ISO and continues to refine and extend the options for such missions.

[1] Author of several papers on the interstellar object (ISO), 1I/'Oumuamua and related topics, see *In Situ Exploration of `Oumuamua-like objects* Principium 21, May 2018, and *On the Anomalous Acceleration of 1I/2017 U1 `Oumuamua* Principium 25, May 2019.
[2] See *Was 'Oumuamua made of molecular hydrogen ice?*, Principium 30, August 2020, *An Interstellar Visitor: sorting the fact from the speculation* by Professor Alan Aylward, Principium 32, February 2021 and *Book Review: Extraterrestrial: The First Sign of Intelligent Life Beyond Earth, Avi Loeb*, reviewed by Patrick Mahon, Principium 33, May 2021
[3] The Vera C. Rubin Observatory in Chile will begin observing by the middle of this decade, with its 8.4-metre, wide-field survey telescope. If predictions hold true, it is expected to discover at least one interstellar interloper every year.

Laser Inertial Confinement Fusion

In *Interstellar Propulsion Using Laser-Driven Inertial Confinement Fusion Physics*, our co-founder, Kelvin F Long, continues his active contribution to interstellar thinking. This latest paper [1] is part of a wider Special Issue of Universe, *Exploration of Interstellar Space: Concepts, Space Science and Missions*, edited by Prof Dr Roman Ya Kezerashvili (New York City College of Technology, The City University of New York).

Kelvin's paper examines the basics of inertial confinement fusion propulsion and options for its use. Inertial confinement fusion is the basis for the terrestrial experiment at the National Ignition Facility (wci.llnl.gov/facilities/nif) and the 1978 BIS design study, Daedalus [2]. He looks at the system design of such propulsion, examining mechanisms and inefficiencies. He suggests a model spacecraft system, as illustrated below.

See also News item *NIF 2021 record yield shot* later.

Kelvin also surveys some early fusion propulsion thinking including Orion, 1957-1965, Helios, 1964-1965, Enzmann, 1966, Sirius, 1970, Hyde, Wood and Nuckolls, 1971-1972 and Daedalus, 1973-1978 (and a parallel Soviet Icarus, 1976), And later work including Hyde, 1983, Vista, 1987-2003, Longshot, 1988, Schulze (NASA), 1991, Halyard, 1997 and Icarus (specifically the Resolution design), 2009. This is a wide survey, though the writer has a reservation

> "It was not the intention here to give a fully comprehensive review of ICF propulsion, but merely to illustrate the various physics processes at work which go into calculating the performance of a space vehicle propelled by this mechanism and to describe some of the vehicle concepts that have been developed."

However this is a substantial piece of work, 39 pages with 86 references. The technical aspects are sometimes challenging to the non-specialist but I think it will be valuable to all interested in interstellar propulsion.

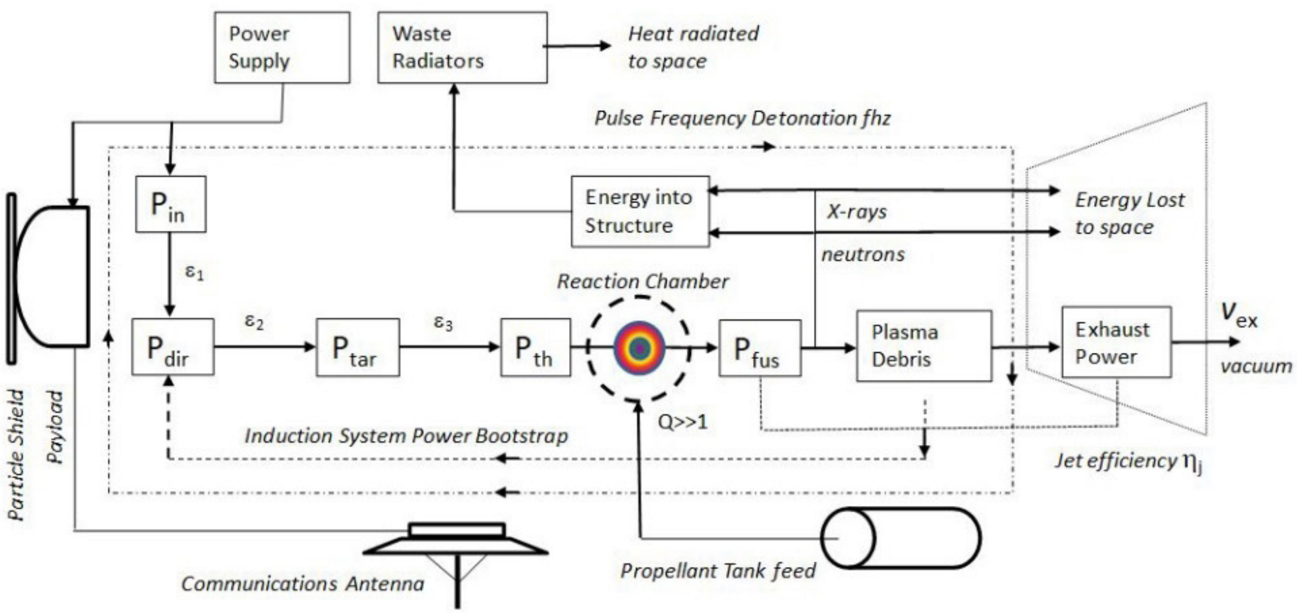


Figure 5. Illustration of an ICF spacecraft and its engine power cycle. Credit (image and caption): K F Long

[1] *Interstellar Propulsion Using Laser-Driven Inertial Confinement Fusion Physics*, Universe 2022, 8. www.mdpi.com/2218-1997/8/8/421
[2] See Project Daedalus – A Beginners' Guide in Principium 24, i4is.org/principium-24/.

Is anyone out there? Two SETI papers

Three papers reported in this issue take different views of the likelihood of successful SETI, neutral, pessimistic and optimistic, but their approaches and objectives differ considerably. In *Perhaps galaxy migrants are choosy?*, above, the author is optimistic. In the two papers reported here a less positive view is taken.

In *Avoiding the "Great Filter": Extraterrestrial Life and Humanity's Future in the Universe*, Jonathan H Jiang (JPL) et al (arxiv.org/abs/2210.10582) take a pessimistic view, proposing several possible doomsday scenarios for ourselves, including anthropogenic and natural hazards, suggesting reforms we require in individual, institutional and intrinsic behaviours to avoid the Great Filter here on Earth. They take a gloomy view of "humanity's technological cleverness outpacing our better judgment". Some of the possible filters discussed are -

- Unchecked population growth
- Nuclear War
- Pathogens & Pandemics
- Artificial Intelligence (but there is no mention of Bostroms's *Superintelligence*, cited in this Interstellar News - *Limit to cosmological communication*)
- Asteroid & Comet Impacts and
- Climate Change

However they cite the Democratic Peace Theory [1] – which holds that democracies are hesitant to go to war with each other, saying it has historically been borne out.

The paper contains a minor mistake, referring to "William Gibson's Necromancer" – which looks like a classic spell-checker assisted error.

In *Exploration of M31 via Black-Hole Slingshots and the "Intergalactic Imperative"*, Andrew Gould (Max-Planck-Institute for Astronomy, Konigstuhl), shows that a gravitational slingshot using a stellar-mass black hole (BH) orbiting SgrA* [2] could launch robotic spacecraft toward M31 at 0.1c – with timescales of several million years for settlement. However he remarks that the achievable speed is ultimately limited by the BH mass but also by the tensile strength of steel, (the latter sounds absurd since we are likely to improve well beyond steel before we can get anywhere near the required BH mass of 5 solar masses or build a craft to go to M31). He states that the BH encounter must be accurate to ~1 km. Deceleration into M31 would rely on a similar BH. Some quotes indicating the scope of this idea –

"The shepherd spacecraft [guiding the longer distance craft to the BH encounter] would travel a few hundred AU in front. It would make a map of all the small BHs and choose the best one."

"After carrying out this mission, the shepherd spacecraft could plunge deep into the potential well of SgrA*, which would enable it to head back toward Earth. On its return, it could receive a report from the primary spacecraft summarizing the success (or otherwise) of its launch. Then it could convey this message to Earth when it reached the solar neighborhood, a few Myr later."

The author suggests using a network of white-dwarf-binary "hubs" as the backbone of a 0.002c [3] transport system, which would enable complete exploration of the Milky Way (hence full measurement of all non-zero terms in the Drake equation) on 10 Myr timescales.

This paper thus takes a very long-term view as in some earlier articles in Principium 17 and 18 by Dmitry Novoseltsev, *Engineering New Worlds: Creating the Future* – and in Principium 32 by David Gahan, *AMiTe Treffpunkt - A proposal for communication between Kardashev Type IIb civilisations*.

The topic will no doubt challenge some of our best minds for some time to come. Even if a positive is achieved there will be remaining questions and issues to address.

[2] Sagittarius A, the supermassive black hole at our galactic centre

[1] They cite Bueno de Mesquita et al, *An Institutional Explanation of the Democratic Peace*, The American Political Science Review, V93, 1999

[3] c=300,000 km/sec so 0.002c is 600 km/sec. Contrast the speed of the Voyagers on their very long interstellar journey, 15-17 km/sec

Why We Don't See ETI Super-AIs

In *A Solution to the Fermi Paradox Based on Adaptations and Diminishing Returns: On What Super-AIs Are Like and Why We Don't See Them* (osf.io/bq438/), Daniel Vallstrom suggests that evolving AIs will be subject to the same cooperative evolutionary pressure as biological entities. He also suggests that diminishing returns from increased access to material resources may mean that there will be no incentive to colonise entire galaxies, thus providing a possible explanation of the Fermi paradox. He invokes Planck's principle in the sociology of scientific knowledge, parallel to and predating Kuhn's "paradigm shift" ideas, and simply saying that progress occurs when the proponents of defunct theories simply die [1]. He also references ideas in economics such Nash's game theory and morality including the ethics of vegetarianism (for biological beings of course!). He suggests that there is little to be gained from expansion beyond a certain point where diminishing returns accrue from further expansion so Kardashev progression does not occur [2]. He also sees no "payoff" for communication with lesser intelligences (presumably including our own).

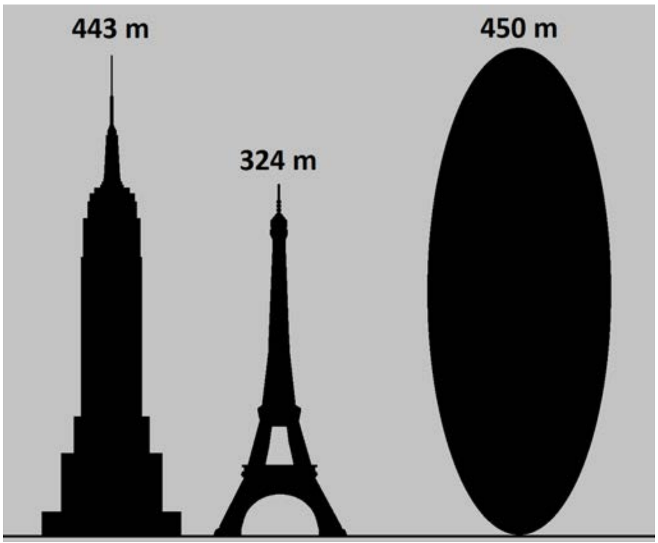
No laser signals from Alpha Cent A or B

G W Marcy of the Center for Space Laser Awareness, Santa Rosa, California suggests that "Speculative models of the Milky Way Galaxy include communication networks composed of transmitters, receivers, and nodes stationed near and between stars" and cites references from Bracewell 1973 to Hippke 2021 [3]. Marcy has conducted a search for laser light from the directions of Alpha Centauri A and B using spectra gathered between 2004 and 2018 but found no laser emission lines in *A Search for Optical Laser Emission from Alpha Centauri AB* (Monthly Notices of the Royal Astronomical Society, October 2022 (academic.oup.com/mnras/article/516/2/2938/6668809).

The data included 15 056 spectra of Alpha Cen B and 306 spectra of Alpha Cen A, from the HARPS spectrometer between 2004 and 2018, available on the European Southern Observatory (ESO) public data archive (archive.eso.org). He says that his criteria would have revealed optical laser light from the directions of Alpha Cen B if the laser had a power of at least 1.4-5.4 MW and of three times that for Alpha Cen A. The conclusion is that "... a growing desert is emerging in the search for extraterrestrial technology."

Laser sailcraft for PHO and ISO missions

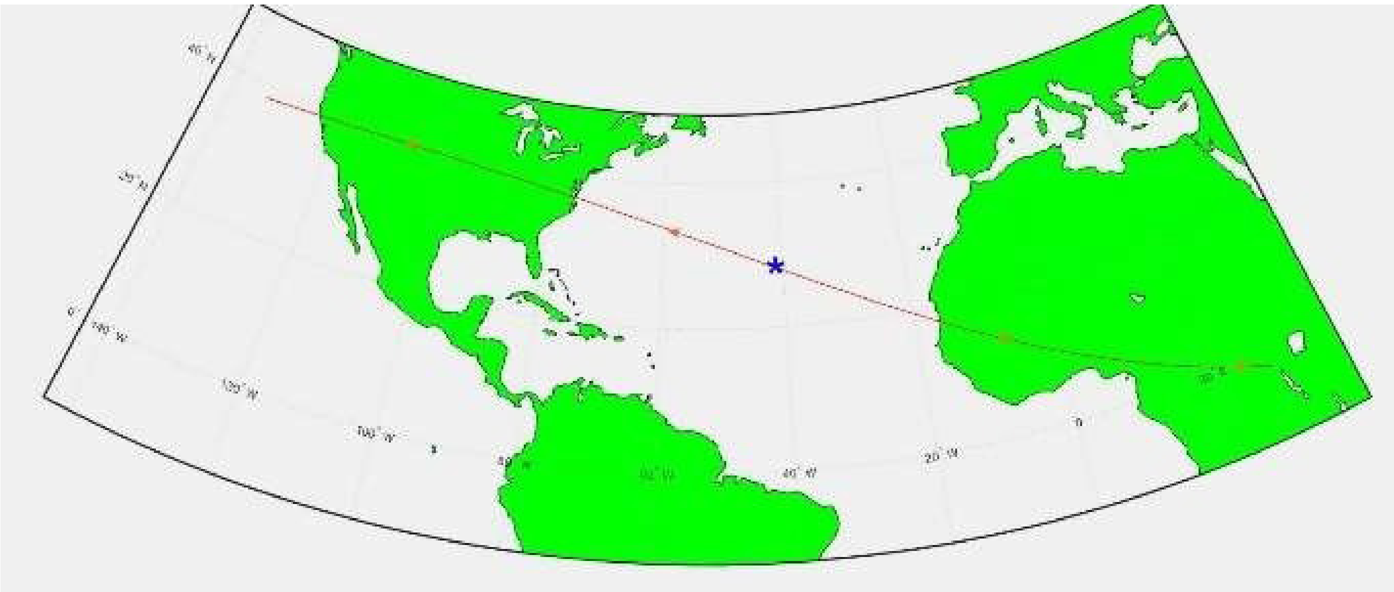
A recent paper *Sailing to Apophis LPSC-2016* [4] by a team, mainly of i4is researchers, demonstrates that using laser-driven light-sail probes to implement quick-reaction missions to intercept potentially hazardous objects (PHOs) approaching Earth would be a cost-effective alternative to keeping a fuelled rocket with a conventional probe on standby. The team suggest an initial test of this capability using the upcoming close approach of Asteroid 99942 Apophis. Apophis is a near-Earth asteroid 450 metres in size that will harmlessly pass close to Earth on April 13, 2029 [5]. Apophis will pass approximately 30,000 km from Earth, traveling approximately 7,400 m/s at closest approach, taking about 12 hours to cross the Moon's orbit. So it will be will within geostationary altitude. Not to "freeze the blood" but this is a big object!



Credit: Phoenix CZE/Wikipedia

[1] Contrast Popper's concept of conjecture and refutation and consider the possible counter example to Planck, that of Continuous Creation cosmology which died out years before its principal proponent, Fred Hoyle.
[2] For thoughts in this see the series *Engineering New Worlds: Creating the Future* by Dmitry Novoseltsev in Principium issues in Principium 17, May 2017 and Principium 18, August 2017
[3] Bracewell *The Opening Message from an Extraterrestrial Probe*, Astronautics & Aeronautics. 11: 1973 and Hippke *Interstellar communication network. III. Locating deep space nodes*, arxiv.org/abs/2104.09564
[4] *Sailing to Apophis LPSC-2016*,, William Paul Blase (DCS Corporation), Marshall Eubanks (Space Initiatives Inc and i4is), Adam Hibberd (i4is), Robert G Kennedy III (Tetra Tech and i4is), A M Hein (i4is) , May 2022, www.researchgate.net/publication/361730796
[5] NASA information at solarsystem.nasa.gov/asteroids-comets-and-meteors/asteroids/apophis/in-depth/

Apophis Groundtrack Earth Encounter 2029 April 13th
(* = Perigee of Apop1his at 31653km, 21 h 45m 21s UTC)



Apophis trajectory during encounter. Ground track is from right to left and will proceed over possible launch sites in Virginia 42 minutes after perigee, and sites in Colorado and the Western US during the next 40 minutes
Credit (image and caption): Blase et al

Two sailcraft would be launched on a Black Brant sounding rocket; one to be released at 75 km altitude – the minimum altitude at which the laser could still overcome atmospheric drag, the other at the rocket's maximum altitude of 1,500 km. The laser would then thrust each probe in succession to 30,000 km apogee, timed to bracket the asteroid's pass so that one probe encounters it while falling back to Earth, the other while ascending. Both probes would acquire images and data from Apophis during their pass. One probe would be timed to impact Apophis so that the second probe could acquire data on the resulting debris plume. The impacting probe could also carry a hardened and cushioned transponder to enable future tracking of the asteroid. Both launches could be from US launch sites. The ground track lies across the continental USA and Africa.
They propose a solid-sail approach in which the sail is a solid body, albeit made from ultra-light materials, with the entire rear surface being the reflective sail element and the electronics mounted on the forward layer. These are sounding rocket launches and in the subsequent trajectory the data-acquiring probe would be light enough to decelerate to relatively slow speeds in Earth's thermosphere and then fall slowly to the Earth's surface for retrieval. Initial calculations show the probe as described can be driven to the required apogee at 30,000 km using a drive laser at a wavelength of 1,064 nm (which readily penetrates the atmosphere and is currently available with industrial fibre lasers) and a total drive beam intensity of 17 MW (industrial electric furnaces routinely consume at more that ten times this rate).
Also worth a look is *To The Kuiper Belt! Solar System Precursor Missions with Solar and Laser-Driven Sailcraft* [1], by the same authors. Sailcraft are our (immediate) future for these ambitious missions; Hard to reach with reaction propulsion but feasible relatively short term using early and not-too-demanding laser propulsion.

[1] *To The Kuiper Belt! Solar System Precursor Missions with Solar and Laser-Driven Sailcraft* (presented at the Breakthrough Initiatives, "Sundiver" workshop, University of Luxembourg, where Andeas Hein is Associate Professor of Space Systems Engineering) www.researchgate.net/publication/360937695_To_The_Kuiper_Belt_Solar_System_Precursor_Missions_with_Solar_and_Laser-Driven_Sailcraft

NIF 2021 record yield shot

Three peer-reviewed papers highlight the scientific results of a National Ignition Facility (NIF) record yield shot on 8th August 2021 (www.llnl.gov/news/three-peer-reviewed-papers-highlight-scientific-results-national-ignition-facility-record) .

Given the ultimate energies promised for this technology the chief scientist for the Lawrence Livermore National Laboratory inertial confinement fusion program seems appropriately named - Omar Hurricane. He said "The record shot was a major scientific advance in fusion research, which establishes that fusion ignition in the lab is possible at NIF."

This is inertial confinement fusion as in BIS Project Daedalus and some of its successors. Perhaps we are just a little closer to propulsion to take big payloads to the stars (and much faster transit around our solar system)?

The papers cited are -

Lawson Criterion for Ignition Exceeded in an Inertial Fusion Experiment, H Abu-Shawareb et al. (Indirect Drive ICF Collaboration) Phys. Rev. Lett. 129, 075001 – Published 8 August 2022 journals.aps.org/prl/abstract/10.1103/PhysRevLett.129.075001
Open publication at - researchgate.net [1]

Experimental achievement and signatures of ignition at the National Ignition Facility, A B Zylstra et al. Phys. Rev. E 106, 025202 – Published 8 August 2022, journals.aps.org/pre/abstract/10.1103/PhysRevE.106.025202
No open publication found

Design of an inertial fusion experiment exceeding the Lawson criterion for ignition, A L Kritcher et al. Phys. Rev. E 106, 025201 – Published 8 August 2022 journals.aps.org/pre/abstract/10.1103/PhysRevE.106.025201
Open publication: journals.aps.org/pre/abstract/10.1103/PhysRevE.106.025201

Overview of The Galileo Project

Professor Avi Loeb is a distinguished astrophysicist, former head of astronomy at Harvard and chair of the Advisory Council of Breakthrough Starshot. His ideas about alien object in the solar system are radical and he has published a book, *Extraterrestrial: The First Sign of Intelligent Life Beyond Earth* - which suggested an artificial origin for the first observed interstellar object (ISO) 1/'Oumuamua, We reviewed this in P33, last year. In our last issue we reviewed the comprehensive survey, *Life in the Cosmos: From Biosignatures to Technosignatures*, by Manasvi Lingam and Avi Loeb. In P35 last year we had a News Feature, *Loeb on an Artificial Origin for `Oumuamua*.

This latest paper, *Overview of The Galileo Project*, arxiv.org/abs/2209.02479, by Prof Loeb is an overview of his Galileo Project, a scientific research programme to search for extraterrestrial equipment near Earth. He suggests that "Taking the path not taken, it is likely to pick some low-hanging fruit."

He describes it as "a fishing expedition" whose results would be primarily natural and human-made objects. He hopes and expects to find objects that appear to be of non-human but artificial origin. He aims to use novel instruments to monitor the sky in the optical, infrared and radio bands, as well as in audio, magnetic field and energetic particles signals to be analysed and catalogued by artificial intelligence. He quotes Sherlock Holmes "When you have eliminated all which is impossible, then whatever remains, however improbable, must be the truth." (from *The Sign of Four*). In the short term he plans an expedition to retrieve the fragments of a meteor, believed to have been an ISO [2] from the ocean floor in an attempt to determine its composition and structure. He proposes planning for a mission to rendezvous with "the next 'Oumuamua" (though he appears to take no note of ideas from i4is Project Lyra and others to intercept 1/'Oumuamua itself). He believes that the instruments developed by the Galileo Project will "represent a brand-new observatory design with unprecedented capabilities".

[1] www.researchgate.net/profile/Aaron-Fisher-2/publication/364331337_Lawson_Criterion_for_Ignition_Exceeded_in_an_Inertial_Fusion_Experiment/links/6349a8a62752e45ef6b7c93f/Lawson-Criterion-for-Ignition-Exceeded-in-an-Inertial-Fusion-Experiment.pdf
[2] CNEOS_2014-01-08 (en.wikipedia.org/wiki/CNEOS_2014-01-08)

Testing the light-sail scenario for an ISO

In a new paper *Observable tests for the light-sail scenario of interstellar objects*, arxiv.org/abs/2208.13818, Wen-Han Zhou, Université Côte d'Azur, and colleagues from China and the USA, examine the idea that the first observed interstellar object (ISO), 1I/`Oumuamua, is a light sail. They also aim to characterise future ISOs using similar techniques. They suggest that the drift of a freely rotating light sail in the interstellar medium would be about 100 AU even if the travel distance is only 1 parsec (one parsec is about 200,000 AU or 3.26 light-years). They also suggest that a tumbling light-sail would be most unlikely to be visible in all 55 observations spread over two months after discovery and that radiation pressure could cause a larger displacement that is normal to the orbital plane for a lightsail. All these factors are at odds with actual observations of 1I/`Oumuamua. In short, they conclude that `Oumuamua is a very odd object but it is not odd enough to be a lightsail.

Search for an Alien Message to a Nearby Star

In this paper [1] Michaël Gillon (University of Liège), Artem Burdanov (Massachusetts Institute of Technology) and Jason T Wright (The Pennsylvania State University) suggest that if alien probes have colonised the whole galaxy, they could have formed an efficient galactic-scale communication network by establishing direct gravitationally lensed links between neighbouring systems. If so it could make it possible to eavesdrop on the emission of local probes to one of these stars from positions opposite the nearest ecliptic stars and thus this is a promising artifact-seeking SETI strategy. The authors hypothesise alien Focal Interstellar Communication Devices (FICDs) discoverable in our solar system.

The paper cites related work from Rob Swinney and Pat Galea in 2011, *Project Icarus: Mechanisms for Enhancing the Stability of Gravitationally Lensed Interstellar Communications*, P Galea & R Swinney JBIS v64, p. 24-28), and Rob will be commenting in more detail on this work in our next issue.

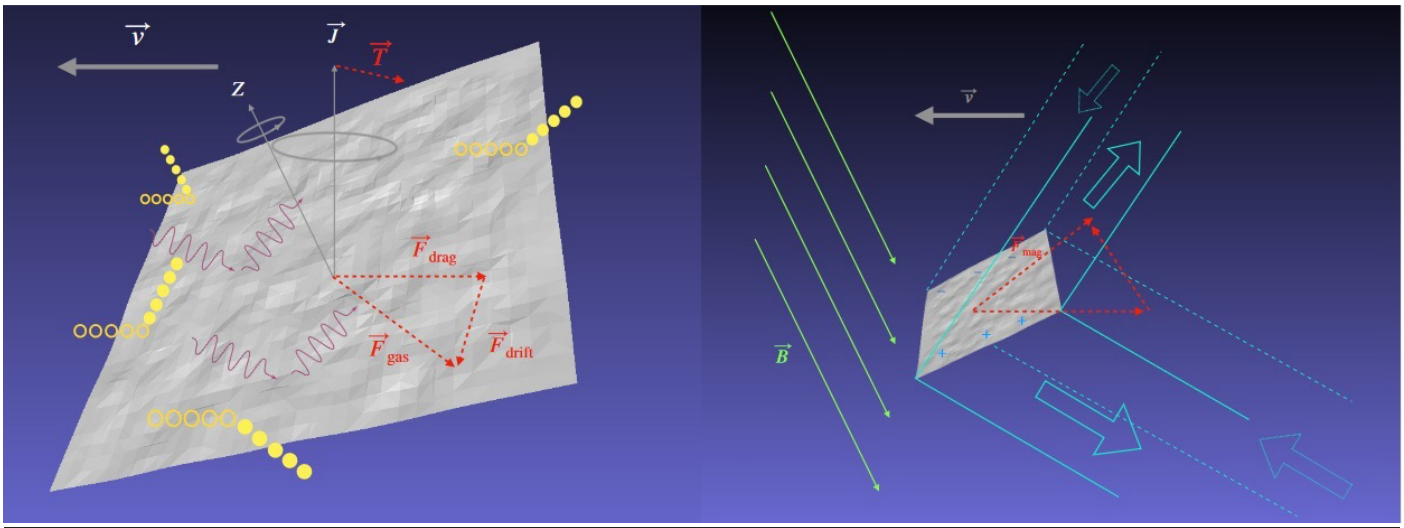


Fig 1. Schematic illustration of the hydrodynamic (left panel) and magnetic (right panel) drag on a moving light sail in a turbulent ISM with a magnetic field, B (green). The tumbling sail is represented by a thin gray sheet with a bumpy surface and a spin axis in the Z direction that precesses around its angular momentum, J, axis.
Credit (image and caption): Zhou et al

[1] *Search for an Alien Message to a Nearby Star* The Astronomical Journal, Volume 164, Number 5, 27 October 2022, iopscience.iop.org/article/10.3847/1538-3881/ac9610/pdf

Frank Drake 1930-2022

We were sad to hear of the passing of Frank Drake - May 28, 1930—September 2, 2022. However, 92 years is a "good innings" as we in the cricket-playing nations put it. He was one of the very few true pioneers of SETI. His famous equation gives us all a very useful "rule of thumb" for the likelihood of meeting any interstellar neighbours -

"The number of detectable civilisations in the Milky Way galaxy = the rate at which stars are born * the fraction of stars that host planets * the number of habitable planets per planetary system * the fraction of those planets on which life evolves * the fraction of life that evolves intelligence * the fraction of intelligent life that develops communicative technologies * the average length of time civilisations are detectable."

Drake just missed the Second World War but was briefly an engineer officer in the US Navy as part of his engineering physics degree at Cornell University. A PhD in astronomy at Harvard followed. He was at Green Bank observatory for most of his career. Later he was at the University of California at Santa Cruz and was a founder of the SETI Institute.

Drake, the man and the astronomer, is captured fondly by his daughter, Nadia, a science journalist, in *My dad launched the quest to find alien intelligence. It changed astronomy.* (www.nationalgeographic.com/science/article/father-launched-quest-find-alien-intelligence-changed-astronomy).

Frank and Nadia Drake at the Green Bank Observatory in 2016. Behind them is the 85-foot Tatel Telescope, which Frank used to conduct Project Ozma—the first modern scientific search for communicating extraterrestrials—in 1960.
Credit (image): Nadia Drake.
Credit (caption): nationalgeographic.com

Our team had only fleeting encounters with Drake.

Marshall Eubanks recalls meeting him several times towards the end of his life, and he was always kind, gracious, and quick to include the young researchers in NASA's NIAC, and other meetings, in his discussions. He had a good sense of humour and was a good comrade in after-meeting conversations in the bar.

Andreas Hein recalls the impression he gave at a Breakthrough Discuss in 2019 at UC Berkeley - relaxed and definitely not aloof.

If our species is to reach the stars then an encounter with ETI would perhaps be the greatest milestone - whether it occurs before or after. *Nature* remembered him "He showed Earth that SETI was possible and practical, and embraced the idea that the most fascinating science might not yield results in one person's lifetime www.nature.com/articles/d41586-022-02962-8.

News Feature - The Third i4is Summer School at the Royal Institution

John I Davies

i4is has been delivering education outreach to both adults and young people since its birth, nearly 10 years ago. Just this year we have worked with schools in both UK and USA - and in earlier years we have also reached much further – examples include Nigeria and Viet Nam. Also this year we have briefed astronomical societies in the UK and in earlier years venerable institutions like the Bath Royal Literary and Scientific Institution. The jewel in our outreach crown is the Royal Institution, Faraday's workplace and the source of the famous Christmas lectures (www.rigb.org). This is an account of our latest work with them and where it originated. If you know an organisation, school or college which would like to know more about things from the maths of rockets to the challenges to interstellar travel and communication - and from the issues arising from the discovery of interstellar objects (ISOs) in our solar system to the challenges of reaching them – then get in touch via our ubiquitous email address, info@i4is.org. We are always listening on that frequency!

The Royal Institution Library with members of the i4is team 2022. Terry Regan and Khemare Chung in the foreground and Rob Swinney pointing to the i4is banner in the background.
Credit: Satinder Shergill

1 Introduction

On 25th and 26th August 2022, a team from i4is delivered the third i4is Summer School at the Royal Institution, London. We call it *Skateboards to Starships*. Our organisation has been delivering education and information about our objectives and technologies and the work of all who share the goal of reaching out to the stars. Back in 2016 (which feels like just after the Stone Age in these changing times) the i4is education team and STEM Learning Ltd (a UK government initiative - www.stem.org.uk) delivered an *Interstellar Challenge for London Schools* at Imperial College London [1]. Our primary partner at STEM Learning was Aasiya Hassan. Aasiya subsequently moved to the Royal Institution as Engineering Masterclasses Coordinator and, in the following year, put us in touch with her colleagues to discuss a possible session on the mathematics of rocketry. For various reasons this did not happen but later that year Aasiya [2] invited us to a Masterclass taster event and after some discussion we were asked to deliver our proposed *Skateboards to Starships* on 20 August 2018. This initial student group was to ages 13-15. This was successful enough for the RI to invite us back in 2019 to deliver two classes for ages 13-15 and 16-18 (the latter is often called Sixth Form in the UK and the stage just before university entrance). An unfortunate world biological problem made 2020 and 2021 quieter years for the Royal Institution but once things had calmed down a little, we were invited back this year, 2022. This is the story of what we have delivered to the Royal Institution, a pinnacle of science outreach in the UK and a world-renowned institution since the days of Michael Faraday. Its Royal Charter was granted in 1800 and a very brief history follows.

2 The Royal Institution

The Royal Institution of Great Britain (RIGB) dates back to a meeting at the Soho Square house of the President of the Royal Society of London (founded 1660), Joseph Banks, on 7 March 1799. Its Christmas lectures have been running since 1825 and it was the base for the science discoveries and engineering inventions of Michael Faraday from around the same time until 1860 just before his death in 1867. Today it operates by its motto "Science Lives Here". If you get the chance to visit, make sure you look into the beautiful main lecture theatre and the library (as on the opening page of this article), where our i4is Summer Schools were delivered this year.

3 The First Two Summer Schools

3.1 2018

In May 2017, Aasiya Hassan, Royal Institution (RI) Engineering Masterclasses Coordinator, contacted us to put us in touch with her colleague, Secondary Maths Masterclass Coordinator Dominique Sleet. We attended a briefing session at the RI and discussed a session based on Tsiolkovsky's Ideal Rocket Equation, why it matters and how to derive it from Newton's second law. However turning this from a one-hour school session to a full day proved too heavy a workload for i4is at the time. The following February 2018 we attended a Masterclass taster event and made contact with Peter Gallivan, RI Family Programme Manager. This led to our proposal for a whole day Summer School, Skateboards to Starships for school students age 13-15 for August of 2018. Aasiya continued to be our prime RI contact through to June that year [3].

Satinder Shergill, an old contact of ours at Space Studio West London (www.spacestudiowestlondon.org/) got involved in April and soon became an equal partner with John Davies. Having an experienced physics teacher from a space-oriented school who was also doing a space-based PhD at Cranfield University made an enormous difference to both the content and delivery of this, our first RI Summer School.

[1] See *Interstellar Inspiration for School Students: The i4is Interstellar Challenge*, Principium 19, November 2017, i4is.org/principium-19/

[2] Aasiya is now at BDSIP, bdsip.co.uk/, a UK educational support not-for-profit where she is Head of Careers, Higher Education and Work Experience.

[3] The RI listing for this at www.rigb.org/whats-on/events-2018/august/summer-schools-skateboards-to-starships-age-1315.

The i4is team included principal presenters Satinder Shergill and John Davies with Rob Matheson and Terry Regan provided practical support dealing with much of this highly interactive show [1].

The Summer School was well received and we were invited back the following year.

3.2 2019

In 2019 Peter Gallivan again asked us to run *Skateboards to Starships*, and we agreed an extra day to deliver to an older age group, ages 16-18. For this group Satinder added a major component covering orbital dynamics showing how patched conics and the Hohmann transfer defined the trajectory of a mission to Mars and more about fusion propulsion. We were again supported by Rob Swinney [2] and Rob Matheson– but Terry Regan could not make it due to work priorities.

After the Summer School the team adjourned to the local pub to celebrate.

Satinder explains a point at *Skateboards to Starships 2018*. Credit: Rob Matheson

The two 2019 Summer Schools were again well received and we were discussing delivery in the following year when the virus which afflicted us all came upon the world and the RI closed its in-person outreach activities.

The 2019 team, Satinder Shergill, Rob Matheson, John Davies and Rob Swinney

[1] Rob Matheson was at the UK Government Department of International Trade. He is now Head of Spaceflight Economics at the UK Space Agency. Terry is the i4is ace model builder. His "day job" is heavy freight vehicle maintenance – a true practical engineer

[2] Rob Swinney was and is Director of Education for i4is. He is a former engineering officer, Squadron Leader, in the Royal Air Force.

4 The Third i4is Summer School 2022

This year's Summer School followed a two-year gap as a result of that virus you may have heard of. Once

Skateboards to Starships 2019. John Davies explains how Freeman Dyson's team proposed a fast spacecraft powered by hydrogen bombs!

Credit: Rob Swinney

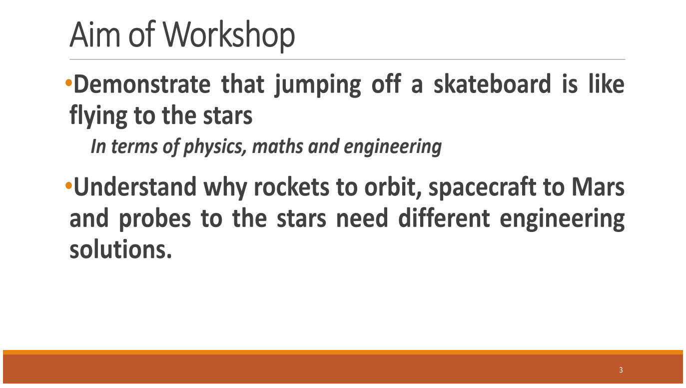
the Royal Institution returned to (more or less) normal they invited us again to deliver two consecutive days for a 13-15 age group and a 16-18 age group.

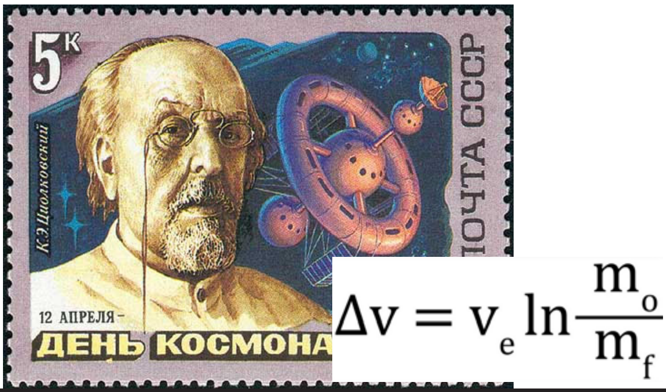
The team this year consisted of our two main presenters, Satinder Shergill and John Davies, Rob Swinney, who presented the fusion propulsion section [1] and, supporting the practical work, Terry Regan and Khemare Chung – a former school student of Satinder, now studying aerospace at Southampton University.

[1] Rob was Project Director of Project Icarus. This was an update of Project Daedalus supported by the BIS and the US Tau Zero Foundation. The most developed of several studies arising from that was Icarus Firefly, described in *Reaching the Stars in a Century using Fusion Propulsion*, by Patrick Mahon. This was in Principium 22 i4is.org/principium-22. The article can also be read online at i4is.org/reaching-the-stars-in-a-century-using-fusion-propulsion/

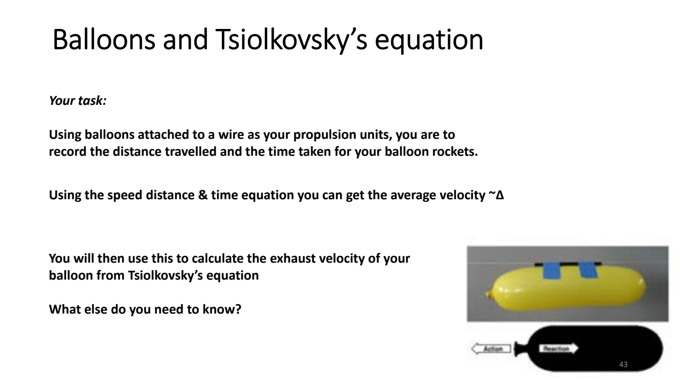
4.1 The Presentations

Here are some samples from this year's version of *Skateboards to Starships*

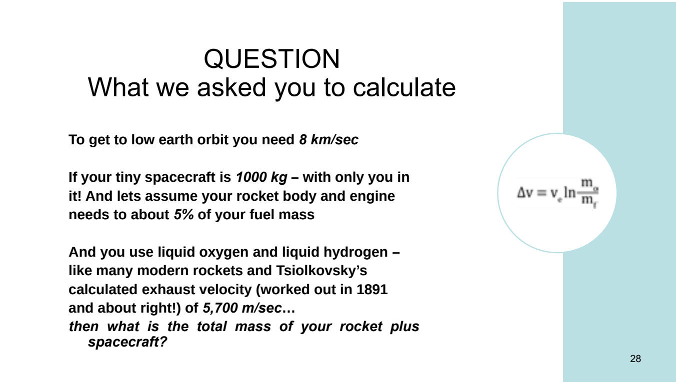




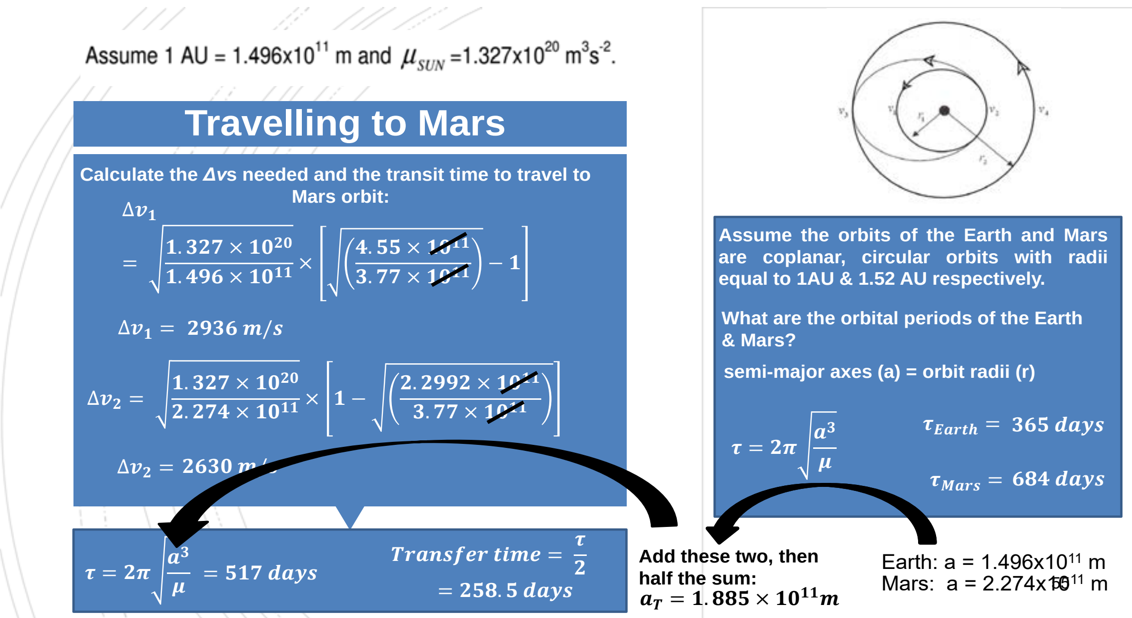
Konstantin Eduardovitch Tsiolkovsky and his Rocket Equation



the Balloon Rockets experiment – the problem to solve [1]

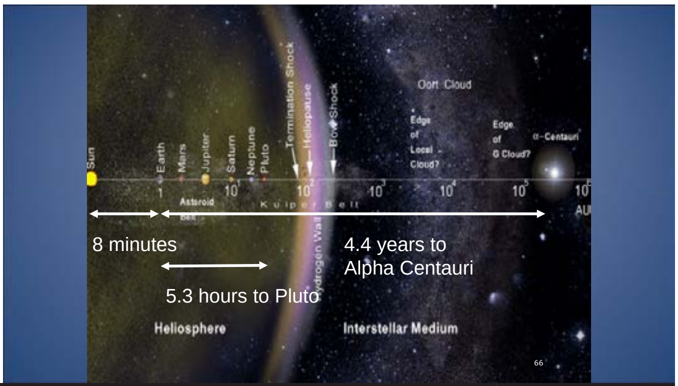


How much fuel do you need to get into orbit? This is a slightly trickier one since the rocket body and engine mass varies with the fuel mass. But we only asked for an approximation [2].

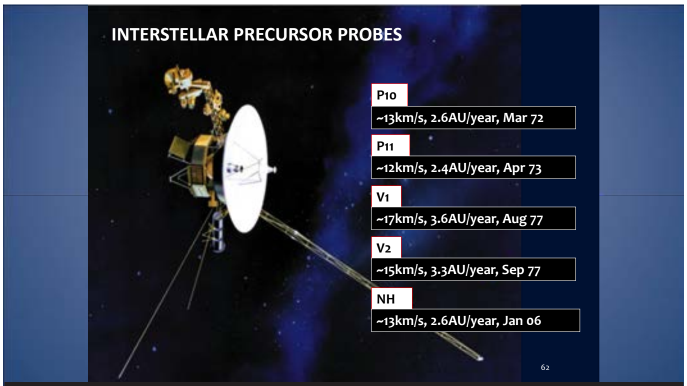


Travelling to Mars (16-18 Group). A challenging problem to take away…

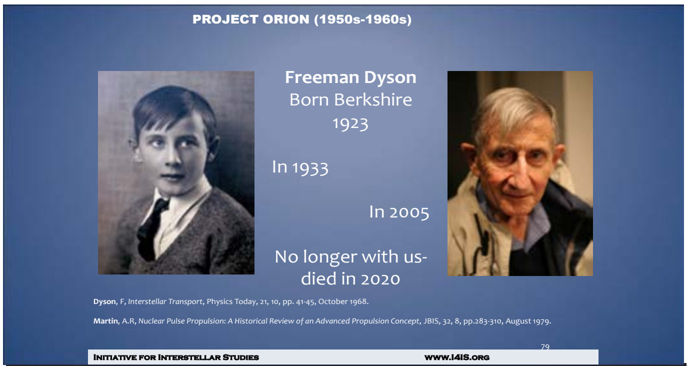
[1] To set up the balloon rocket experiment we used portable coat racks about 1.8 metres high and 3-4 metres apart. We attached 3 lines between them so that three teams at a time could do a few balloon runs each.
[2] The results obtained by the students were remarkable. See *4.2 The Balloon Exhaust Velocity Experiment* below



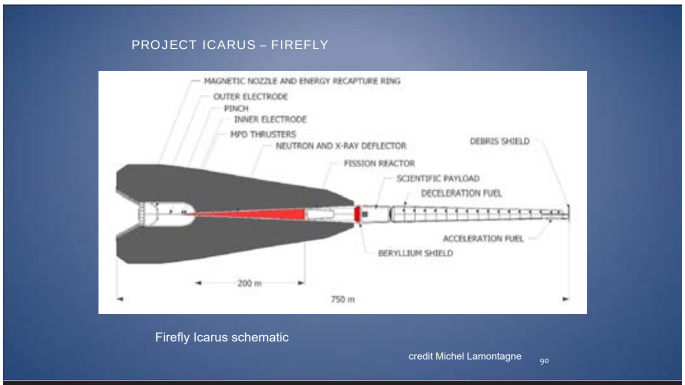
It's a long way to Alpha Centauri



How far and how fast have we gone so far?

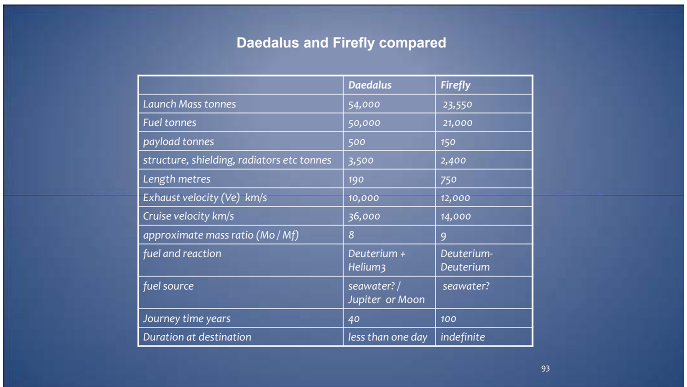


Freeman Dyson – hydrogen bomb propulsion, Dyson spheres – and lots of physics and pure maths [2]



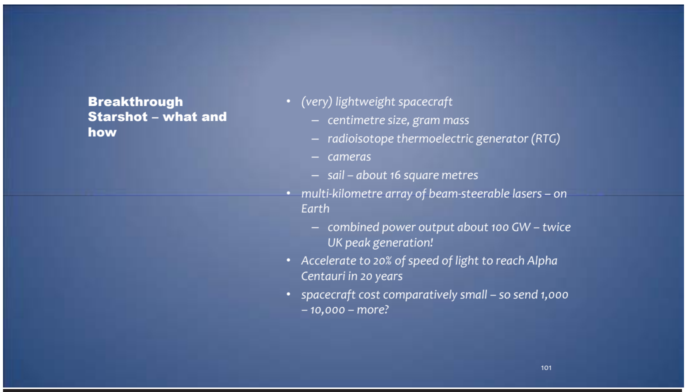
The Icarus Firefly fusion-propelled probe

Major components and dimensions



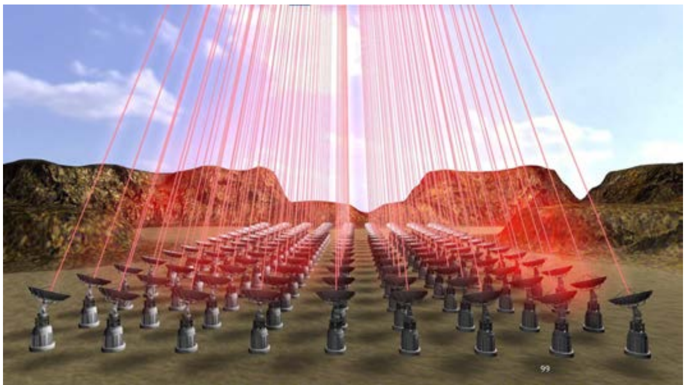
	Daedalus	Firefly
Launch Mass tonnes	54,000	23,550
Fuel tonnes	50,000	21,000
payload tonnes	500	150
structure, shielding, radiators etc tonnes	3,500	2,400
Length metres	190	750
Exhaust velocity (Ve) km/s	10,000	12,000
Cruise velocity km/s	36,000	14,000
approximate mass ratio (Mo / Mf)	8	9
fuel and reaction	Deuterium + Helium3	Deuterium-Deuterium
fuel source	seawater? / Jupiter or Moon	seawater?
Journey time years	40	100
Duration at destination	less than one day	indefinite

Fusion-propelled probes -
Daedalus vs Firefly What are the pros and cons?



Breakthrough Starshot – the numbers

[1]
[2] .
[3]



Breakthrough Starshot – the laser array visualised

Star Trek may take a lot longer!

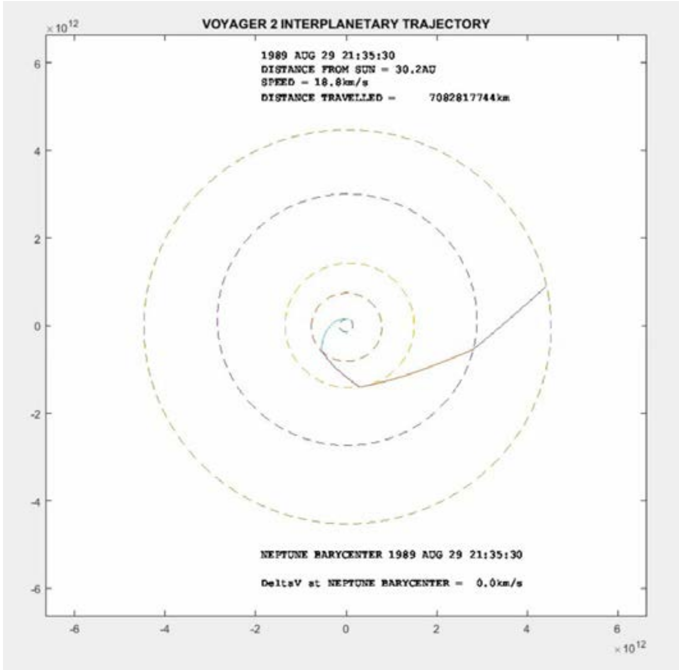
[1] *Freeman J. Dyson (1923–2020), Scientist and Writer, Who Dreamt Among the Stars, Dies at 96* https://www.ias.edu/press-releases/2020/freeman-j-dyson-1923%E2%80%932020

The slides were delivered to all the students in a PDF file after the workshop - via the Royal Institution.

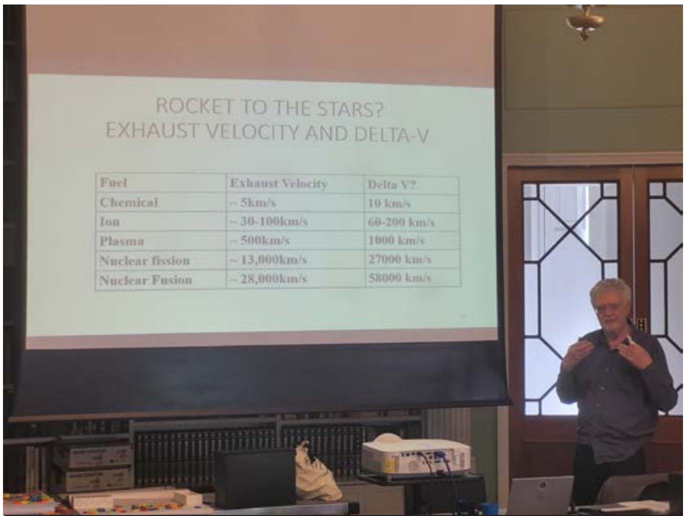
4.2 Skateboards to Starships

On the day -

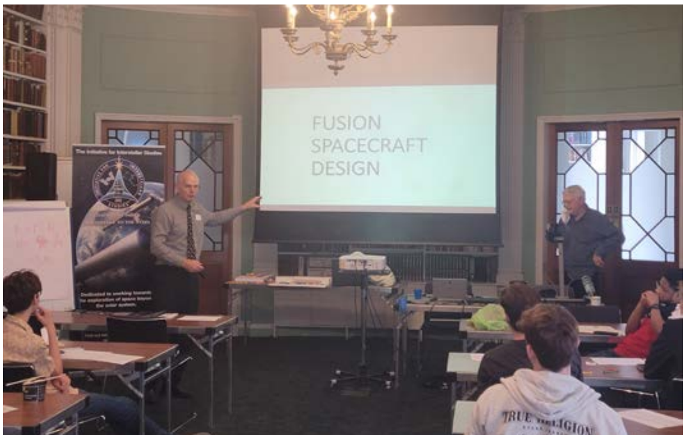
John shows an animation of a Voyager trajectory. Illustrating the gravitational slingshot to the 16-18 group. Credit: Satinder



Voyager 2 interplanetary trajectory – animation illustrating the gravitational slingshot



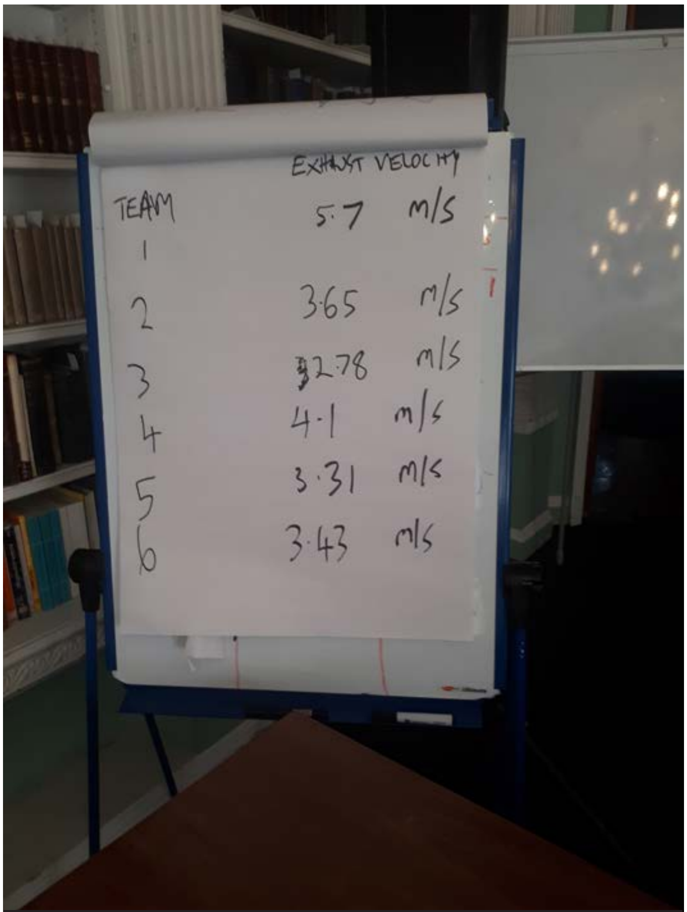
John explains how rocket fuels, chemical to fusion, deliver different exhaust velocities. Credit: Rob



Rob introduces fusion propulsion as the powerful way to fuel rockets

John introduces the Breakthrough Starshot project for a laser sail interstellar probe. Credit: Rob

Satinder introduces the 16-18 age group to Keplerian orbits. Credit: Rob



Balloon Ve values calculated by the six teams of the 13-15 group. Credit: Rob

4.2 The Balloon Exhaust Velocity Experiment

We asked the teams to compute the exhaust velocity of balloon rockets using the mass of air, the volume of the balloon, the flight time and the distance – plumbing the values into a transposed Tsiolkovsky rocket equation. The equation is ΔV = Ve*ln(Mo/Mf) where ΔV is velocity gained by the balloon, Ve is the exhaust velocity of the air coming out of the balloon, Mo is the mass of balloon+straw+air in the balloon and Mf is the balloon+straw as it finished its journey along the fishing line. We gave the teams the mass of balloon+straw and the density of air - so they could calculate the approximate mass of the expelled air by measuring the inflated balloon.

Teams had to transpose the equation to -

Ve = ΔV/ln(Mo/Mf)

- to work out Ve is the exhaust velocity of the air coming out of the balloon using the flight time of the balloon and the distance travelled to produce the ΔV, velocity gained by the balloon as a result of the expulsion of the air.

They came up with values 2.78, 3.31, 3.43, 3.65 and 5.7 metres per second. Inevitably differences in observation, the effect of friction between the straw (to which the balloons were taped) and the fishing line and, of course, air resistance - all are factors.

Not bad results for such a simple experiment!

As in previous years, the team adjourned to the pub after the second day's Summer School.

The team at the Royal Institution provided the usual RI excellent support. They were Sofi Tilahun, Richard Marshall and Peter Gallivan.

Get in touch (info@i4is.org)– we can deliver variants of both *Skateboards to Starships*, a highly interactive presentation and workshop with lots of physics, maths and engineering, or the *The i4is Interstellar Challenge for School Students*, a competitive team event covering not only physics, maths and engineering but also social issues, human biology, art and creative writing - the full STEAM package!

The building (top) and the people (below) about 1840. Credit: RIGB www.rigb.org/about-us

i4is 10th anniversary

The Initiative for Interstellar Studies founded 2012

In this, our 10th anniversary year, we are even more optimistic that our species will reach out to the stars in the foreseeable future - Initially via probes crossing the space to the nearest stars in timescales similar to existing deep space missions such as the NASA Voyagers and ultimately via presence in an ever-widening sphere. There are already no boundaries in principle to this and advances in technology will enable this to happen more quickly and our sphere of knowledge and presence to extend more widely.

Our team includes scientists, engineers and broader expertise both science- based and with a wider perspective extending to all the capacities and dreams of our species. We are working with academics, professionals, other institutions engaged in similar endeavours and the widest possible circle of humanity.

The Initiative for Interstellar Studies (i4is.org) was founded in the UK in 2012 and incorporated in 2014. The Institute for Interstellar Studies was founded and incorporated in the state of Tennessee, USA, in 2014. The two are legally separate but act as a single international organisation with board members in UK, USA. Luxembourg and Germany - and volunteers worldwide. Both organisations are registered as non-profit making companies, as a Company Limited by Guarantee in the UK and as a Public Benefit Corporation (Nonprofit Corporation - Domestic) in Tennessee, USA. The Initiative for Interstellar Studies is applying for Institute status in the UK.

Our activities are technical, scientific and educational and we also strive to promote a wider vision of humanity as a species going out into our solar system and into the galaxy beyond. More about all of this and the whole of Interstellar Studies in our quarterly Principium published free since our founding - all editions available free at (i4is.org/publications/principium/).

Our membership scheme was launched in 2019 with the objective of encouraging and reinforcing Interstellar Studies. Subscribing members receive several newsletters each year. They have access to early preprints of Principium draft articles, exclusive access to some of our online presentations and to our annual report. We are a low overhead organisation with all our core team working pro bono and members fees support necessary overheads such as web hosting, the Alpha Centauri prize and our technical, educational and outreach activities.

The next ten years will bring humanity closer to achieving an interplanetary culture and an interstellar outreach. The i4is will work with like-minded people and institutions to achieve this.

John I Davies

IAC 2022

72nd International Astronautical Congress 2022
The Interstellar Presentations - part 1

edited by John I Davies

This year the International Astronautical Federation held the 2022 International Astronautical Congress in Paris 18-22 September. Here is our first 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 40, in February 2023. Our reporters, for both reports, are Adam Hibberd, Al Jackson, Alan Cranston, Dan Fries, Graham Paterson, John Davies, Michel Lamontagne, Patrick Mahon and Samar AbdelFattah.

The reports include - Code - the unique IAC code, Paper title, Speaker, institutional Affiliation and Country. 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.

The Congress was divided into these main subject areas -

A1. IAF/IAA SPACE LIFE SCIENCES SYMPOSIUM

A2. IAF MICROGRAVITY SCIENCES AND PROCESSES SYMPOSIUM

A3. IAF SPACE EXPLORATION SYMPOSIUM

A4. 51st IAA SYMPOSIUM ON THE SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE (SETI) – The Next Steps

A5. 25th IAA SYMPOSIUM ON HUMAN EXPLORATION OF THE SOLAR SYSTEM

A6. 20th IAA SYMPOSIUM ON SPACE DEBRIS

A7. IAF SYMPOSIUM ON ONGOING AND NEAR FUTURE SPACE ASTRONOMY AND SOLAR-SYSTEM SCIENCE MISSIONS (this item was removed from the IAC22 website around 30 June 2022)

B1. IAF EARTH OBSERVATION SYMPOSIUM

B2. IAF SPACE COMMUNICATIONS AND NAVIGATION SYMPOSIUM

B3. IAF HUMAN SPACEFLIGHT SYMPOSIUM

B4. 29th 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. 20th IAA SYMPOSIUM ON BUILDING BLOCKS FOR FUTURE SPACE EXPLORATION AND DEVELOPMENT

D4. 20th IAA SYMPOSIUM ON VISIONS AND STRATEGIES FOR THE FUTURE

D5. 55th 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. 50th STUDENT CONFERENCE

E3. 35th IAA SYMPOSIUM ON SPACE POLICY, REGULATIONS AND ECONOMICS

E4. 56th IAA HISTORY OF ASTRONAUTICS SYMPOSIUM

E5. 33rd IAA SYMPOSIUM ON SPACE AND SOCIETY

E6. IAF BUSINESS 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

LBA. LATE BREAKING ABSTRACTS

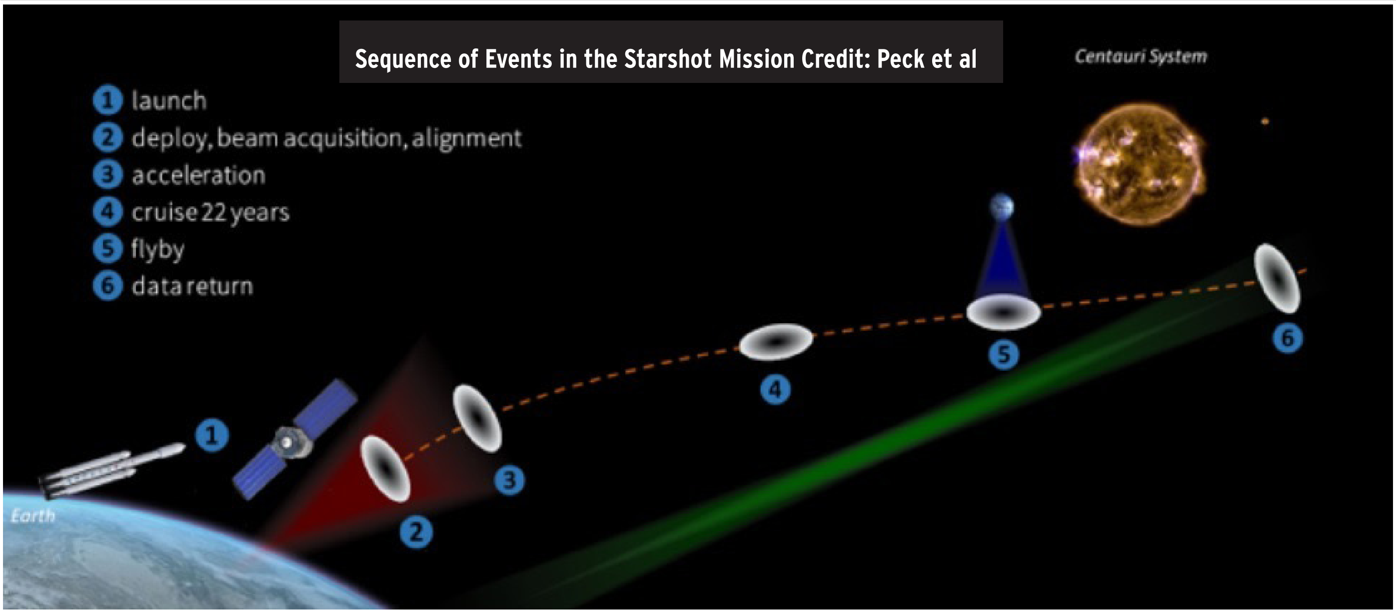
The Reports

In this issue-

More in our next issue.

◀ The Papers

IAF ref	title of talk/paper	presenter	institution	nation
C3,4,1,x73419	Power Requirements and Technologies for Gram-Scale Interstellar Spacecraft	Dr Mason Peck	Cornell University	USA



IAF abstract: iafastro.directory/iac/paper/id/73419/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/C3/4/manuscripts/IAC-22,C3,4,1,x73419.pdf title shown: *Power for Interstellar Lightsails*

IAF cited presentation/video: none cited

Open paper: none found

Reported by: John I Davies

Professor Peck's paper is co-authored by several core participants in Breakthrough Starshot, notably Dr Kevin Parkin (Systems Director, Breakthrough Starshot) and James Schalkwyk (Program Manager, Breakthrough Initiatives) – and contributors from Cornell, Princeton, UCSB, Arizona State and Howard Universities - also Caltech and NASA.

See also our summary in Principium 38 August 2022 page 37 (i4is.org/wp-content/uploads/2022/08/IAC-2022-Principium38-AW-2208290830-opt-3.pdf)

The paper identifies the three major technical elements of the baseline Starshot design now underway - the ground-based laser beamer, the lightsail's material and stability and the interstellar communications program element. To these it adds this fourth – onboard power (including energy storage) as part of the overall systems engineering approach (already exemplified in Parkin's earlier paper [1]). Studies now suggest that power and energy-storage technologies requiring concentrated mass are less viable than those that can be realised as distributed, low area-density masses and the current estimate of this mass-concentration limit is 90 mg. This precludes technologies that require dense components. Other issues identified include the requirements arising from the arrival propulsion needed to achieve a close pass of the target system, spindown from the interstellar configuration and possibility of an in-transit downlink to provide both reassurance and data to inform missions launched during the planned 20 year transit time (the base mission suggests a yearly re-orientation to achieve this). The team is studying in-transit power from both onboard (eg radioisotope thermal generator – RTG) or from interaction with the interstellar medium (ISM).

[1] *The Breakthrough Starshot system model*, Kevin L G Parkin, Acta Astronautica Vol 152 November 2018 parkinresearch.com/wp-content/uploads/2018/07/starshotmodel.pdf
[2] This presumably implies an approach distance of less than 2-3 AU or equivalent for the target star since current missions beyond that use inboard RTG power

▶

Approaching the target star the craft re-orients to capture solar energy [2]. The paper states that the interstellar communications system is likely to require the most power from the power subsystem. It summarised a minimum-power case (large communications apertures) and a maximum-power case (more modest apertures) in a table.

Communications system power requirements Credit: Peck et al, *Computational requirements categorised by subsystem function*

Max energy use	Min energy use
3×105mW h	120 mW h
1×106 J total energy	400 J total energy
Small transmit aperture: 0.1 m	Medium transmit aperture: 1 m
Medium receive aperture:	200 m
Large receive aperture:	1000 m

The paper emphasises that - in contrast to traditional satellite design - where total cost arises from budgets for mass, power, and cost of subsystems, for interstellar sailcraft, the cost of the sailcraft mass and power is driven by the very large capital cost of the beamer which thence sets the mass of the sailcraft and thus the performance of each component and function. An ideal design would distribute all functions across the largest and most massive element, the sail. In any case at least 90% of the mass budget needs to be allocated to the sail.

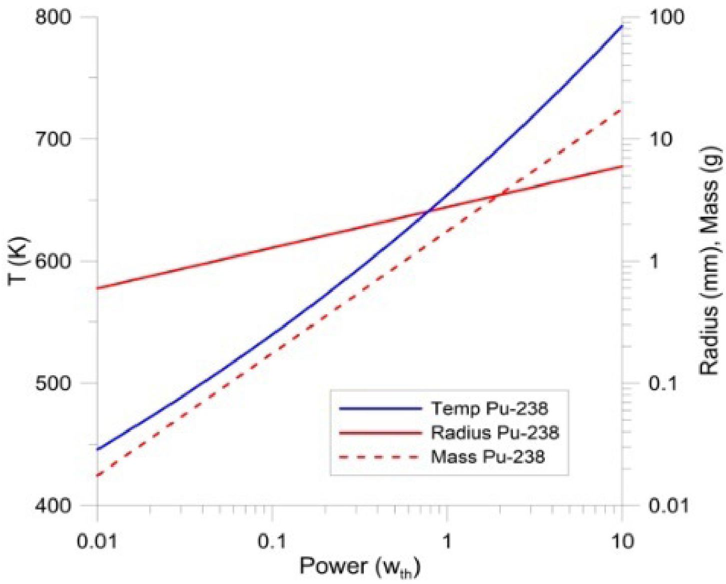
Computation requirements might be optimised by networking in a swarm of vehicles but this early study concentrates on a single craft as a baseline case. Data storage volume is critical here since the fly through will be very brief, 0.2c = 1.4 AU/hr, so much data must be stored and transmitted after fly through – and that on a challenging downlink [1].

Extrapolating technology to 2040 they expect a storage energy cost of around 0.4 µJ/bit (microjoule/bit). Other power demands include imaging (at minimum to meet the “take a snapshot” requirement), guidance, navigation, and attitude control.

They make the point that a passively superconducting storage technology could use the naturally cold ISM. The technical challenge is mainly physical damage from ISM impact. Other possibilities such as chemical or alpha/betavoltaic power would require major advances to meet the requirement.

Can power be obtained from the environment? Ions and/or electrons from ISM impacts might be collected or current induced in an on-board conductor. This would naturally have the desirable property of even mass distribution. The temperature gradient between areas with ISM versus areas with minimal impact could be harnessed.

On board power from a tiny RTG might be feasible and is being studied in detail by Prof Philip Lubin’s group at UCSD. This is, in principle, a scalable source but might still challenge the requirement for even mass distribution – and the scaling has limits as the team show in this diagram.



RTG - Temp, Radius, Mass vs Power
from Lubin 2021 - "The Path"

[1] See Principium 31, *The Interstellar Downlink*, i4is.org/wp-content/uploads/2021/08/The-Interstellar-Downlink-Principium31-print-2011291231-opt.pdf

They also considered energy from starlight, bioluminescence and microscale non-RTG nuclear though none look promising at this stage.

They suggest future research on power and energy storage across the most promising technologies they have identified, constrained by -

Requirements:

● Store >2 J

● Deliver >0.1 W

● >21 year lifetime

● Can be realised at <360 mg or 10% of the total

Additional guidelines that may influence solutions:

● Operates at <20 K

● Withstands > 10 GRad TID if face on or >200 rad TID if edge on

● Consistent with eventual sail structure design

● Consistent with flight mechanics (acceleration)

IAF ref	title of talk/paper	presenter	institution	nation
A3,4B,10,x70801	Mission architecture and spacecraft design for long-term contact studies of the interstellar asteroid 1I/Oumuamua	Dr Olga Bannova	University of Houston	USA

IAF abstract: iafastro.directory/iac/paper/id/70801/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A3/4B/manuscripts/IAC-22,A3,4B,10,x70801.pdf

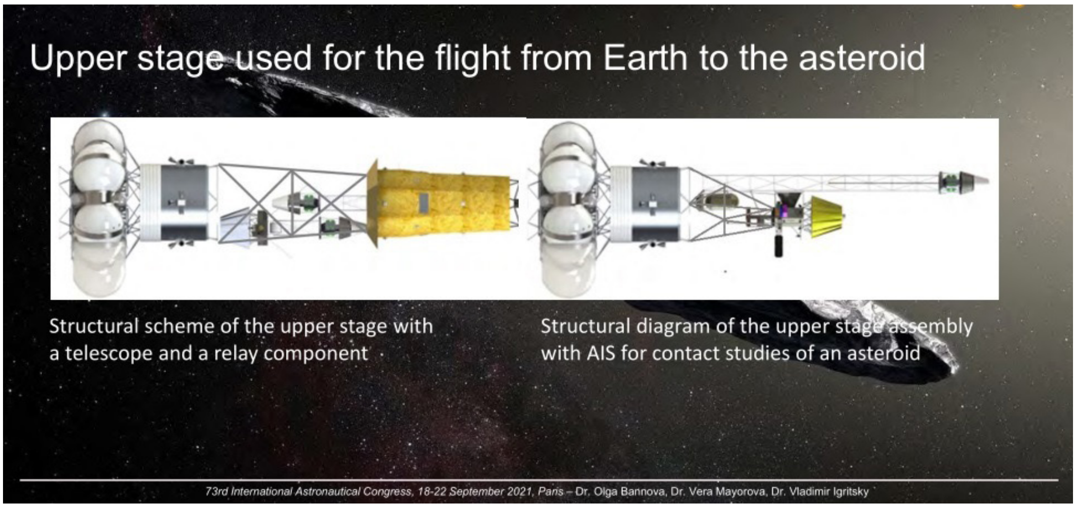
IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A3/4B/presentations/IAC-22,A3,4B,10,x70801.show.pdf

Open paper: none found

Other authors: Dr Vera Mayorova, Prof Vladimir Igritsky

Reported by: Adam Hibberd [1]

This is a report on a paper which is in itself a report on an explorative study to identify the architecture and systems necessary for what they term a ‘contact’ mission (ie rendezvous and robotic lander) to ‘Oumuamua, the first interstellar object to be discovered passing through our solar system. This study was performed by a team of international students from countries such as Russia, UK, USA, France and held at Bauman Moscow State Technical University.



The relay and telescope system and the AIS encounter vehicle. Credit: Bannova et al

[1] Adam has been the principal astrodynamicist for most of our i4is technical team papers under Project Lyra, a continuing programme investigating the interception and study of the interstellar object (ISO), 1I/'Oumuamua and of related ISOs and other challenging objects of interest.

Several spacecraft, each with different functions are envisaged -

Firstly a Space Telescope Spacecraft (STS) of mass 4.4 tons, in order to search for 'Oumuamua, with its consequential high positional dispersion as a result of the large proposed intercept distance.

Secondly a dedicated relay spacecraft, mass over 1.5 tons, would accompany the STS, presumably travelling along the same flight path as the STS and designed to convey STS data back to Earth with a High-gain antenna.

Thirdly an Automatic Interplanetary Station (AIS) would be required and would possess Xenon ion thrusters to slow the spacecraft down for a rendezvous with 'Oumuamua.

Close to 'Oumuamua a Space Net System would be utilised, and would encapsulate 'Oumuamua, allowing a spider robot lander to gain a good purchase on 'Oumuamua which would in turn enable activities such as drilling to be undertaken.

With a launch in 2026 and a Gravitational Assist of Jupiter, this is clearly a mission which is unlikely to be realised (the near-term launch and the lack of funding resources being the major factors for this).

Nevertheless, it is an ambitious and meticulously planned mission which no-doubt stretched the imagination and technical abilities of the students to the limit.

IAF ref	title of talk/paper	presenter	institution	nation
A4,1,12,x72537	Upper bounds on technoemission rates from 60 years of silence	Claudio Grimaldi	Ecole Polytechnique Fédérale de Lausanne	Switzerland / Italy

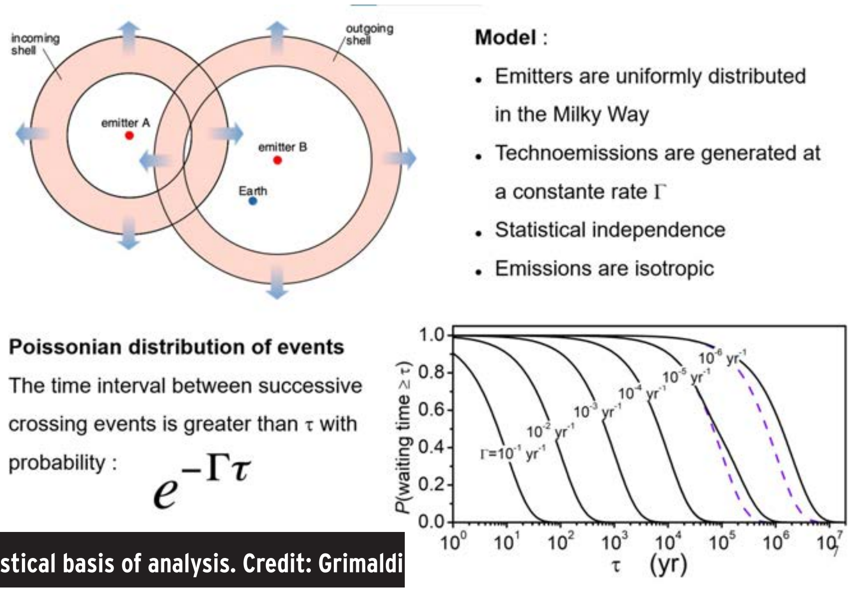
IAF abstract: iafastro.directory/iac/paper/id/72537/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A4/1/manuscripts/IAC-22,A4,1,12,x72537.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A4/1/presentations/IAC-22,A4,1,12,x72537.show.pptx

Open paper: none found

Reported by: John I Davies



Statistical basis of analysis. Credit: Grimaldi

No electromagnetic technosignatures have been detected in the 60 year history of SETI so far. Dr Grimaldi asserts that this must mean that we have incomplete sampling of the search space or that we cannot detect them because the Earth has been located during the entire history of SETI in a region of space not covered by artificial extraterrestrial emissions. Assuming a constant rate of transmissions he has derived probabilistic upper bounds and in the case of isotropic emissions, finds a 5% probability that there are more than one to five emissions per century that are generated across the entire Milky Way and shows that higher emission rates can only be derived if we assume that a significant fraction of all technoemissions are anisotropic – in randomly oriented narrow beams.

He produces an intermediate result which is independent of the average longevity of the emissions. His conclusion is guarded but pessimistic. Maybe the first of Clarke's twin hypotheses [1] is, in fact the case.

[1] "Two possibilities exist: Either we are alone in the Universe or we are not. Both are equally terrifying."

IAF ref	title of talk/paper	presenter	institution	nation
A4,1,10,x72939	Extragalactic SETI	Prof Mike Garrett	University of Manchester	UK

IAF abstract: iafastro.directory/iac/paper/id/72939/summary/

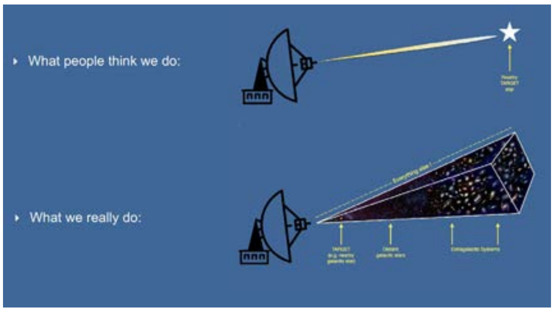
IAF cited paper: none given

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A4/1/manuscripts/IAC-22,A4,1,10,x72939.pdf

Open paper: arxiv.org/abs/2209.08147 *Constraints on extragalactic transmitters via Breakthrough Listen*, Garrett & Siemion, Sep 2022 – note this paper has also provided input to this report.

Reported by: John I Davies

Prof Garrett starts with a "reality check" on the scope of Breakthrough Listen [1].



He looks at nearby galaxies and is particularly interested in "exotica" including interacting galaxies and star forming regions, galaxy clusters, active galactic nuclei (AGN), radio loud galaxies and useful gravitational lenses. The Breakthrough Listen survey has a Full Width Half Maximum (FWHM) is 8.4 minutes of arc (60 minutes in a degree) and the Aladin New Edition shows 143,024 extragalactic objects within that field of view.

This includes –

- 17,810 point sources,
- 28,405 galaxies,
- 87,841 Infrared sources,
- 44 QSOs,
- 8,016 Ultraviolet sources,
- 401 X-ray sources,
- 398 radio sources,
- 11 Absorption line systems,
- 5 Gamma ray sources,
- 53 Galaxy cluster members, 33 galaxy groups, 6 galaxy pairs and 1 galaxy triple,
- Two gravitational lens systems.

- a daunting selection!

Prof Garrett cited the Garrett & Siemion (paper cited and linked above - open access) – which is due for publication in the Monthly Notices of the Royal Astronomical Society.

He concluded by pointing out that –

- SETI observations in the radio, sample a wide range of different cosmic objects.
- It's time to take this into account (eg via Gaia & updated galactic models) to improve the constraints we place on the prevalence of extraterrestrial transmitters in the Milky Way.
- Observations of nearby mass concentrations eg galaxies, galaxy groups and galaxy clusters encompass many potential sites for ETI.
- Every line-of-sight contains "exotica", both near and far…!

More in the Garrett & Siemion paper *Constraints on extragalactic transmitters via Breakthrough Listen*, cited above.

[1] Warden et al *Breakthrough Listen – A new search for life in the universe*, Acta Astronautica, V139, Oct 2017

IAF ref	title of talk/paper	presenter	institution	nation
A4,1,8, x73676	SETI India: A search for techno-signatures from extraterrestrial life using uGMRT.	Mr Arun Muraleedharan	Amity University Mumbai	India

IAF abstract: iafastro.directory/iac/paper/id/73676/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A4/1/manuscripts/IAC-22,A4,1,8,x73676.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A4/1/presentations/IAC-22,A4,1,8,x73676.show.pdf

Open paper: none found

Reported by: John I Davies

The Upgraded Giant Metrewave Radio Telescope (uGMRT - www.ncra.tifr.res.in/ncra/gmrt) permits SETI coverage frequencies from 300 to 700 MHz, which are currently less explored. The instrument comprises 30 steerable 45 metre parabolic antennas covering both celestial hemispheres down to −53° declination.

The paper explains the SETI processing pipelines -

- and plans for their future development.

The pipeline has now been tested using pulsar data and by signal injections for drifting narrowband signals with signals from artificial broadband using existing SETI software tools. They plan searching for wide-band signals with embedded modulations, a signal class which has not yet been comprehensively searched.

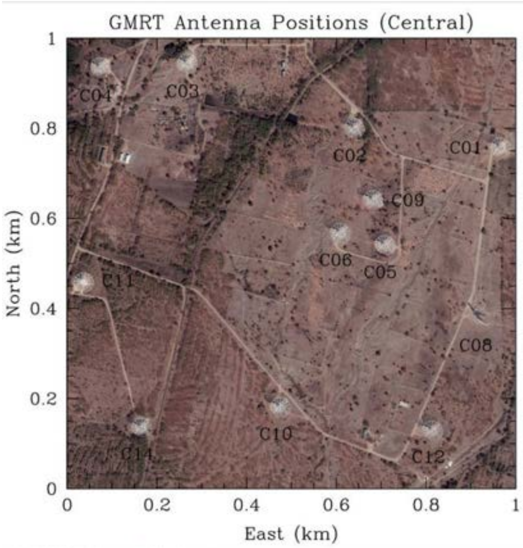
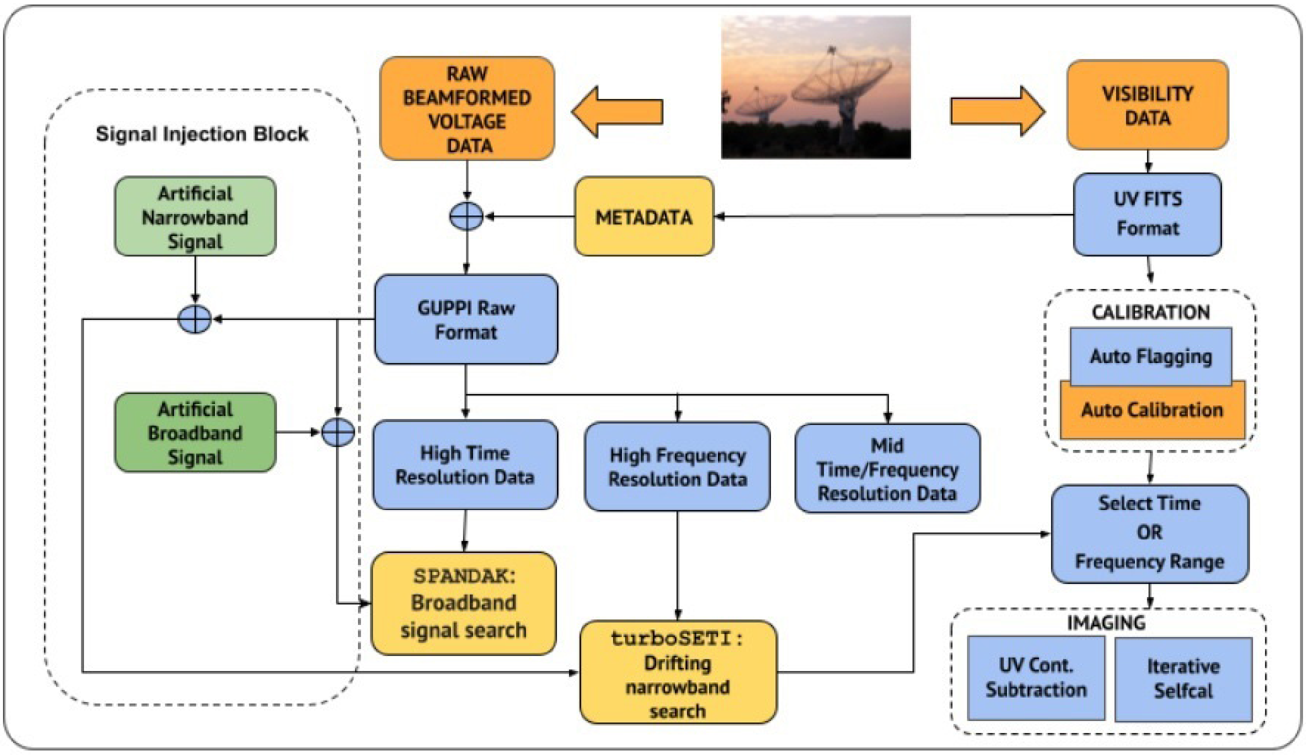


image credit: The Australian National University, Mount Stromlo Observatory www.mso.anu.edu.au/~plah/Home_Page_Stuff/GMRT_array/GMRT_array.html



The relay and telescope system and the AIS encounter vehicle. Credit: Bannova et al

IAF ref	title of talk/paper	presenter	institution	nation
D4,4,6, x67947	Transformational Release of Scientific Payloads From the Apex Anchor – Any Size, Every Day, Anywhere	Dr Peter Swan	International Space Elevator Consortium	USA

IAF abstract: iafastro.directory/iac/paper/id/67947/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/4/manuscripts/IAC-22,D4,4,6,x67947.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/4/presentations/IAC-22,D4,4,6,x67947.show.pptx

Open paper: none found

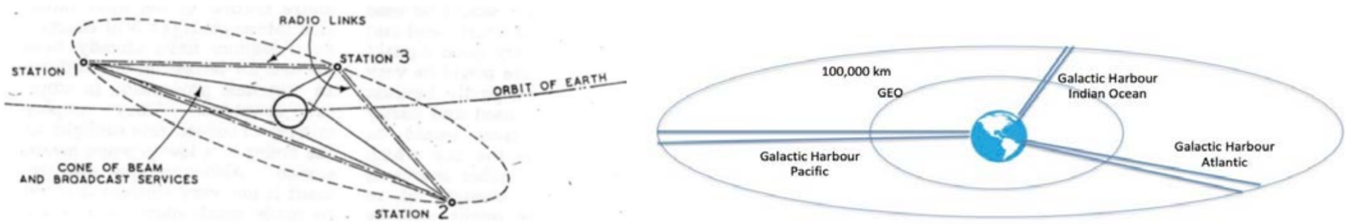
Reported by: John I Davies

A space elevator requires an apex anchor to approximately twice geostationary altitude. A simple "thought experiment" explains why. Consider a series of unconnected satellites at altitudes up to and beyond geostationary altitude. If they have a geocentric velocity identical to that required for geostationary orbit, as all the components of a space elevator must have, then those below geostationary altitude will not be travelling fast enough to maintain orbit and will fall to Earth while those above geostationary altitude will be travelling too fast to stay in Earth orbit and must fly off into interplanetary space. A space elevator needs to have a net centre of mass which is at geostationary altitude and thus requires a mass distributed equally above and below geostationary altitude. The component above geostationary altitude forms an apex anchor and at its furthest point is a natural release point for interplanetary missions. This paper considers the usefulness of the apex anchor for such missions in the context of the broader objectives of the International Space Elevator Consortium (ISEC www.isec.org/).

This paper characterises a space elevators apex anchor as a Galactic Harbour. This would be at about 100,000 km altitude. The paper states that this would have capacity of 30,000 tonnes per year, maturing to 170,000 tonnes with launches at a minimum 7.76 km/second. For example, current missions from Earth to Mars take 8 months and are every 26 months with mass to the surface of Mars about 1 percent of the mass at launch. The paper refers to the gravitational region as the Sphere of Influence altitude and the capability to reach it without rockets as the Green Road to Space. At the more modest geostationary altitude it becomes economically feasible to assemble almost any size communications antenna or science spacecraft to be moved easily by a space tug to another position on the geostationary circle.

The paper points out that long-term planning at NASA and other space agencies is based on the economics of ground launches and that an elevator would alter that enormously. The suggested benefits are -

- Planetary Sciences: massive payloads, assembled outside of the gravity well, to any planet and at low cost. With low-cost delivery to any solar system destination, planetary science will blossom.
- Massive movement: Initial Operational Capability 30,000 tonnes/yr and Full Operational Capability 170,000 tonnes/yr.
- Rapid transit and long distance: reaching beyond Mars without reaction propulsion.
- Enhanced interstellar capability: Lift capacity will allow assembly of large vehicles and the apex anchor can add substantial deltaV.
- Mininise adverse impacts: on Earth atmosphere and clutter in low Earth orbits.



Left: Three satellite stations for complete coverage of the globe Credit: Clarke [1]. Right: Three Galactic Harbours Credit: Swan

[1] One possibility is that specialised satellite receivers and antennas would no longer be required for TV reception - making it possible for a conventional UHF television receiver to be fed from a geostationary satellite. This would deliver Arthur C Clarke's dream of universal coverage with simple receiver technology, *Extra-Terrestrial Relays – Can Rocket Stations Give World-wide Radio Coverage?* Wireless World, October 1945, scienceandsf.com/wp-content/uploads/2019/03/Extra-Terrestrial-Relays2.pdf

IAF ref	title of talk/paper	presenter	institution	nation
C4,10- C3.5,6,x67247	Nuclear Fusion Powered Titan Aircraft	Mr Michael Paluszek	Princeton Satellite Systems	USA

IAF abstract:iafastro.directory/iac/paper/id/67247/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/C4/10-C3.5/manuscripts/IAC-22,C4,10-C3.5,6,x67247.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/C4/10-C3.5/presentations/IAC-22,C4,10-C3.5,6,x67247.show.pptx

IAF cited presentation video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/C4/10-C3.5/talk/IAC-22,C4,10-C3.5,6,x67247.talk.mov

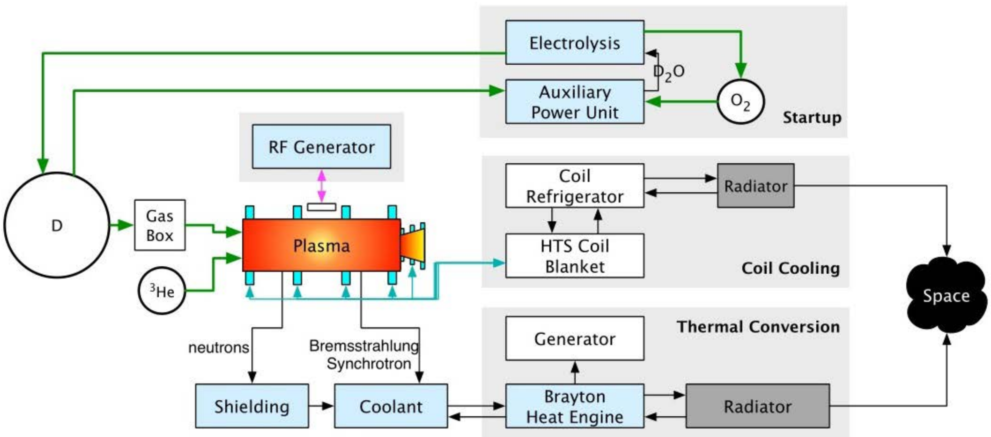
Open paper: none found

Reported by: Al Jackson

This paper is part of a series leveraging work done by Samuel A Cohen of the Princeton Plasma Physics Laboratory in the early 2000s. The core mode of propulsion here is a Direct Fusion Drive, DFD. The heart of this fusion reactor is near aneutronic fusion, that is one that produces few neutrons in the reaction process. In this case it is one of the deuterium – helium 3 reactions branches have small neutron production.

The Direct Fusion Drive (DFD) is a conceptual fusion-powered spacecraft engine, named for its ability to produce thrust from fusion without going through an intermediary electricity-generating step. The DFD uses a novel magnetic confinement and heating system, fuelled with a mixture of helium-3 (He-3) and deuterium (D), to produce a high specific power, variable thrust and specific impulse, and a low-neutron-radiation spacecraft propulsion system. Missions to Mars, Pluto and Titan where proposed using this system [2].

This paper summarizes a previous study about a mission to Titan (rendezvous with Saturn is required). An exploration vehicle is part of the mission payload. It uses a second fusion reactor, configured as a power reactor, and would be used for an electric Titan science aircraft. This vehicle would do a powered entry to Titan and then have the capability to fly anywhere on the moon at subsonic speeds. Studies presented in the paper show that the propulsion system is only used at low speeds during entry; hence a distributed propeller system was designed. After its first landing, the aircraft could perform aerial reconnaissance of the surface from any altitude and land at interesting spots. The aircraft could carry multiple payloads including a Titan submarine and a high-power drill. The science vehicle would have up to 1 MW of available power. This would be used for the engine, but also would be available to other contained science payloads. The transfer stage would remain in orbit, acting as a high-power communications relay, and would have its own set of science missions.



Block diagram of the DFD engine - x67247 Figure 7
Credit: Paluszek et al

◀

IAF ref	title of talk/paper	presenter	institution	nation
A1,LBA,9,x74467	Transcriptomic analysis of angiogenesis on datasets derived from experiments performed on mice in space	Mr Subhrajit Barua	ITMO University	Russian Federation

IAF abstract: iafastro.directory/iac/paper/id/74467/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A1/LBA/manuscripts/IAC-22,A1,LBA,9,x74467.matter.pdf

IAF cited presentation video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A1/LBA/talk/IAC-22,A1,LBA,9,x74467.talk.mp4

Open paper: none found

Reported by: Cassidy Cobbs [1]

One of the many physiological effects of spaceflight that has been observed in humans is delayed wound healing. While wound healing is a complex, multi-stage process, one of the most important stages is angiogenesis, or the formation of new blood vessels from existing ones. The new vessels bring nutrients and other factors needed for the later stages of healing. The authors noted a 2008 study showing decreased vascularization in the wounds of rabbits exposed to hindlimb unloading prior to injury, which they consider a reasonable stand-in for microgravity, and sought to examine the expression of genes related to angiogenesis in mice. The NASA Gene Lab has made available multiple RNA-Seq (a molecular method for quantifying gene expression) datasets from the Rodent Research 5 & 6 missions. The authors downloaded raw RNA-Seq files from homogenized skin samples for secondary analysis. They sought to compare angiogenesis genes between mice that had experienced ~30 days microgravity and ground control mice in two strains that differ in their innate immune responses. They identified 12 genes associated with angiogenesis that were differentially expressed between the two mouse strains, however based on Principal Component Analysis, strain played a much larger role in differential expression than microgravity exposure. The authors conclude that genetic background has an effect on the degree or type of delayed wound healing, and that any solutions may have to be personalized. However, the mice in this study were not subjected to wounding, so the gene expression patterns analysed were their baseline skin transcription pattern. It is possible that in the presence of a wound, different expression patterns would emerge between strains and/or between mice in space and on the ground. Authors: Subhrajit Barua (Faculty of Biotechnologies, ITMO University), Ruth Singh (Dept of Biophysics, University of Mumbai), Palvi Garg (Dept of Chemical Engineering, Ambedkar NIT, India), Sarah Rizwan (St Joseph's Girls School).

IAF reference	Title of talk/paper	presenter	institution	nation
D4,4,3,x73132	Advanced Electric Propulsion Concepts for Fast Missions to the Outer Solar System and Beyond	Angelo Genovese, Nadim Maraqten	Initiative for Interstellar Studies	Germany

IAF abstract: iafastro.directory/iac/paper/id/73132/summary/
IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/4/manuscripts/IAC-22,D4,4,3,x73132.pdf
IAF cited presentation video: none available
Open paper: www.researchgate.net/publication/363862726_Advanced_Electric_Propulsion_Concepts_for_Fast_Missions_to_the_Outer_Solar_System_and_Beyond [2]

[1] Cassidy is Secretary of the Institute for Interstellar Studies, the US-based part of our organisation. More about her in *Cassidy Cobbs - Bioscientist* Principium 29, May 2020. i4is.org/wp-content/uploads/2020/05/Principium29-print-2005271554opt.pdf
[2] See also: *Advanced Electric Propulsion Concepts for Fast Missions to the Outer Solar System and Beyond*, Angelo Genovese & Nadim Maraqten www.researchgate.net/publication/363862726_Advanced_Electric_Propulsion_Concepts_for_Fast_Missions_to_the_Outer_Solar_System_and_Beyond

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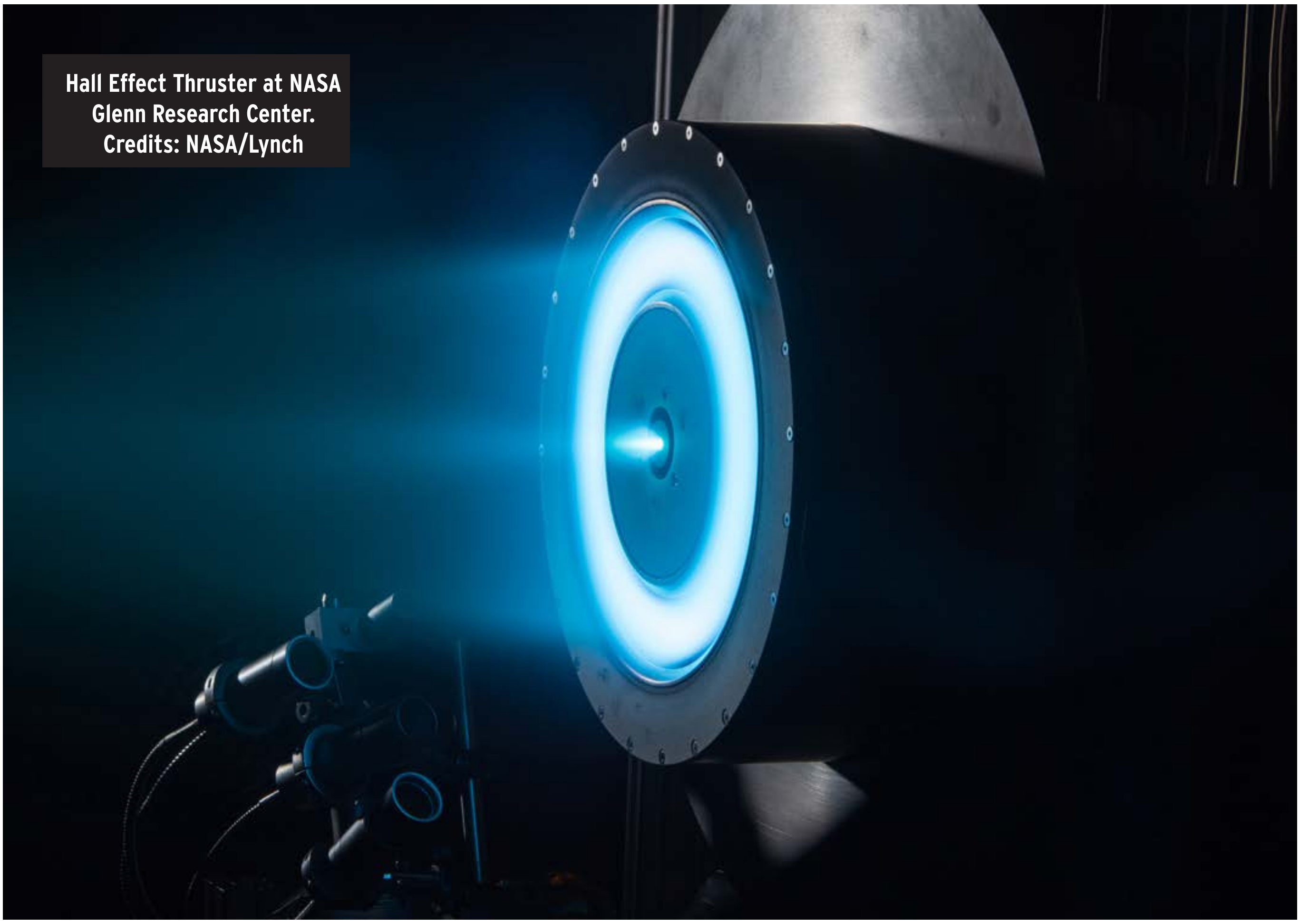
◀ We have two reports on this paper -

REPORT 1 of 2, reported by: Nadim Maraqten (Nadim is also co-author of this paper)

By electrically accelerating ions, the limitations of conventional chemical rockets (Isp < 500 seconds) can be breached and very high specific impulses (> 5000 s) achieved; thus allowing for interstellar precursor missions. In contrast to other proposed propulsion technologies, electric propulsion (EP) has a decades-long heritage and already enabled several demanding missions (DAWN, DART, Hayabusa2, etc). Starting with the first historical sparks, the paper showcases the status quo of electric propulsion and highlights several advanced electric propulsion concepts.

As a matter of fact, it were none other than Robert H Goddard and Konstantin Tsiolkovsky who independently began to consider early forms of electric rockets at the beginning of the 20th century. This ignited the development of a variety of different electric thruster types creating a whole industry branch with enterprises specializing on exactly these systems. Among the most common established ones are the Hall Effect Thruster (HET) and the Gridded Ion Thruster (GIT). The 10 kW regime of these systems shows specific impulses of 2,800 – 7,400 s and thrusts of 610 – 270 mN (both high TRL). Besides these, several advanced high-power (100s kW) thrusters like the Variable Specific Impulse Magnetoplasma Rocket VX-200SS (Isp = 4,900s, T = 5,820 mN) and Applied-Field MagnetoPlasmaDynamic Thruster SX3 (Isp = 4,700 s, T = 2,750 mN) are in development (medium TRL). However, interstellar missions might necessitate even higher specific impulses, which could be provided by Dual-Stage 4-Grid (DS4G) ion thruster (Isp = 15,000s, TRL = 3). Studies suggest that DS4G technology could enable even higher specific impulses of up to 40,000 seconds [1].



Hall Effect Thruster at NASA Glenn Research Center. Credits: NASA/Lynch

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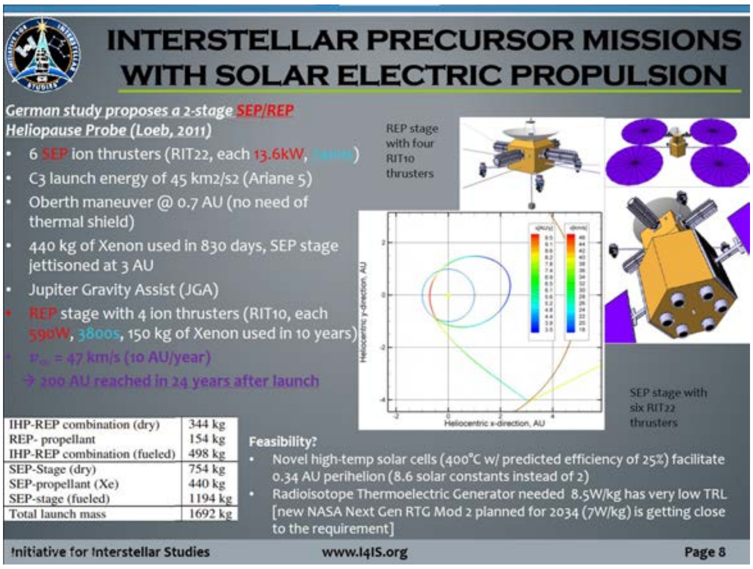
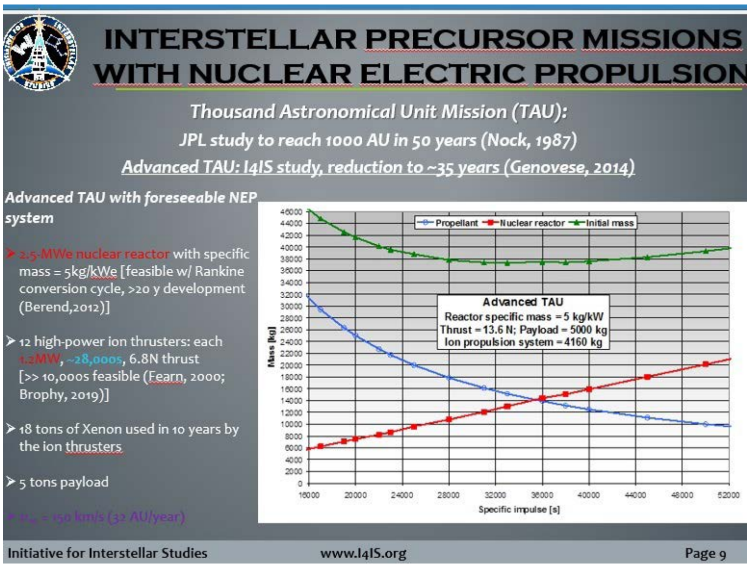
To combine the high Isp with a reasonable high thrust and enable interstellar precursor missions, there is no way around feeding power from a strong and lightweight power plant into the thruster(s). To tackle this issue, three major concepts have been proposed:

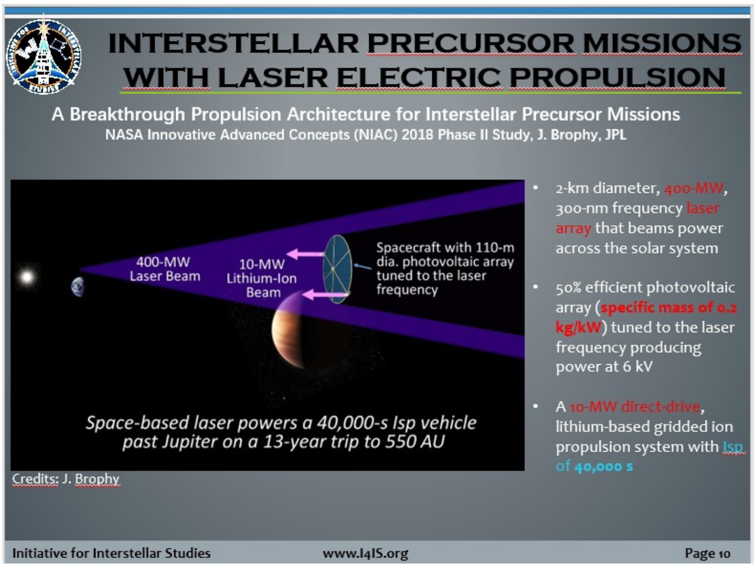
1) Solar Electric Propulsion is the most tangible concept, which has already been exploited by several electric propulsion missions. A near-sun flyby could supply large amounts of power to the solar panels while exploiting the Oberth effect. In combination with Radioisotope Electric Propulsion and a Jupiter gravity assist, a 200 AU mission could be realized within the near future.





2) Nuclear Electric Propulsion with a nuclear power plant of <5 g/kW could facilitate a 1,000 AU mission within 35 years.

3) Laser Electric Propulsion could lead to a paradigm change in power specific mass (0.2 kg/kW) and enable a 550 AU mission in 13 years. A powerful 400 MW laser array could beam power across the solar system which is converted by a photovoltaic array to power a direct-drive EP system.



To conclude, electric propulsion is a major candidate as propulsion system of challenging interstellar precursor missions with "reasonable" trip times. A 7,000s Isp thruster is already flight-ready, while even more advanced systems are in development. Key to the realization of advanced electric propulsion concepts is the realization of (ultra-)low specific mass power plants. Nevertheless, a solar powered 200 AU mission might be possible already within the near-future.

REPORT 2 of 2, reported by: Adam Hibberd

A fascinating article which first usefully outlines the history of spacecraft electric propulsion and then gives an overview of the current state-of-play, with particular regard to interstellar precursor missions, this latter is clearly of relevance to i4is.

It turns out that certain luminaries in the history of astronautics have made significant and sometimes breakthrough discoveries in the field of electric propulsion. Ranging from the 'God' and rocket pioneer, Robert H Goddard; Konstantin Eduardovitch Tsiolkovsky who was the discoverer of the eponymous Tsiolkovsky rocket equation; all the way through to the likes of Hermann Oberth and Wernher von Braun. Additionally Ernst Stuhlinger, an assistant to von Braun, conducted sterling work as far as specifying, designing and quantifying electric propulsion systems, writing a few seminal papers in the field.

Some prophetic quotations

If we look at historical missions, there have been two stand-out missions which have demonstrated the huge value of EP, namely the Deep Space 1 mission and Dawn. The latter mission involved rendezvous with two separate celestial bodies, Vesta and Ceres, which is exceedingly impressive.

With high specific impulses yet low thrust forces, EP systems naturally take their time to achieve what chemical can achieve in seconds or minutes, the pay-off being that the on-board propellant is used much more effectively and efficiently. The paper points out two more salient parameters which affect the design of a spacecraft with EP, namely the 'Specific Power' (measure in kW/N) and secondly the mass to power ratio of the power source (kg/W). Note the tyrannical truth for EP, which is equivalent to that of the Tsiolkovsky for chemical propulsion, is that generally as Specific Impulse increases for EP, so does the Specific Power requirement, thereby necessitating longer periods of thrust to generate the required ΔV.

Addressing the problem of exiting the heliosphere and stepping out into interstellar space, the goal is generally to reach large distances (> 200 AU) in short times (25 years), can EP be brought to bear on this?

Several solutions present themselves depending on the nature of the power-source used. SEP (Solar Electric Propulsion) suffers the disadvantage that an interstellar mission, by its very nature, would involve long periods at huge distances away from the sun (where solar flux reduces as the inverse square of distance).

However Loeb (HW and not A) suggests a combined SEP with REP system can readily do the job – where REP is Radioisotope Electric Propulsion and is fairly self-explanatory. The idea is that SEP would provide the propulsion whilst the vehicle is close to the sun (and so the vehicle can receive huge benefits from the Oberth Effect), following which the REP takes over from the SEP, but first with a velocity-boost from a GA (gravitational assist) of Jupiter.

For the TAU (1,000 au) mission to the ISM, the time requirement is now 50 years which corresponds to a larger heliocentric speed (factor of 2.5 x the velocity of the 200 au goal mission), a challenge which needs pioneering technology to achieve lower mass to power ratios and higher specific impulses. Two solution options are articulated, namely NEP (Nuclear EP) and LEP (Laser EP). The explanation of the NEP option cites a paper Genovese himself constructed a while ago on behalf of i4is.

The LEP option is where photovoltaic cells on board the spacecraft receive intense illumination from a laser beamed from Earth to power the EP.

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IAF ref	title of talk/paper	presenter	institution	nation
A4,2,15,x73175	Romanticism in Science as a form of cognitive bias and SETI	Dr Gabriel G De la Torre	University of Cádiz	Spain

IAF abstract: iafastro.directory/iac/paper/id/73175/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A4/2/manuscripts/IAC-22,A4,2,15,x73175.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A4/2/presentations/IAC-22,A4,2,15,x73175.show.pptx

Open paper: none found

Reported by: Alan Cranston

Is science, is SETI, influenced by our cultural values? Gabriel De la Torre's paper examines the question with particular reference to Romanticism. This cultural movement of the early 19th century was particularly powerful and its influence on our way of seeing the world persists even to this day.

To examine the question let's first consider the nature of Romanticism. It is sometimes seen as a reactionary movement against emerging industrialism and science itself. But if Romanticism was merely reactionary, its force would quickly have been spent instead of exerting the extraordinary force that it did. We should also remember that it was not merely a literary and artistic phenomenon. It had radical thoughts on science too. The difficulty Romanticism had with the science of the day was its mechanistic nature, its belief that everything could (at least in principle) be reduced to simple parts and rules. Romantic science asserted that this was not correct. The whole could not always, even in principle, be understood as the sum of the parts, nature was somehow greater than that.

This view of science is both positive and in principle testable – and is still debated today. It was of course perfectly aligned with other elements of Romantic thought: the literature and art that celebrated rather than feared nature, that found the 'sublime' in it, a higher level of existence than mere rocks and vegetation. Modernism (in art for example) may have tried to make us look more clearly, but Romanticism still holds an influence beyond mere nostalgia. In England, for example, many people in the UK still find the barren hills of the Lake District, 'picturesque' despite the fact that they are biologically a barren desert. The question is whether there are similar issues in science and in SETI.

The charge that was quickly made against Romanticism in science was of plain irrationality, but this was not correct. Rather, Romanticism argued that reductionism itself distorted and limited our understanding of the natural world. One of the greatest scientists of the time (still too little recognised in the anglophone world), Humboldt was a Romantic. Much influenced by Goethe, he saw the connectedness of nature and was perhaps the first modern ecologist. Reading him now, one sees how much he anticipates James Lovelock and the Gaia metaphor. But still, narrower views regained sway in the middle of the 19th century as positivism came to the fore, largely restoring Enlightenment values. Though ideas such as Humboldt's, and other non-reductionist approaches continue to gain support in modern science. But – in SETI – what remains and what influence, for better or worse does it have?

De la Torre's starting point is another aspect of Romanticism: belief in the heroic, and in humanity itself being more than just flesh and blood. Bertrand Russell saw this as the dark side of Romanticism, the fantasy that led to the Third Reich, but De la Torre fairly makes the point that heroic adventure remains a key part of scientific endeavour, be it in space or particle research. If Romanticism had never happened would our science be more mechanical, more prosaic?

To elucidate how matters are, De la Torre conducted a study of beliefs held by SETI folk, with questions about various possibilities of detecting extra-terrestrial life. I confess I did not readily see how the questions bore on the level of Romantic 'overhang' in the minds of the respondents. They seemed to me to be more a measure of scientific optimism.

▶

De la Torre also sometimes seems to associate Romanticism with an (impliedly dangerous or unhelpful) anthropocentric perspective. For my part I am not sure I see the link. Man (in Western culture) has tended to place himself above the world since Biblical times and in fact it was the arch-reductionist Descartes who reduced all else to mere automata. And anyway, if we naturally think of possible intelligent extra-terrestrial life forms as probably a bit like us, is that such a bad thing? As De la Torre's short paper is good and interesting and I would have liked to hear his illustrated presentation. It is important for scientists to understand that their work is never conducted in some kind of cultural vacuum, that there is always history and context. I'm completely sure that he is right that Romanticism remains an important influence. Whether it is as important in science as he suggests it might be, I am less sure. I am also unsure whether it really matters. We all, scientists included, live by stories; it is arguable that we simply could not live structured lives without them. If modern SETI folk live by stories, by ideas, and by optimism, that seems to me to be a good thing. It is only when the stories begin to determine the facts that we should become concerned.

IAF ref	title of talk/paper	presenter	institution	nation
B2,1,1,x69864	Methods for Navigation in the Nearby Interstellar Medium	Dr John Christian	Georgia Institute of Technology	USA

IAF abstract: iafastro.directory/iac/paper/id/69864/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/B2/1/manuscripts/IAC-22,B2,1,1,x69864.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/B2/1/presentations/IAC-22,B2,1,1,x69864.show.pptx Open paper: none found

Reported by: Adam Hibberd

An introduction which squarely lays down the goal of the paper, to summarise the various on-board navigation options which can be exploited by spacecraft intending to explore the nearby interstellar medium (NISM). It neglects the importance of interstellar objects (ISOs) and how these visitors to our Solar System may provide revolutionary insights to other systems in our galaxy, instead adopting the now obsolete viewpoint that objects beyond our Solar System can only be studied by remote sensing.

Nevertheless it makes the extremely compelling point that if humanity is to embark on interstellar travel by robotic spacecraft, then a clear and in-depth knowledge of the nature and composition of the NISM will be needed, and this can best be achieved by precursor missions out to 2,000 AU. But what navigation options are there for such missions?

Firstly IMUs (Inertial Measurement Units). These provide measurements of acceleration with respect to. an inertial reference frame, which when integrated can compute velocity and then again to compute position. There is an issue with IMUs which I know all-to-well from my experience of Ariane 4 (the European work-horse launch vehicle) in that they fail to measure gravitational accelerations, only accelerations due to thrust (and for Ariane 4 drag). Furthermore due to biases and misalignments inherent in these devices, over long periods of time these measurements become unreliable. Thus for long duration missions to the NISM, where thrust will be extremely rare and where flight times are extremely protracted, IMUs may not be the best option.

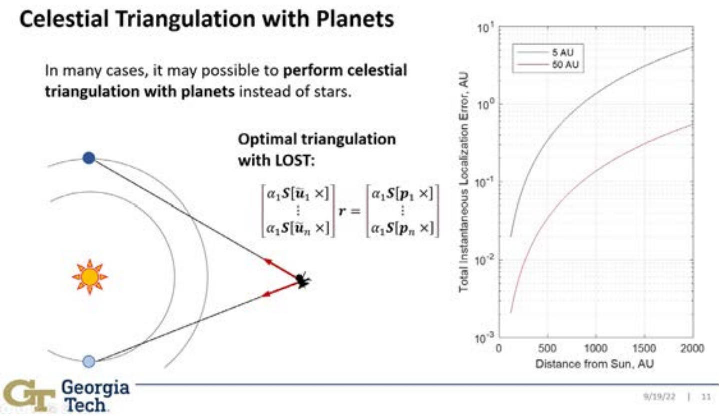
Next Radiometric Navigation. Exemplified by the NASA DSN (Deep Space Network), this is a tried and trusted technique for interplanetary missions, but what about its use for missions to the NISM? As the Earth-Spacecraft distance increases, complications arise in the form of inaccuracies, especially when 2-way or 3-way ranging methods are used. There is promise on the horizon however, in the development of extremely precise atomic clocks and what's more their gradual reduction in mass and size. Such a clock installed on a spacecraft would allow accurate 1-way ranging to be performed.

Star Trackers for Attitude Determination. As used currently, star trackers exploit optical observations of stars to identify the current attitude of the spacecraft, but what about their use for attitude determination in interstellar missions? For accurate determination of the spacecraft's attitude, clearly pattern recognition will be important, thus mapping a set of current visible star locations against a catalogue stored in the onboard computer. Various algorithms to solve such a problem exist and note that dimmer stars – which tend to be further away – would be prioritised as they are less affected by parallax.

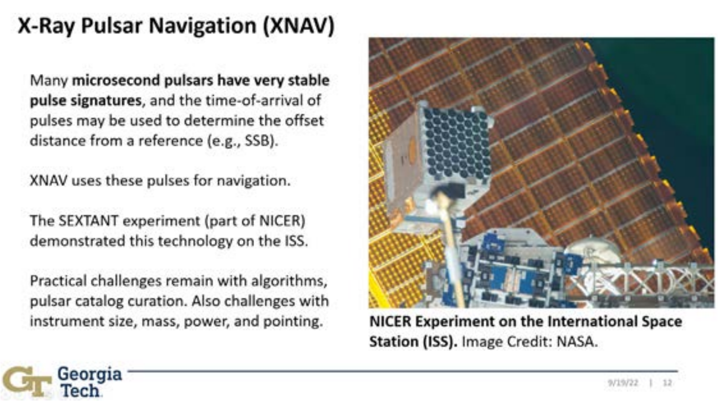
Celestial Triangulation with Stars. As the spacecraft moves through interstellar space, the apparent location of distant stars will stay fixed making them useless for navigation. Although as previously mentioned this low parallax is extremely desirous for attitude determination, for the purpose of navigation, the higher parallax of nearby, brighter stars can be conveniently and usefully exploited to derive position. We obviously need accurate knowledge of the 3D locations of these stars and estimates of the positional error achievable through triangulation are around 1.3 AU, which is rather large compared to radiometric navigation for example.

Doppler Shift of Stellar Spectra. This technique uses the shifts in stellar spectra due to the spacecraft's velocity with respect to the stars in question. The article does not mention the uncertainty which might be inherent due to exoplanets orbiting these stars, affecting the Doppler shift measurements, however by their nature these will be periodic and so therefore might be correctable. Also StarNAV is a tried technique (for lunar missions) to measure stellar aberration of lots of stars to determine the spacecraft's velocity vector. In the context of an interstellar probe, its velocity would remain pretty-much unchanged and so positional information would be problematic to derive.

Celestial Triangulation with Planets and other Celestial Bodies. This is a self-explanatory method used extensively by interplanetary spacecraft which exploits our accurate knowledge of the positions and velocities of solar system bodies such as planets, moons and asteroids, to enable triangulation in an analogous approach to that of celestial triangulation with stars. However for missions to the NISM, with the corresponding large distances from the sun, uncertainties of 150,000 km would be present.



Credit: Christian



Credit: Christian

Finally, X-Ray Pulsar Navigation (XNAV). Neutron stars are extremely compact rotating spheres which have a magnetic field. X-rays are projected out from the poles which may not align with the spin vector, introducing a conic spread of emitted X-ray directions and so a periodicity is observed in the intensity of these X-rays observed at Earth - Pulsars. Moreover, the period of each cycle is extremely precise (their stability is on the order of an atomic clock) and so can be used as celestial clocks for accurate interstellar navigation, we have XNAV. An outstanding problem with this technology is the very fact that the pulses are so precisely repeated in time. This causes the cold start problem which is that given the XNAV detects a particular pulse from a specific pulsar – how does it relate this to a reference pulse? The XNAV may be an integer N out, introducing navigational errors. These problems and others are mainly issues with algorithm development which need to be further addressed for future missions.

IAF ref	title of talk/paper	presenter	institution	nation
A6,8-E9.1,10,x69130	Financial Incentives for Debris Removal Services	Mrs Morgane Lecas	Astroscale Ltd	UK

IAF abstract: iafastro.directory/iac/paper/id/69130/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A6/8-E9.1/manuscripts/IAC-22,A6,8-E9.1,10,x69130.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A6/8-E9.1/presentations/IAC-22,A6,8-E9.1,10,x69130.show.pptx

Open paper: none found

Reported by: Samar AbdelFattah

The objective of this paper is to discuss potential incentives for satellite operators to motivate them to adopt debris removal services. Since debris generating events continue to occur (with already more than 36,500 debris objects larger than 10 cm and 4,852 active satellites in orbit), the risk on existing and future satellites will only continue to increase. Debris generating events include the Fengyun-1C Anti Satellite Weapons (ASAT) test (2007), Iridium Cosmos Collision (2009), and more recently the Russian ASAT test destroying Cosmos 1408 (2021) which created 1,500 pieces of debris larger than 10 cm and thousands of smaller ones.

Space debris poses a persistent threat to governments, industry space assets, and their downstream applications, as well as a growing risk to the sustainability of the entire orbital environment.

The main idea is to have debris removal funds to be accounted during the operational and revenue generating phase of an asset life using potential incentive models presented to satellite stakeholders. The survey conducted by the Organisation for Economic Cooperation and Development (OECD) Space Forum in 2019 for a group of twenty commercial satellite operators active in satellite communications and Earth Observation showed that implementation of incentives for sustainable operations over the imposition of fines for pollutive practices is the most preferred model.

Thus, the paper will assess different financial incentives including external sinking funds, advanced market commitments (AMCs), subsidies, and performance bonds. This assessment is presented in the format of advantages and disadvantages of each method.

However, governments have more tools and approaches at their disposal to empower debris removal services, including:

• Invest in Research and Development (R&D) to mature debris removal technology

• Advocate and prioritize space debris solutions on the public and political agenda

• Become a customer and early adopter of debris removal services

• Support industry in overcoming barriers for debris removal service adoption

• Incentivise the commercial debris removal market

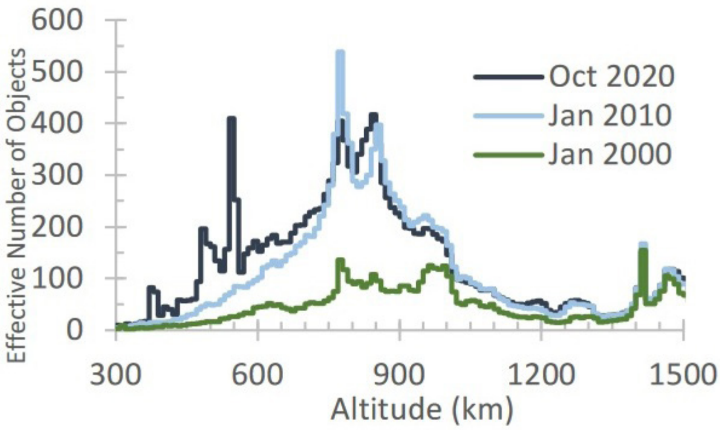


Fig. 1. Evolution of objects in LEO Credit (image and caption): NASA Orbital Debris Program Office

Financial Incentives Assessment

1. External Sinking Funds: funds set aside during the operational lifetime of an asset to cover future decommissioning costs.

Advantages	Disadvantages
• Operator pays during operational lifetime whilst assets are revenue generating. • Ensures funding for End-of-Life (EOL) is reliably acquired, depending on definition of decommissioning/thresholds set for space debris mitigation.	• Sufficient funds must be accrued ahead of the end of life of the installation or asset. • Uncertainty around fund size and timescale of satellite operators

2. Subsidies: include payments from governments to producers, grants, subsidized loans, loan guarantees, Value Added Tax (VAT) exemptions on specific technologies (eg electric cars), feed-in tariffs, or tax credits for environmentally relevant investments.

Advantages	Disadvantages
• Provides immediate benefit for the debris removal market, depending on how the subsidy is structured, reducing barriers for satellite operator to adopt EOL services.	• Risk of technology lock-in, rebound effects, windfall gains and free-riding. • Unlikely to work as a market-based solution.

3. Advance Market Commitments (AMCs): AMCs are financial mechanisms through which binding contracts are secured in advance to purchase a set quantity of useful, but currently unavailable products, thereby establishing a guaranteed viable initial market for the products at an attractive starting price once it has been successfully developed by the private sector. In exchange, private sector developers agree to offer a minimum quantity of the product or service at a lower subsidized rate for a set period. AMCs offset the private sector's hesitance to invest in cost-intensive technologies that could meet a critical need but are considered high-risk in the absence of reliable or easily predicted indicators of future demand or returns.

Advantages	Disadvantages
• Reduces demand uncertainty thus incentivising market entry. • Creates demand that justifies research and development (R&D) investment.	• Relies on Government agreeing to pay for debris removal. • Challenging to identify a single entity to manage an AMC; best applied collaboratively.

4. Performance Bonds: A performance bond is a surety bond issued by an insurance company or a bank to guarantee satisfactory completion of a project by a contractor. The underwriter guarantees an amount equal to the decommissioning sum in return for an arrangement fee and premium. Performance bonds are used in other industries that operate under risk-laden conditions in extreme environments, such as offshore wind, maritime, and mining industries. For these industries, performance bonds applied to decommissioning operational equipment at end-of-life are often coupled with other incentives, such as subsidies, levies, and tax incentives, among others.

Advantages	Disadvantages
• Surety bonds boost liquidity and financial flexibility and allows for other investments or paying down on debt. • Ensures funding for EOL in advance, depending on definition of decommissioning/ thresholds set for space debris mitigation. • Established precedent for bonds in the satellite industry.	• Lack of enforceability and capacity of the government to enforce them • Only covers partially the estimated liabilities (leaving the financial risk to government). • Uncertainty around performance bond value and timescale of satellite operators that could be agreed through satellite licensing process

Challenges

In Japan, sub-working group for on-orbit servicing formed by the Japanese Government's Space Debris Task Force, has discussed the economic externality of space debris issues. The study report by the Sub-Working Group on On-Orbit Servicing pointed out that “what is needed now is to make it clear how a government vision and design in order to create an economic ecosystem where Active Debris Removal commercially viable.” Since “any rule that enable to internalize the cost of removal of space debris requires an approach that adopts both regulation and incentives”, the report introduces some policy ideas instead of making a single policy recommendation and leaves it for future consideration that includes economic incentives.

While in the US, operators’ response to the suggested performance bond rule was that if implemented, the proposed performance bond calculation methodology could lead to unintended consequences wherein satellite operators seek to minimize the bond value, at the expense of space safety. Astroscale US called for the establishment of a working group to help assess methodology proposed by the Commission, with the intention of successful application to space activities.

ESA’s countries such as the UK and France already introduced in-orbit third party liability insurance and France also has one of the most stringent regulations regarding legally binding debris mitigation requirement which could be coupled with financial incentives to incentivise compliance and support the market of In-Orbit Services.

The authors initial recommendation is to use AMCs and performance bond could present an effective financial incentive provided industry criticisms are addressed. Once tailored for the industry, AMCs and performance bond ensure that funds are allocated to decommissioning thus reducing the uncertainty on market demand and allowing for investment in debris removal services.

Implementation wise, financial incentives could be part of the satellite mission license process to enforce required measurements. This can sustain both space environment neutrality and enablement of debris removal market and technologies.

IAF ref	title of talk/paper	presenter	institution	nation
D4.4.9,x69502	The Pragmatic Interstellar Probe Study: Results	Ralph L McNutt, Jr	Johns Hopkins University	USA

IAF abstract: iafastro.directory/iac/paper/id/69502/summary/ >

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/4/manuscripts/IAC-22,D4,4,9,x69502.pdf

Open paper: interstellarprobe.jhuapl.edu/Resources/Publications/

Reported by: Samar AbdelFattah

Previous edition (P38) reviewed the Interstellar Probe mission which is a joint effort that was requested by the Heliophysics Division within NASA’s Science Mission Directorate (SMD), focuses on a pragmatic interstellar probe with the ability to operate at 1,000 AU and a design lifetime of 50 years and assesses its technical readiness for a launch in 2030 to help support the next round of Decadal Surveys covering the time frame of 2023–2032 (For mission preview, please refer to P38-IAC2021 report).

The mission funded by NASA Heliophysics Division to provide data on the Solar and Space Physics Decadal Survey which has recently started operations. Even though the concept is not really new and goes back to at least 1960. The nominal mission expected to use Super Heavy Lift Launch Vehicle SHLLV with additional 3rd and 4th stages and a separated space craft “observatory” of 860 Kg holding 90 Kg of instruments.

Starting with a quick review on launch scenarios starting with the "new ingredient" of using The Ares V in combination with a spacecraft using an advanced radioisotope electric propulsion (REP) system and cryogenic upper stages which was report in 2009 during the 60th IAC. However, the Ares V and the Constellation Program were cancelled in October 2010. Also, a quick review on the use of the Space Launch System (SLS) to enable an Interstellar Probe. The initial work was presented in the 65th and 66th IAC. In addition, work on Interstellar Systems for Interstellar Probe was presented in the 67th and updated in the 68th IAC meetings.

The broad engineering requirements for the mission were set as the following, conditioned by being ready to launch by 2030:

1. Readiness: Launch no later than 1 January 2030

2. Downlink: Operate from 1,000 au

3. Power:

a. Power at start: No more than 600 Watts required

b. Power at end: No less than half at beginning

4. Longevity: Lifetime of not less than 50 years

Spacecraft systems were driven by recent missions with very similar requirements, including:

1. New Horizons – 16-year design lifetime, General Purpose Heat Source-Radioisotope Thermoelectric Generators GPHS-RTG, significant autonomy, dual-mode (3-axis stabilized/spin stabilized)

2. Van Allen Probes – Space physics payload. Long (50 m) wire booms, spin stabilized

3. Parker Solar Probe (PSP) – Space physics payload including imager (coronal), 3-axis stabilized, heavily autonomous operation

Figure 1 Science Tracibility Matrix (STM) for Goal 1 "Baseline Mission"
Credit (image and caption): McNutt et al

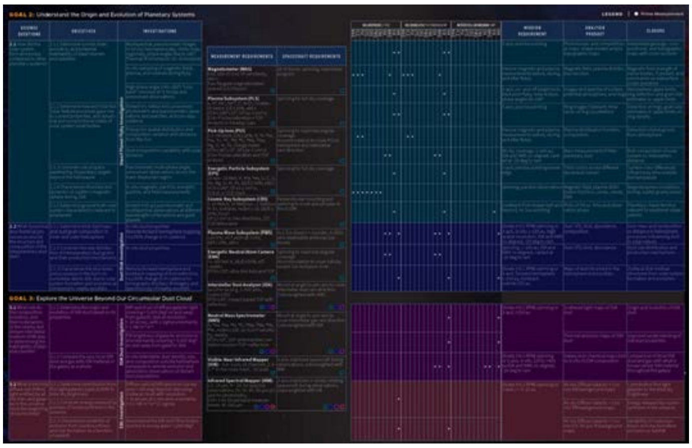
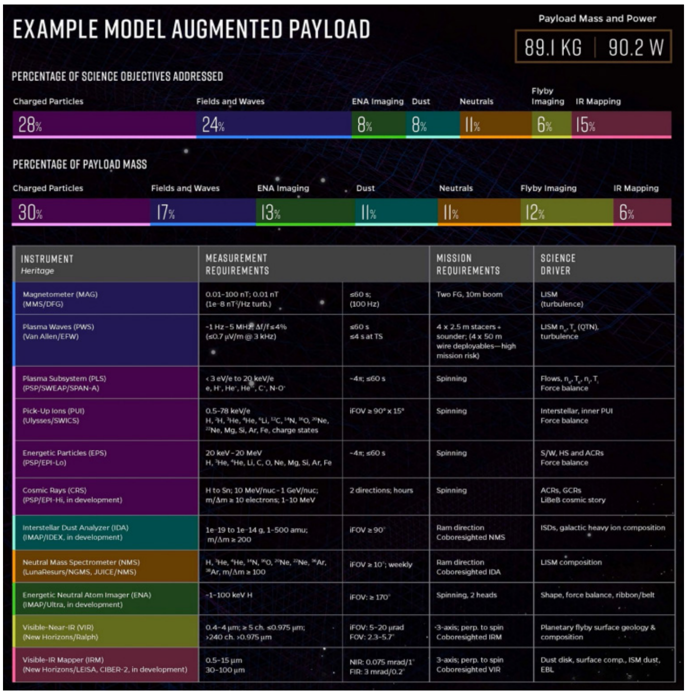


Figure 2 Science Tracibility Matrix (STM) for Goals 2&3 "Augment Mission"
Credit (image and caption): McNutt et al

The mission development starts with developing a Science Traceability Matrix (STM), its logic flow and aligning the goals to it with the baseline Goal 1 and Augmented mission Goals 2, 3. The STM for Goal 1 is shown in Fig.1, while Fig. 2 is showing the augmented mission Goals 2 & 3 along with Goal 1, with the modified payload.



EXAMPLE MODEL AUGMENTED PAYLOAD

Payload Mass and Power: 89.1 KG | 90.2 W

PERCENTAGE OF SCIENCE OBJECTIVES ADDRESSED

Charged Particles	Fields and Waves	ENA Imaging	Dust	Neutrals	Flyby Imaging	IR Mapping
28%	24%	8%	8%	11%	6%	15%

PERCENTAGE OF PAYLOAD MASS

Charged Particles	Fields and Waves	ENA Imaging	Dust	Neutrals	Flyby Imaging	IR Mapping
30%	17%	13%	11%	11%	12%	6%

INSTRUMENT *Heritage*	MEASUREMENT REQUIREMENTS		MISSION REQUIREMENTS	SCIENCE DRIVER
Magnetometer (MAG) (MMS/DFG)	0.01–100 nT; 0.01 nT (1e–8 nT^2/Hz turb.)	≤60 s; (100 Hz)	Two FG, 10m boom	LISM (turbulence)
Plasma Waves (PWS) (Van Allen/EFW)	~1 Hz – 5 MHz; Δf/f ≤ 4% (≤0.7 µV/m @ 3 kHz)	≤60 s ≤4 s at TS	4 x 2.5 m stacers + sounder; (4 x 50 m wire deployables—high mission risk)	LISM n_e, T_e (QTN), turbulence
Plasma Subsystem (PLS) (PSP/SWEAP/SPAN-A)	< 3 eV/e to 20 keV/e e, H^+, He^+, He^{++}, C^+, N-O^+	~4π; ≤60 s	Spinning	Flows, n_e, T_e, n_i, T_i Force balance
Pick-Up Ions (PUI) (Ulysses/SWICS)	0.5–78 keV/e H, ^{2}H, ^{3}He, ^{4}He, ^{6}Li, ^{12}C, ^{14}N, ^{16}O, ^{20}Ne, ^{22}Ne, Mg, Si, Ar, Fe, charge states	iFOV ≥ 90° x 15°	Spinning	Interstellar, inner PUI Force balance
Energetic Particles (EPS) (PSP/EPI-Lo)	20 keV – 20 MeV H, ^{3}He, ^{4}He, Li, C, O, Ne, Mg, Si, Ar, Fe	~4π; ≤60 s	Spinning	S/W, HS and ACRs Force balance
Cosmic Rays (CRS) (PSP/EPI-Hi, in development)	H to Sn; 10 MeV/nuc – 1 GeV/nuc; m/Δm ≥ 10 electrons; 1–10 MeV	2 directions; hours	Spinning	ACRs, GCRs LiBeB cosmic story
Interstellar Dust Analyzer (IDA) (IMAP/IDEX, in development)	1e–19 to 1e–14 g, 1–500 amu; m/Δm ≥ 200	iFOV ≥ 90°	Ram direction Coboresighted NMS	ISDs, galactic heavy ion composition
Neutral Mass Spectrometer (NMS) (LunaResurs/NGMS, JUICE/NMS)	H, ^{3}He, ^{4}He, ^{14}N, ^{16}O, ^{20}Ne, ^{22}Ne, ^{36}Ar, ^{38}Ar, m/Δm ≥ 100	iFOV ≥ 10°; weekly	Ram direction Coboresighted IDA	LISM composition
Energetic Neutral Atom Imager (ENA) (IMAP/Ultra, in development)	~1–100 keV H	iFOV: ≥ 170°	Spinning, 2 heads	Shape, force balance, ribbon/belt
Visible-Near-IR (VIR) (New Horizons/Ralph)	0.4–4 µm; ≥ 5 ch. ≤0.975 µm; >240 ch. >0.975 µm	iFOV: 5–20 µrad FOV: 2.3–5.7°	3-axis; perp. to spin Coboresighted IRM	Planetary flyby surface geology & composition
Visible-IR Mapper (IRM) (New Horizons/LEISA, CIBER-2, in development)	0.5–15 µm 30–100 µm	NIR: 0.075 mrad/1° FIR: 3 mrad/0.2°	3-axis; perp. to spin Coboresighted VIR	Dust disk, surface comp., ISM dust, EBL

The paper then present the example models for both baseline mission and augmented mission. In Fig. 3 an example model for the augmented mission can be shown with detailed instrument capabilities, masses, power and data downlink requirements, as well as estimated instrument costs have been studied and are detailed in the final report. The corresponding integrated spacecraft layout of the augmented mission is shown in Fig. 4. From the various other optimization studies, all spacecraft stages are used during and shortly after leaving Earth orbit. The spacecraft is then spun up to its nominal cruise characteristics. The magnetometer boom and plasma wave system wire antennas are then deployed.

Figure 3 Example Model for Augmented Payload
Credit (image and caption): McNutt et al

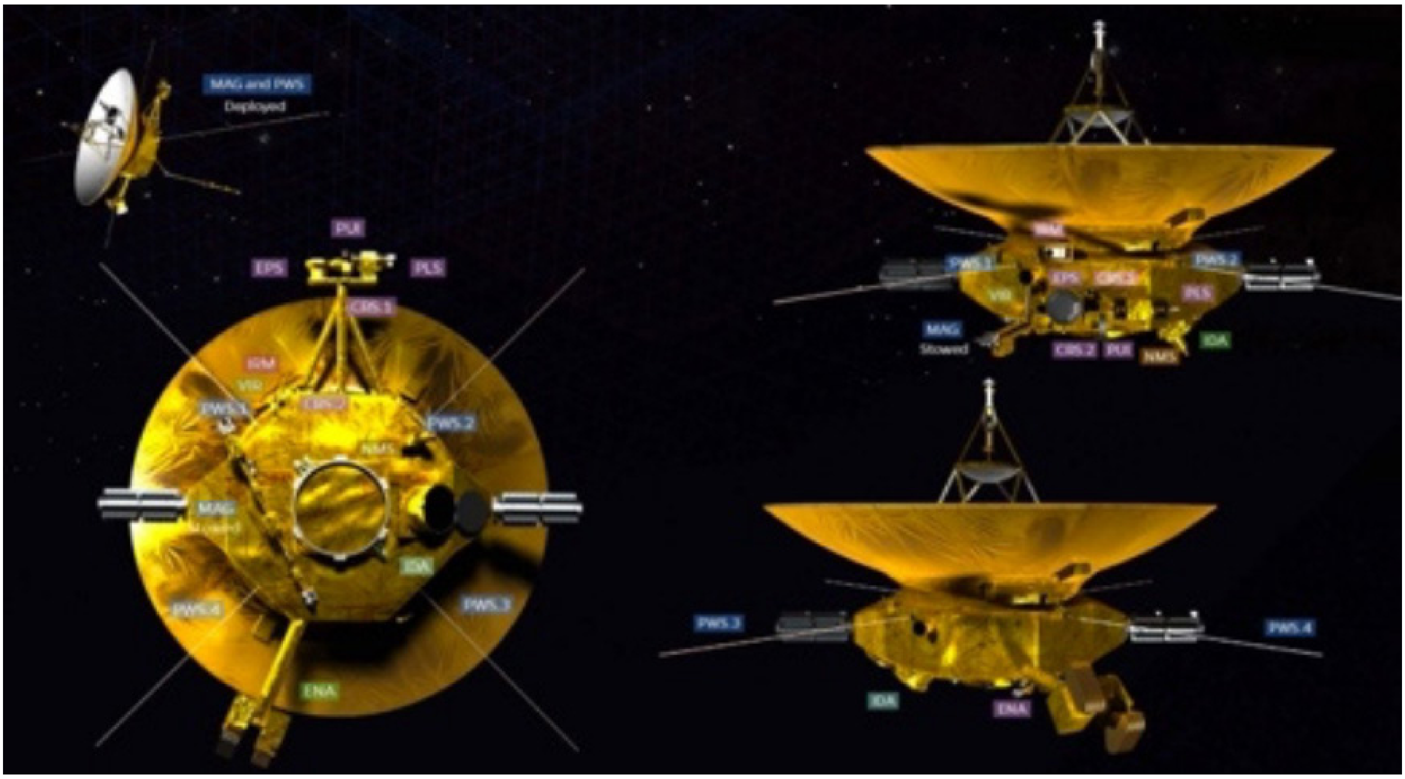


Figure 4 Instrument Layout for the Augmented Mission
Credit (image and caption): McNutt et al

Mission details include the Launch Vehicle where initial work had focused on the notional SLS Block 2 Cargo configuration as an SHLV that should be available in the 2030s and also have the appropriate number of launches to be certifiable for including a radioisotope power supply (RPS) akin to the notional NextGen Radioisotope Thermoelectric Generator (RTG) now under development by the Department of Energy (DOE) for NASA.

The mass and power requirements for both baseline and augmented mission were agreed to be "payload agnostic" with appropriate margins and reserves to inform the mass of the spacecraft till the completion of new thermal material investigation. In addition, the team developed an analytic tool to estimate flyout times and asymptotic solar system escape speeds using coplanar, circular orbits for Jupiter and Earth and a patched conic approximation to deal with flybys for -

• Option 1 (passive Jupiter flyby),

• Option 2 (powered Jupiter flyby),

• Option 3 (passive Jupiter flyby.

- followed by a powered close-Sun flyby (perihelia of 2 to 6 solar radii from the centre of the Sun in steps of one solar radius). A "best" Option 1 and Option 2 configuration were then examined in depth across the Jupiter orbit of the Sun from 2030 through 2042 for looking at more launch details, including science enabled for the final aim point in the sky.

For telecommunication, a set of trades were made across X-band, Ka-band, and optical downlink, and use of ground-assets as receiving stations. At the spacecraft systems level, the favourable choice is a 5 m diameter high gain antenna (HGA).

The sustainability of the mission targeted lifetime of 50 years and the fund for such mission were also considered in the mission study. An overview of the mission top level requirements can be shown in Fig. 5.

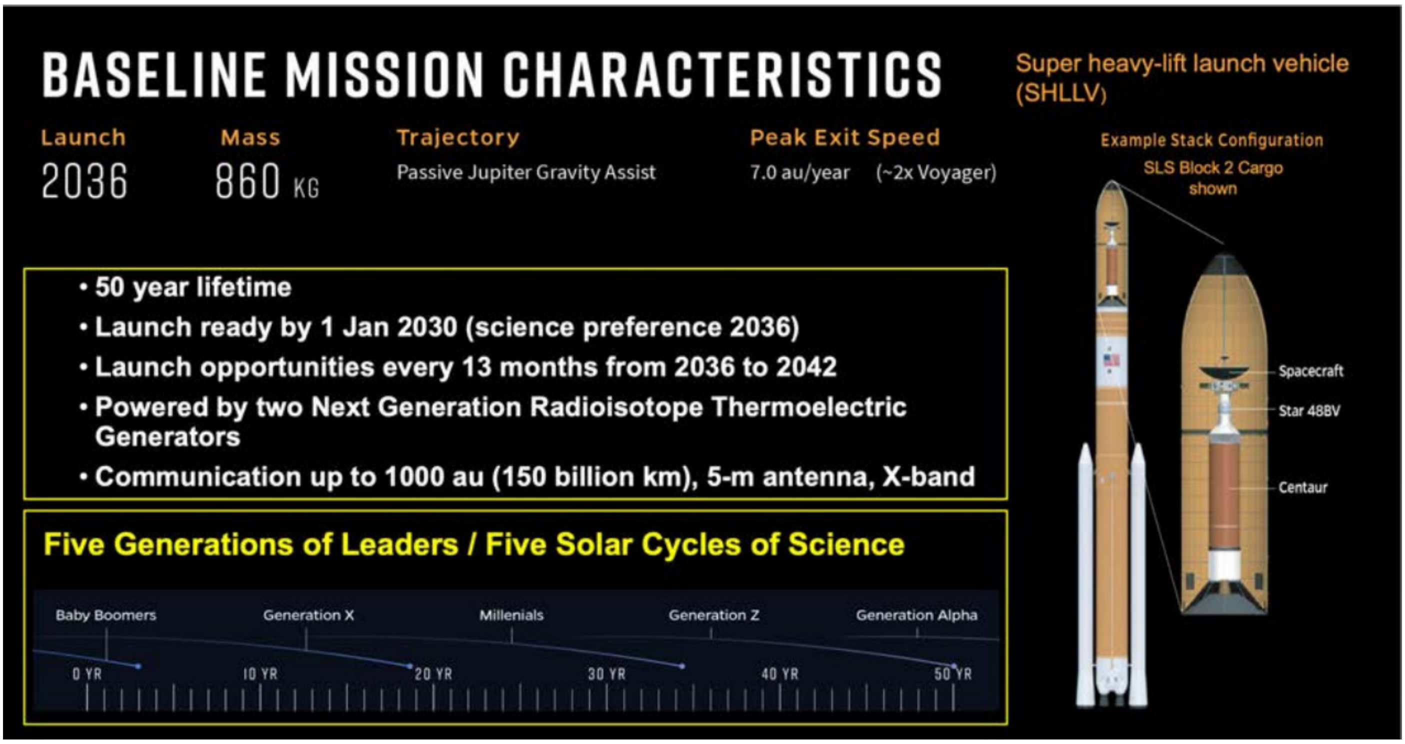


Figure 5 Baseline Mission Summary & Overview
Credit (image and caption): McNutt et al

In general, the Interstellar Probe mission has been an iterative one so most of the work updates have been progressively shared during IAC events but also collectively presented in the mission report published to the public. Thus, it is recommended to go through the Interstellar Probe report (interstellarprobe.jhuapl.edu/).

IAF ref	title of talk/paper	presenter	institution	nation
A6.1.x71592	On-orbit Optical Detection of Lethal Non-Trackable Debris	Mr Andrew Nicholas	Naval Research Laboratory	USA

IAF abstract: iafastro.directory/iac/paper/id/71592/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A6/1/manuscripts/IAC-22,A6,1,8,x71592.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A6/1/presentations/IAC-22,A6,1,8,x71592.show.pptx

Open paper: none found

Reported by: Samar AbdelFattah

Concerned by the alarming rate of increase of debris objects, small objects in the size of few centimetres to 0.1 mm are considered in this paper. Since they are abundant, difficult to track or even to detect on a routine basis, and have enough kinetic energy to damage spacecraft, they are labelled as "lethal-non-trackable" objects. A sample of damage caused by small objected moving at orbital velocities is shown in Fig. 1.

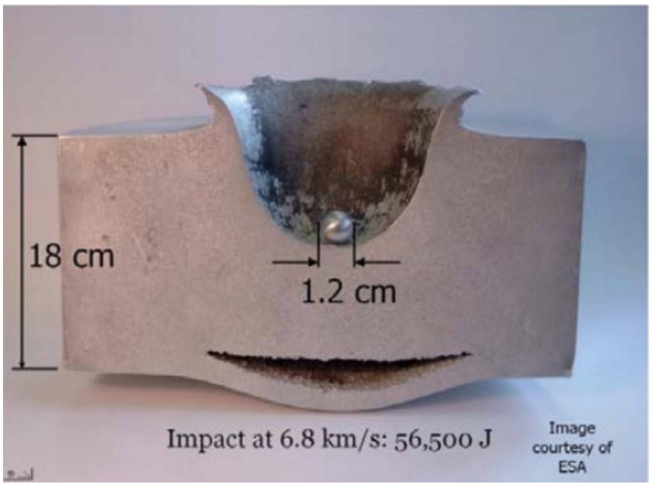


Figure 1 Damage caused by a 1.2 cm diameter aluminum sphere striking an 18 cm thick plate of aluminum at 6.8 km/s. Credit: ESA

The paper presents a method, Lightsheet Anomaly Resolution And Debris Observation (LARADO), to use a sensor-based light sheet that would be able to detect photons passing by the host spacecraft. The concept will enable detection of tiny to small objects that the current concept won't be able to detect.

The lightsheet is created via a collimated light source that is connected to a diffusive optic, such as an axicon, Powell lens, or engineered diffuser. An optical lens coupled to a detector provides a method to monitor the scene. This system creates a virtual witness plate (VWP) for debris observations as seen in Fig. 2 with a scalable functional area defined by the system components including the laser power, the diffusive optic, the lens field of view (FOV) and aperture, and the detector sensitivity.

The LARADO system will be hosted on the DoD Space Test Program on the STP-Sat7 spacecraft.

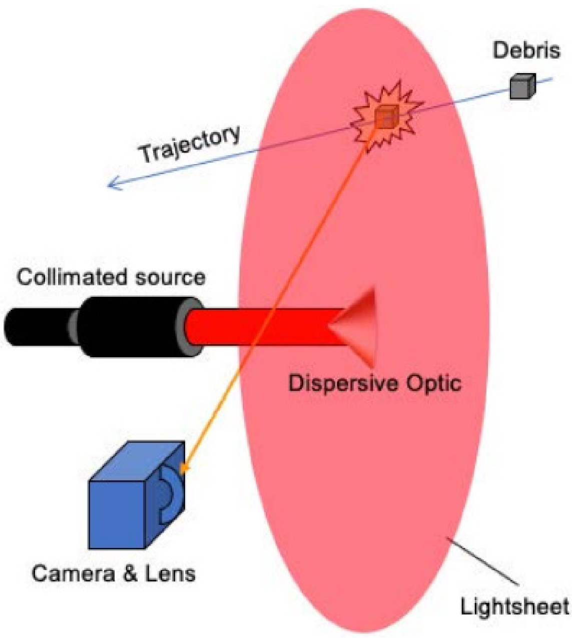


Figure 2 Representative Components for the LARADO Sensor Concept. Credit: Nicholas et al

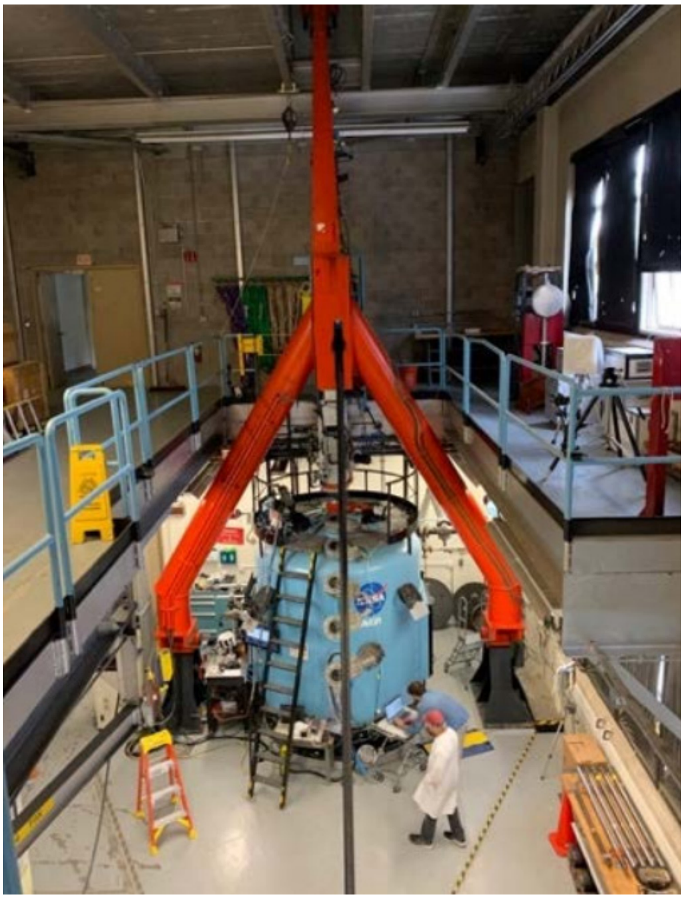


Figure 3 Presents a photo of the AVGR facility, the blue structure is the vacuum chamber, the orange structure raises and lowers the gun.
Credit: Nicholas et al

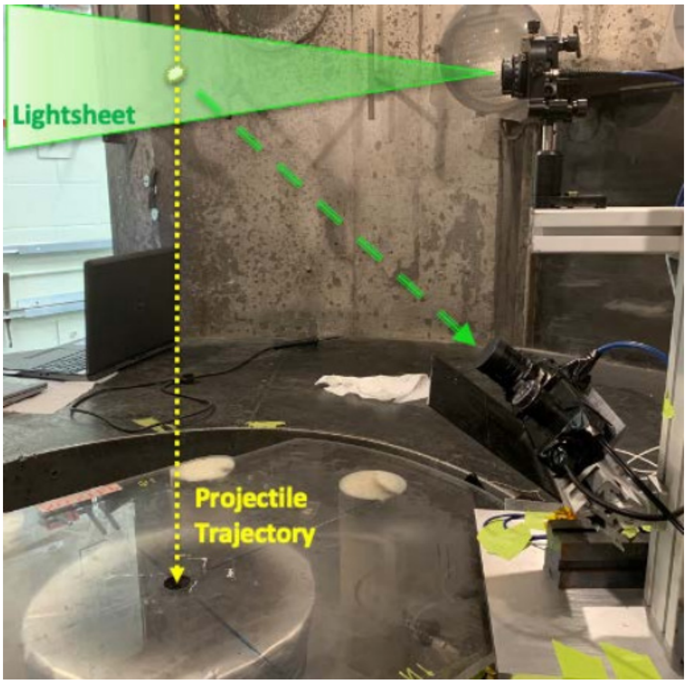


Figure 4 Annotated photo of the LARADO test setup in the AVGR chamber
Credit: Nicholas et al

Testing

The system was tested at the NASA AMES using the Ames Vertical Gun Range (AVGR), Fig.3. With its unique hinged gun apparatus, the AVGR can vary the impact angle relative to the gravity vector (from horizontal to vertical). Targets are contained within a large impact chamber that can be evacuated to simulate impacts on an airless body or backfilled with air or various gases to simulate different environments. The LARADO test support frame was constructed from 80/20 hardware with a 1/2” thick aluminium plate as its base. The setup includes: two cameras, a Ximea and a Prophesee (see below), and the laser sheet generation assembly. A photo of the system during test setup is shown in Fig. 4.

For the laser setup, a survey for available laser and fibre optic combinations was made. Minimal size, weight, and power for future space flight opportunities were the main features during the selection process. Wavelengths compatible with COTS optics and sensors were also necessary. The test reported in this paper was operated at settings that produced 15W optical output.

The light sheet generation was employed through two different methods in general. The first one was using an engineered diffuser which is an array of micro lenses generated by micro replication in a polymer. The engineered diffuser worked well at lower power but the micro lenses and their plastic substrates melted at higher laser powers at exposures of over 1 minute.

Thus, the second method was used in the test presented in the paper, which used cylindrical lens called Powell lens to generate the light sheet. The cylindrical lens made of glass can be figured to produce uniform light sheets based on the laser beam diameter and intensity distribution and is able to survive the 30 W beam in vacuum without convective cooling.

In addition to the laser setup and light sheet lens, two cameras were used as part of the test setup in the AVGR. A XIMEA camera and Prophesee (Neuromorphic) camera. Table 1 shows the angular fields of view (FOV) for the two cameras with various short focal length lenses.

Table 1. Camera and Lens Specifications

Camera	Ximea 1" format	Prophesee 1/2.5" format				
	length	width	diagonal	length	width	diagonal
Chip size mm	12.485	9.988	15.989	6.220	3.499	7.136
Focal length mm	FoV full angle deg.					
2	144.47	136.35	151.91	114.51	82.36	121.46
4.7	106.05	93.47	119.10	66.99	40.83	74.41
6	92.27	79.54	106.22	54.80	32.51	61.48
8	75.93	63.95	89.96	42.49	24.67	48.08
10	63.95	53.08	77.28	34.55	19.85	39.28
12.5	53.08	43.56	65.20	27.94	15.93	31.86
14	48.06	39.26	59.45	25.05	14.25	28.60

Credit: Nicholas et al

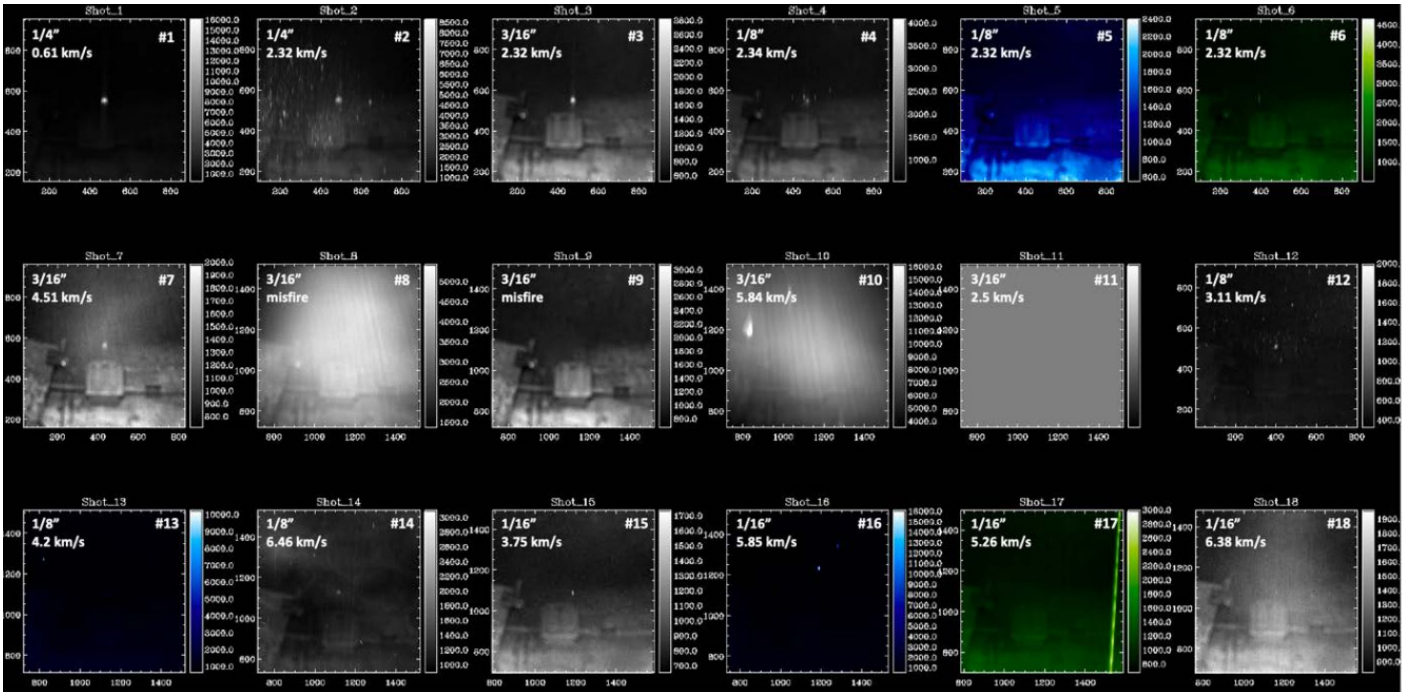


Figure 5 Cropped (100 x 100) differenced 18 shots. Grayscale images represent alumina shots, green represent quartz or borosilicate glass, and blue images represent aluminum projectiles
Credit: Nicholas et al

AVGR Data

In total twenty shots were taken over a test period of five days at the AVGR facility. Six shots were taken with the powder gun (PG), twelve shots were taken with the light gas gun (LGG), and additional two LGG shots were taken in an alternate configuration for an application on the surface of the moon. The analysis was then carried out by creating image difference between the simulated debris event crossing frame and the frame of image before using the Ximea CCD camera images. The difference images were represented for alumina, quartz, borosilicate glass and aluminium projectiles. The 18 shots used in the analysis had exposure times of 40 ms, and the start of the exposure time was random with respect to the projectile crossing time, hence sometimes there is little gas accumulation in the frame with the event and other times there is a lot. This gas accumulation along with Light Gas Gun (LGG) misfires, different signal strengths, and camera connection issues were shown in the 18 shots sequence, Fig 5.

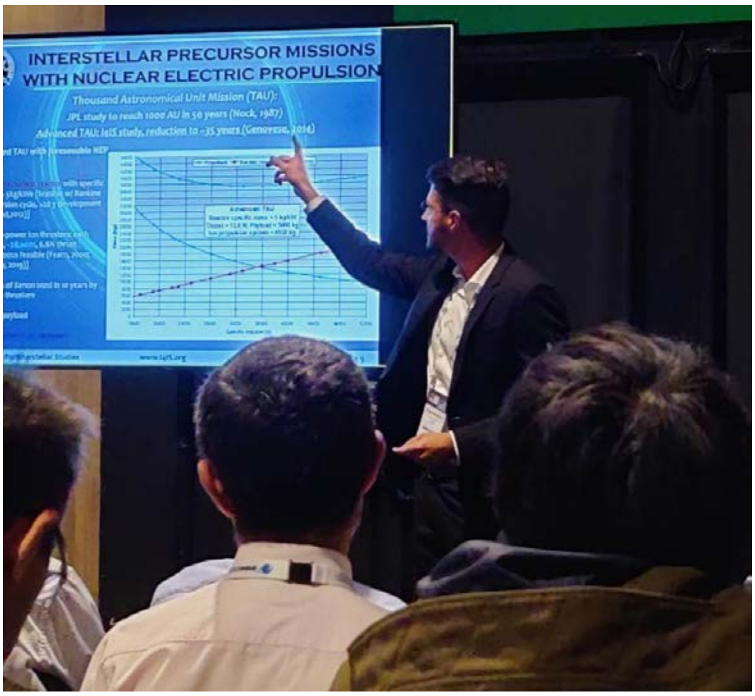
The Prophesee neuromorphic camera was able to measure the projectiles crossing the laser sheet but after the optic filter issue were fixed by fitting stock 5 mm lens. However, further analysis and tuning of the neuromorphic camera's bias settings are planned for future research. In general, lasersheet technique has been verified using small projectiles at near orbital velocities. This has increased the technological readiness level (TRL) of the LARADO sensing technique to TRL 6 on the NASA scale. Critical Design Review (CDR), along with future work is expected to be done to include the LARADO instrument on the STPSat-7 spacecraft which is expected to launch early-mid 2024.

Impressions of IAC22

Nadim Maraqten

There was much to remark upon at IAC22 - as for all IACs. Here are some images gathered by Nadim Maraqten, Researcher, Initiative & Institute for Interstellar Studies and Student Research Assistant Electric Propulsion Lab, University of Stuttgart.

Interstellar Session: Strategies for Rapid Implementation of Interstellar Missions - Precursors and Beyond



i4is Presentation on Advanced Electric Propulsion Concepts - see IAC-22,D4,4,3,x73132 in *News Feature: IAC 2022* in this issue

Germany Corner at the Exhibition - Stand on the left is OHB (Orbitale Hochtechnologie Bremen), on the right is the German Space Agency DLR

Greeting by the Arianespace Engines at the Entry of the Exhibition

Arianespace Engine: We think this the Vulcain engine of Ariane 5 core stage - but please correct us if we are wrong!

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

JBIS

4 issues of JBIS (May, June, July, August 2022) have appeared since the report in our last issue, P38.

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

JBIS VOLUME 75 NO.5 MAY 2022		
Utilising a Nuclear Transport System as an Earth Orbit Transfer Vehicle	Mark Hempsell	Hempsell Astronautics Limited, UK
The Scorpion is a multi-role crewed transport vehicle designed to extend the human space infrastructure beyond low Earth orbit. One of these roles is as an orbit transfer vehicle to reach higher Earth orbits. The payloads to circular orbits between geostationary to one and half million kilometres from a 400 km altitude orbit using Hohmann transfers were found to range between 465 to 640 tonnes, with the minimum around 100,000 km. Orbits above that, in High Earth Space, have increased payload as the altitude increases. This highlights a little appreciated fact that most of High Earth Space is easier to reach than geostationary orbit. Geostationary, Earth/Sun L2 and various lunar support missions are looked at in more detail. An example geostationary payload was created which suggests the payload provisions on the Scorpion have difficultly handling cargo at its maximum mass. So, for most missions the Scorpion would probably be used well below its capability but this does not introduce any serious inefficiency. A comparison is also made with an orbit transfer vehicle called Taurus which repackages the Scorpion's propulsion system into a simpler rocket stage. This increases the payload by a third but requires spaceports to operate and is therefore more suited to increasing the capability of an architecture already established by the Scorpion.		
Toward the Engineering Feasibility of the Centrifugal Nuclear Thermal Rocket	Dale Thomas et al	University of Alabama in Huntsville
The Centrifugal Nuclear Thermal Rocket (CNTR) is a Nuclear Thermal Propulsion (NTP) concept designed to heat propellant directly by the reactor fuel. The primary difference between the CNTR concept and traditional NTP systems is that rather than using traditional solid fuel elements, the CNTR uses liquid fuel with the liquid contained in rotating cylinders by centrifugal force. If the concept can be successfully realized, the CNTR would have a high specific impulse (~1,800 s) at high thrust, which may enable viable near-term human Mars exploration by reducing round-trip times to ~420 days. The CNTR could also use storable propellants such as ammonia, methane, or hydrazine at an Isp of ~900 s, enabling long-term in-space storage of a dormant system. Significant engineering challenges must be addressed to establish the technical viability of the CNTR. Research is presently underway to determine resolutions for these engineering challenges. In particular, research has begun on the analytical modeling and simulation of the two-phase heat transfer between the liquid metallic uranium fuel and the gaseous propellant. Subsequent research will progressively address the remaining CNTR engineering challenges.		

VOLUME 75 NO.6 JUNE 2022		
Space-Based Solar Power: a Literature Survey from The Journal of the British Interplanetary Society	Griffith J Ingram	British Interplanetary Society
A literature survey of past papers in the Journal of the British Interplanetary Society that have in some way considered the use of space generated energy to meet terrestrial power demand has been performed, in order to make past work on this topic more accessible.		

VOLUME 75 NO.7 JULY 2022		
Comparative Overview of Nuclear Electric Propulsion Programs and Concepts	Manuel La Rosa Betancourt et al	NeutronStar Systems UG, Köln
Human space exploration is at the dawn of a new era. The desire to establish a permanent presence beyond low Earth orbit (LEO) has never been higher. The Moon and Mars are first targeted to demonstrate our ability to extend our expanse. As of today, the alternatives offered by the likes of SpaceX, Blue Origin and others are not sustainable. Chemical propulsion will not be the solution for humanity to explore other worlds. Other forms of propulsion offer a more compelling and sustainable alternative: Nuclear Electric Propulsion (NEP) is the key to unlock more cost-effective and sustainable space transportation for interplanetary voyages. NEP combines the unmatched megawatt level of power provided by a nuclear reactor with the high specific impulse (Isp) of electric propulsion. This would enable cargo missions to the Moon, Mars and beyond, on a larger scale than the low Isp chemical propulsion would allow and at a higher cost-efficiency. The development of such technologies is at the core of the new space race. It dictates the direction and evolution of NEP programs and concepts. This paper presents an overview of the geopolitical and technological considerations behind different NEP programs worldwide. While the two major actors remain NASA and ROSCOSMOS, other space agencies such as CNSA, ESA and UKSA have shown extended interest in the progress of NEP. Amongst the various types of electric propulsion systems, Gridded Ion Thrusters (GIT) and Hall Effect Thrusters (HET) are usually the first considered for NEP use due to their high space heritage at low power levels (several kilowatts). However, GIT and HET present a number of fundamental drawbacks at higher power levels: scalability limitation, number of thrusters needed and lifetime concerns. Superconductor-based Readiness Enhanced Magnetoplasmadynamic Electric Propulsion (SUPREME) could be a better alternative for high power manned and cargo missions from LEO to the Moon or to Mars. Applied-Field Magnetoplasmadynamic (AF-MPD) Thrusters have been around since the 1960s, they offer a range of operations wider than any other existing electric propulsion technology. Recent developments achieved by the Institute of Space Systems at the University of Stuttgart have proven thrust efficiencies over 62% with the use of LaB6 hollow cathodes. This paper reviews current concepts and programs for NEP, and underlines the possibilities offered by MPD thrusters, especially by Neutron Star Systems' SUPREME thruster, for these NEP programs and concepts.		

Active Debris Removal – Policy and Legal Feasibility	Josef Koller et al	The Aerospace Corporation, USA

Over the last few decades, the complexity of space operations has grown, the number of commercial entrants into the space economy has increased, and the amount of space debris has inflated to a degree that threatens space operations and often requires satellites to maneuver to avoid collisions. Such maneuvers are becoming more common in certain orbital regimes. Preventing the creation of new debris is one way to preserve the space operational environment; removing debris is another. Yet viable options for Active Debris Removal (ADR) remain elusive due, in part, to technical, economic, and legal challenges. Without diminishing the technical and economic challenges of ADR, this paper focuses on the legal questions associated with ADR which are often described as seemingly insurmountable. Our proposed framework aims to resolve these legal questions by applying a simple, bottom-up approach based on mutual consent, regulatory approval, and contractual agreements between participants. Our approach contrasts against the often-discussed comprehensive approach that promotes multilateral agreements and the establishment of international institutions as a necessary means. Recognizing that building a comprehensive, international framework is fraught with challenges, our framework instead centers not on what is difficult, but on what is achievable: (1) removing debris involving only one nation or (2) removing debris where the service provider and the debris owner share the same interests and recognize the need for active debris removal. Further, this framework offers an initial first step towards establishing that active debris removal is indeed legally feasible, leading the way to eventually building more comprehensive debris removal agreements between states at a future time.

A Potential Legal Basis for Harvesting Orbital Debris Without the Owner's Prior Consent	George A Long	Legal Parallax LLC, USA

Outer Space Treaty Article VIII is construed as prohibiting the salvage of orbital debris as it expressly provides perpetual ownership of a space object and its component parts. Pursuant to Article VIII, ownership of a space object and its component parts is "unaffected by their presence in outer space or on a celestial body or by their return to Earth." This concept impedes orbital debris removal as it is construed as requiring a third party to obtain the debris owner's prior consent as a prerequisite for touching the space junk. This legal obstacle necessitates an analysis of the space law treaty regime which will allow orbital debris removal without the owner's prior consent. Accordingly, Rescue Agreement Article 5 can be read and interpreted as providing a potential legal avenue for a third party harvesting orbital debris without obtaining the owner's prior consent.

A Technical Description of Some Scorpion Derivatives	Mark Hempsell	Hempsell Astronautics Limited UK

The Scorpion is a general purpose nuclear powered transport system that can operate from low Earth orbit out to Venus and Mars orbits and can prepare for missions by directly interfacing with the launch system without any other in orbit support. In an extension to the initial outline of the basic spacecraft, the study explored three specialist derivatives of the Scorpion that can transport cargo (Taurus), propellant (Aquarius), and people (Zibanna). It was found that significant improvements in performance could be achieved with these specialist systems without advancing technology. However, this approach to establishing a compete infrastructure requires much higher acquisition investments, both in new system level developments and the establishing of supporting spaceports. Such investments can only be justified if there is a mature and extensive level of activity that has evolved from the initial programmes in high Earth orbits and lunar environment. But in the expectation of such expansion and evolution it makes sense for the very high value investments, like the nuclear rocket engines, to include the likely requirements for the next generation specialist systems to be included in their initial development for the first generation system.

VOLUME 75 NO.8 AUGUST 2022 Special Interstellar Issue		
Galactic Crossing Times for Robotic Probes Driven by Inertial Confinement Fusion Propulsion	Kelvin F Long	Stellar Engines Ltd, UK
In the future it is possible that spacecraft may be constructed that can travel to the nearby stars and beyond to the wider galaxy. The speed of those spacecraft will depend on the type of reaction engine adopted for the mission. This work considers the transport of replicating robotic probes across the galaxy driven by Inertial Confinement Fusion propulsion (ICF) engines. This includes an examination of a range of possible wave speeds with the addition of stopping time for material mining acquisition and self-replication. The work also discusses reducing cruise velocity for probe random walk pathways as a function of percentage performance degradation with each n generation where the distance attained per crossing is proportional to $\sqrt{n}$. For probes in the engine pulse frequency range of ~100-1,000 Hz it is found that galactic crossing times of order ~1-4 million years may be feasible depending on the average cruise speed of the spacecraft over the range 0.05-0.15c. This will require a total of 20,000-40,000 separate individual probes or star hops to accomplish the full crossing of the galactic diameter. Dispersal calculations are also performed for both exponential population growth and exponential population decay of robotic probes. Some implications for the Fermi paradox are discussed as a spatial-temporal variance model. It is then estimated that for robotic probes a galactic crossing may be possible in ~1-2 million years through the galactic disc, or may be as low as ~0.5-1 million years assuming a central starting position of the probe population since it is a spherical dispersal wave, or assuming multiple seed populations of probes. It is argued that an exploration strategy of this form may have a high dependence on the ability of the probe to maintain its design specification and performance and may exhibit pathway dissipation and random walk along the trajectory. Finally, we give a brief discussion on search strategies for the detection of robotic probes. It is concluded that such probes are likely already here within the vicinity of our solar system despite the limited performance constraint of using ICF propulsion technology. In addition, probability favours that they would likely originate from a star system of less than ~200 ly distance from Sol which is suggestive of search priorities for their detection.		

Self-Replicating Interstellar Probes and Runaway Growth Reconsidered	Stephen Ashworth	Oxford UK
The idea of a robotic interstellar probe which, after arrival in the planetary system of a nearby star, constructs a copy of itself and launches it towards a star more distant from its point of origin, has been a popular one in the technical and science-fiction literature. Some recent papers have claimed that such machines will necessarily fail after a certain number of generations, and thus the volume of space explored by them will remain small on a galactic scale. The question is reconsidered taking into account the likely growth rates, propulsion methods, sizes of seed economy, and motivations of actors in the launching civilisation as well as of the machines themselves. It is concluded that self-replicating probes are indeed likely to emerge as a natural consequence of interstellar exploration and that they may spread freely on a galactic scale, given favourable initial conditions. Their observational absence in the Solar System is a constraint on the abundance of industrial life in the Galaxy, but only a weak one: one or a very few instances of such civilisations are not ruled out.		

Acta Astronautica

Title	Number+date	Author	Affiliation
Abstract/Précis/Highlights			

Design of impulsive asteroid flybys and scheduling of time-minimal optimal control arcs for the construction of a Dyson ring (GTOC 11)	Volume 201, December 2022	Carlos Ortega Absilet et al	Thales Services Numériques, France
This paper describes the approach used by the team named the Eccentric Anomalies to obtain the sixth best solution to the problem of the eleventh Global Trajectory Optimization Competition, whose futuristic scenario of Dyson sphere building remained mathematically relevant for current space mission design and engineering in general. As usual for this recurring challenge, it involved large-scale combinatorics at a high level and a multitude of optimal control problems at a lower level. Furthermore it proposed additional layers of complexity by adding a strong scheduling component to the usual flyby sequencing, and by featuring both impulsive and continuous-thrust trajectories. The authors took advantage of modern theoretical techniques and open-source tools to put together a sequential process including analysis based on analytical trajectory models, tree searches using efficient data structures, global and local finite-dimensional optimization and multi-objective trade-offs. The optimal control part was both tackled with direct transcription as well as indirect shooting methods, and the mixed-integer scheduling reformulated as a bi-level optimization. From a programming point of view, the main framework was set in an interpreted language whilst using as much as possible dependencies written in compiled ones for speed.			

High-temperature superconductor-based power and propulsion system architectures as enablers for high power missions	Volume 201, December 2022	Marcus Collier-Wright et al	Neutron Star Systems UG, Germany
The increasing competitiveness of electric propulsion systems (EPS) for primary spacecraft propulsion has paved the way for higher payload mass fractions by offering significantly higher specific impulses than chemical systems. Concurrently, High-Temperature Superconductors (HTS) have reached an unprecedented level of industrial maturity in recent years, and considering their low masses, compactness, and high current densities, they offer the potential to act as a disruptive technology in several spaceflight applications such as power management systems, re-entry and radiation shielding as investigated in the EU-funded MEESST project, as well as EPS. In the latter case, efforts are already ongoing to develop an HTS-enhanced Applied-Field Magnetoplasmadynamic (AF-MPD) thrusters for high power mission applications. The Tsiolkovsky equation infers that the payload mass fraction increases indefinitely with increased Specific Impulse (I_{sp}), however, in the case of electric propulsion, the dependence of thrust on the available power complicates this issue when transfer time is a primary driver. Here, the Tsiolkovsky equation becomes inadequate and considering a non-dimensional version of the Tsiolkovsky equation in terms of the mission ΔV and transfer time, the EPS thrust efficiency, and the specific mass of the power system becomes necessary. This paper first discusses the recent advances in HTS and their suitability for spaceflight, before reviewing. The development of power system technologies is reviewed and a conceptual power system architecture incorporating HTS is presented. These technologies are analysed using a non-dimensional Tsiolkovsky approach and their impacts on the overall payload mass fraction are assessed. For high-power missions (>100 kW), the use of HTS is shown to have a highly beneficial impact on the mass of the power system. Correspondingly, this enables higher payload mass fractions achievable at increased specific impulse operation, thus strengthening the case for high-power, high-I_{sp} EPS technologies such as AF-MPDT.			

Structural stability of a lightsail for laser-driven interstellar flight	Volume 201, December 2022	Dan-Cornelius Savu, Andrew J Higgins	McGill University, Canada
The structural stability of a lightsail under the intense laser flux necessary for interstellar flight is studied analytically and numerically. A sinusoidal perturbation is introduced into a two-dimensional thin-film sail to determine if the sail remains stable or if the perturbations grow in amplitude. A perfectly reflective sail material that gives specular reflection of the laser illumination is assumed in determining the resulting loading on the sail, although other reflection models can be incorporated as well. The quasi-static solution of the critical point between shape stability and instability is found by equating the bending moments induced on the sail due to radiation pressure with the restoring moments caused by the strength of the sail material and the tension applied at the edges of the sail. From this quasi-static solution, analytical expressions for the critical value of elastic modulus and boundary tension magnitude are found as a function of sail properties (eg thickness) and the amplitude and wave number of the initial sinusoidal perturbation. These same expressions are also derived from a more formal variational energy (virtual work) approach. A numerical model of the complete lightsail dynamics is developed by discretizing the lightsail into rectangular finite elements. By introducing torsional and rectilinear springs between the elements into the numerical model, a hierarchy of models is produced that can incorporate the effects of bending and applied tension. The numerical models permit the transient dynamics of a perturbed lightsail to be compared to the analytic results of the quasi-static analysis, visualized as stability maps that show the rate of perturbation growth as a function of sail thickness, elastic modulus, and applied tension. The analytic theory is able to correctly predict the stability boundary found in the numerical simulations. The stiffness required to make a thin lightsail stable against uncontrolled perturbation growth appears to be unfeasible for known materials, however, a relatively modest tensioning of the sail (eg via an inflatable structure or spinning of the sail) is able to maintain the sail shape under all wavelengths and amplitudes of perturbations.			

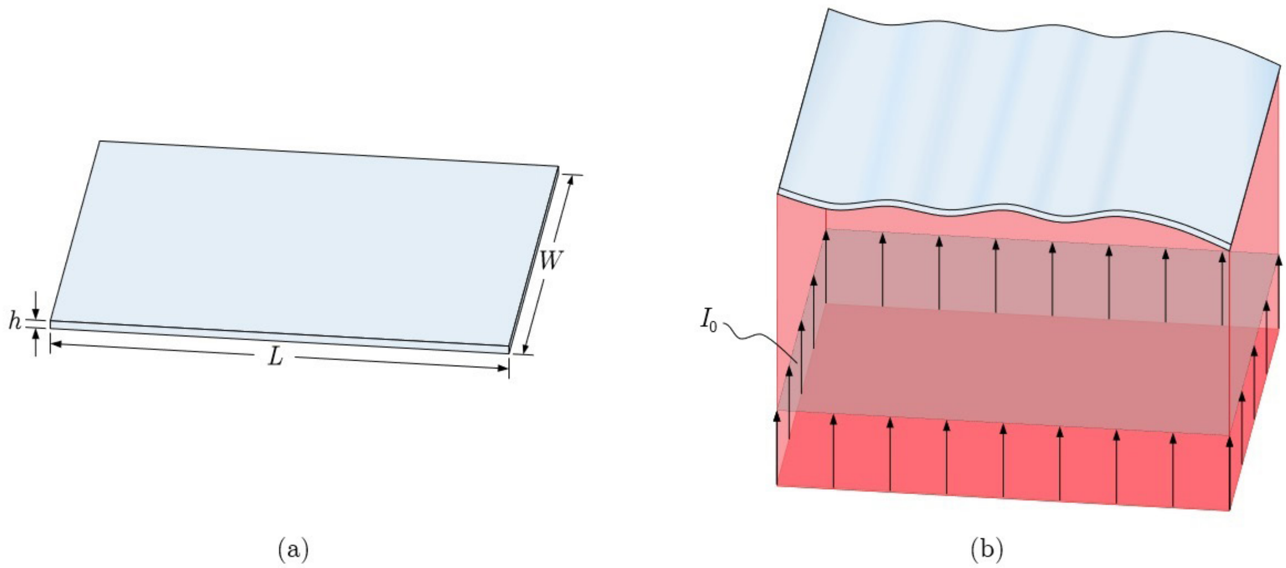


Figure 1: Three-dimensional analytical (plate) model of the lightsail; (a) the lightsail, flat; (b) the lightsail, smoothly perturbed with an incident uniform laser beam.
The problem here considered is whether the perturbations will grow in amplitude or not under the large laser loads
Credit (caption and image): Savu and Higgins, arxiv.org/abs/2210.14399

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‘Oumuamua: A Second Chance?

A Personal Memoir

Adam Hibberd

In this piece our finest astrodynamicist recollects how he came to be involved with i4is and how this developed into the highly productive relationship he now has with colleagues in both the technical and production teams.

A Fateful Day

Although I didn’t realise it at the time, Thursday October 19th 2017 was a fateful day in my life. Previously that year I had been working on a personal project – a software application I called Optimum Interplanetary Trajectory Software (OITS), deriving all the necessary theory and equations whilst on holiday in Staffordshire, near Cheadle. My interest in the subject originated through my involvement in the ‘90s as a software engineer in the space industry. Subsequent to leaving this position, I was diagnosed with a mental health condition , and from 2001 onwards attempted to organise some kind of a living for myself as a pianist and composer. Indeed I had through the services of the Coventry Pod established myself on the arts scene in Coventry, and I’d like to think that my efforts were not entirely unrelated to the city eventually receiving the accolade of ‘UK City of Culture’ in December 2018. I had

before this fateful Thursday occasionally posted the animations and plots generated by my software on Facebook, although to be honest a lot of my artist friends were rather dubious and unimpressed by the whole venture, despite my enthusiasm at what my software was capable of achieving - at this time it was reproducing to great fidelity and with comparative ease historical missions to the planets like Cassini (Saturn), New Horizons (Pluto), Voyager (J-S-U-N) missions etc, etc.
However I am being rather egocentric when I mark this Thursday out as being a personally fateful one, because in fact it changed the lives of many members of a particular community of human beings – scientists and, to be more specific, astronomers and astrophysicists. It was on this fateful Thursday that astronomers, or an astronomer, made a momentous discovery. The astronomer in question was Robert Weryk, working for the PanSTARRS observatory on the Hawaiian island of Haleakala.
On Thursday October 19th 2017 the first interstellar object was discovered passing through our Solar System, which was later designated 1I/'Oumuamua.

Interstellar Objects

So what is an interstellar object (ISO)?
We live on the planet Earth, just one of many celestial bodies belonging to our own solar system. Now what is it about a particular object, say the planet Jupiter, which defines it as belonging to our solar system and not to a different system elsewhere in the Milky Way galaxy, like Proxima Centauri for example?
You might respond that it is simply Jupiter's proximity to our star, the sun. You would have a point but this isn't the whole story. Look at it this way: not only is Jupiter close to the sun but we know it's going to stay that way indefinitely (or at least as far into the future as we are able to accurately predict) - it will always remain bound to it.
In the language of science, more specifically orbital mechanics, Jupiter is in a bound elliptical orbit (almost circular) around the sun because its orbital eccentricity, e, is below a value of 1.
Interstellar objects stubbornly refuse to obey this condition, their orbital eccentricities, e, are greater than 1. This means that these objects are in hyperbolic orbits, so will escape the sun and never

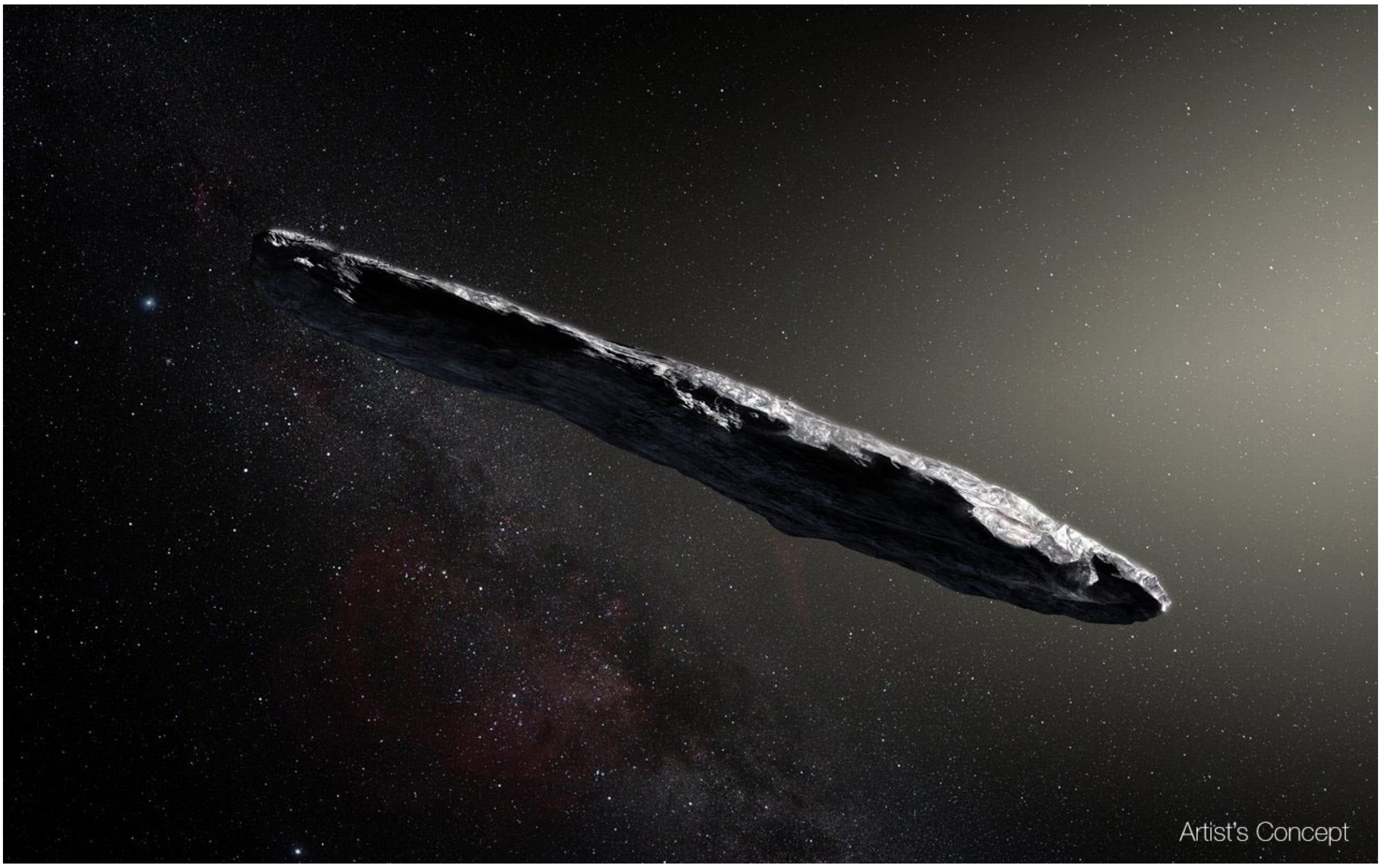

Figure 1 Image Credit: European Southern Observatory / M Kornmesser

return. It turns out by conservation of energy, they must have arrived from a great distance - originating from somewhere else in the Milky Way galaxy - and will also escape to a great distance. So 'Oumuamua has the honour of being the first interstellar object discovered in our solar system, travelling through it with such a speed, that even the gravitational pull of the sun will not prevent it from continuing its journey, out of our celestial locale and on to somewhere else in our galaxy.

An Opportunity

The news was reported widely in newspapers and initially I made no connection to my own work, which at that time involved using OITS to replicate old NASA/ESA robotic missions to the planets. It suddenly dawned on me a week or two later, possibly stimulated by the reference to 'Rendezvous with Rama' (the Arthur C Clarke sci-fi novel) in the papers, that I could study the feasibility of spacecraft missions to 'Oumuamua.
The first 'eureka moment' came when I was able to acquire a binary SPICE kernel file for 'Oumuamua through the NASA Horizons service [1]. To clarify here, essentially for my software to operate it needs precise positions and velocities of the planets and other celestial bodies – in fact whichever bodies are the subject of investigation by the user. In simple language, we need to know where a planet is, in order to work out how a spacecraft might get there.
No problem, NASA can do this you might think. You'd be right – there is some free software called SPICE [2] which, in combination with NASA data files for each object (called kernels) you can link in with OITS, and which OITS can then use to solve trajectories to it. Lo-and-behold it so happened I could generate just such a file for 'Oumuamua. So this was the first step. However further issues remained before I could research missions using OITS.

Optimum Trajectories

With Optimum Interplanetary Trajectory Software (OITS), the user selects a sequence of celestial bodies to be visited by a spacecraft launched from Earth. Depending upon your knowledge of the field, you may be surprised that the direct route isn't always the most efficient or effective to get to a target body in our solar system. Sometimes visiting objects in-between launch from Earth and arrival at the target can be beneficial, despite invariably taking a longer time.
The reasoning behind this becomes clear when one analyses what is actually meant by 'beneficial' in this context – how is it quantified? Generally in the domain of space, scientists and engineers want to limit the mass budget of a mission to as low as possible. The reasoning for this is many-fold but two of the most compelling reasons are (a) the cost of launching spacecraft grows dramatically with the mass of the spacecraft payload, and (b) the lower fuel mass means that more mass is available to dedicate to useful stuff - like instrumentation for example - which will be needed to satisfy the mission requirements.
It so happens that a spacecraft manoeuvre known as gravitational assist (GA), where the spacecraft slingshots close by a planet, is a useful mechanism by which its speed relative to the sun can be augmented without the necessity for thrust being applied by its on-board engines, and so requiring no precious fuel. Hence to reach a particular destination (and so the reason why a user might specify a planet or certain sequence of planets to visit on the way), it would seem exploiting a GA, or even multiple GAs, might be extremely advantageous for mission planners in that less fuel would be consumed.
Now back to the story.

[1] ***Horizons System***, The JPL Horizons on-line solar system data and ephemeris computation service provides access to key solar system data and flexible production of highly accurate ephemerides for solar system objects (1,233,593 asteroids, 3,826 comets, 211 planetary satellites {includes satellites of Earth and dwarf planet Pluto}, 8 planets, the Sun, L1, L2, select spacecraft, and system barycenters). Horizons is provided by the Solar System Dynamics Group of the Jet Propulsion Laboratory. https://ssd.jpl.nasa.gov/horizons/
[2] ***The SPICE Toolkit.*** NASA's Navigation and Ancillary Information Facility (NAIF) was established at the Jet Propulsion Laboratory to lead the design and implementation of the "SPICE" ancillary information system. SPICE is used throughout the life cycle of NASA planetary science missions to help scientists and engineers design missions, plan scientific observations, analyze science data and conduct various engineering functions associated with flight projects. https://naif.jpl.nasa.gov/naif/about.html

A Slingshot by the Sun

What it came down to was that the interplanetary trajectory to ‘Oumuamua would inevitably necessitate what is known as a Solar Oberth Manoeuvre (SOM). A SOM is where the spacecraft reaches a low perihelion (a closest approach to the sun) and delivers a burn/thrust of its rockets, a velocity increment ΔV (deltaV), to generate a considerable velocity at infinity, V_∞, relative to the sun. (This V_∞, also known as the heliocentric hyperbolic excess speed, is the speed the spacecraft will achieve at a great distance, when the sun’s influence is no longer slowing it down significantly.) The spacecraft needs such a high V_∞ because ‘Oumuamua was discovered after its own perihelion and was itself receding from the sun at a huge speed (V_∞ for ‘Oumuamua is around 26.3 km/s). It does not take a great mathematical brain to fathom that the spacecraft must exceed 26.3 km/s to enable it to catch up with ‘Oumuamua.
Sci-fi fans reading this will be quite familiar with this solar slingshot because at the advice of Mr Spock and under the captaincy of James T Kirk, the starship Enterprise conducted just such a manoeuvre both in the original series of Star Trek [1] as well as in the 1986 film production directed by Leonard Nimoy, Star Trek IV: The Voyage Home. In these sci-fi adventures, the purpose of the solar slingshot was not to chase an interstellar object but to travel in time. However, back to the real world.
The second eureka moment arrived when I came up with the notion of what I called an ‘Intermediate Point’ (IP) to enhance the flexibility of OITS and solve all sorts of mission scenarios, including those involving a SOM. This neat little trick opened the path to studying trajectories to ‘Oumuamua.
I was initially uncertain as to how to introduce this functionality into my software, at this stage all the objects along the interplanetary trajectory to be optimised were classed as celestial bodies, each with their own NASA SPICE kernel. However it turned out – and this is the great asset of Object-Oriented Programming – that the change was quite minor, though the flexibility and power of the software was enhanced enormously by this modification. It fairly quickly became a matter of how to try out the modified software on a mission to ‘Oumuamua.

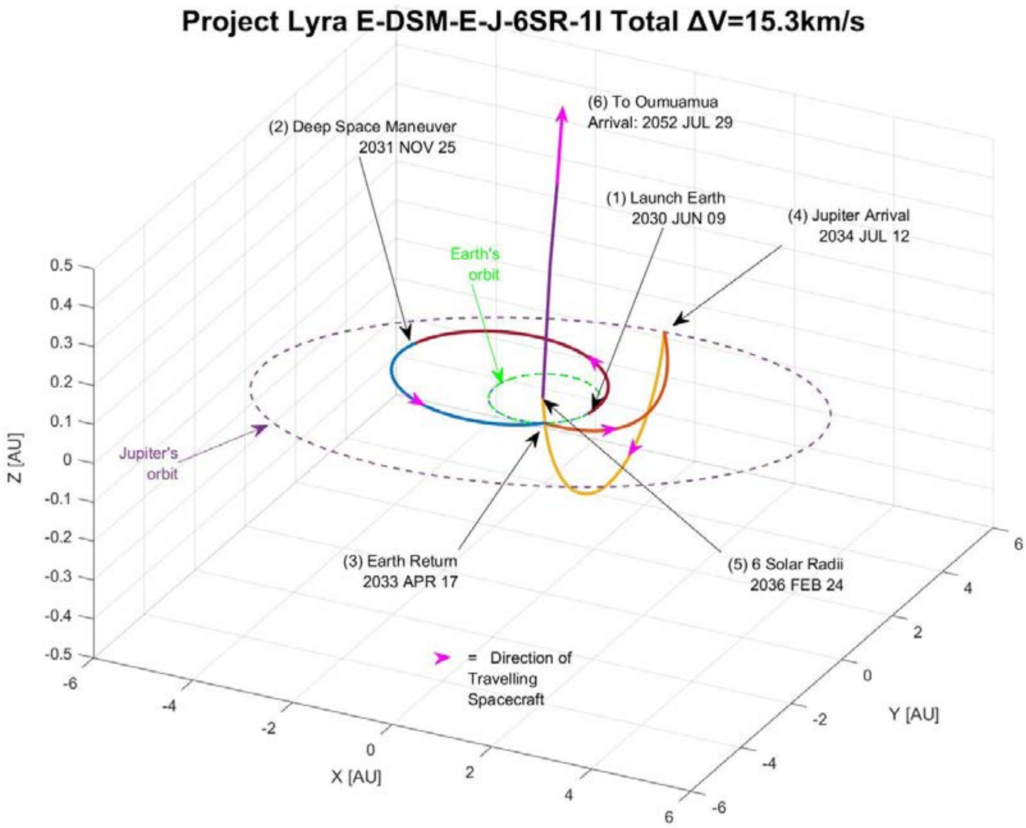

Figure 2 Project Lyra with a spacecraft using a SOM at 6 solar radii (see Bibliography #1)

[1] Star Trek, Season 1, Episode 19, *Tomorrow Is Yesterday*, 1967 https://en.wikipedia.org/wiki/Tomorrow_Is_Yesterday

Perihelion for the Solar Slingshot

The question was what the perihelion of the SOM should be. This wasn't straightforward. You see one would expect the closer one gets to the sun, the greater the slingshot (Oberth) effect, and so the more 'bang-for-your-buck'; or more specifically, the greater the V_∞ generated by any ΔV burn at perihelion. (The actual situation turns out far more complicated than this as will be elucidated further down.) However conversely the closer one gets to the sun, the more massive any heat shield would need to be and so the less usable and useful mass for the spacecraft, in the form of instrumentation for example, available to study 'Oumuamua upon arrival. I settled on the same value used by the KISS (Keck Institute for Space Studies) theoretical study into missions to the interstellar medium (ISM), of 3 Solar Radii from the centre of the sun. This KISS study was relevant because to reach 'Oumuamua would inevitably mean travelling into the ISM – attaining large distances as quickly as possible.

Thus, so equipped with the new software and with a plan of action in terms of how one might get to 'Oumuamua, I attempted to exploit OITS to solve missions to 'Oumuamua. The sequence I selected was E-J-3SR-1I, where E is the Earth launch, J is the encounter with Jupiter, 3SR indicates a SOM distance of 3 Solar Radii and 1I is 'Oumuamua. A Solar Radius, SR, has a magnitude of 696,340 km, and is defined as half the diameter of the sun, or in other words the distance from the centre to the surface. With my innovation of the 'Intermediate Point', mentioned in the preceding section, I could use it to model the SOM at 3SR. Thus 3SR means that the SOM will happen at 2,089,020 km or 0.014 AU , three times farther from the centre of the sun than its surface.

The encounter with Jupiter preceding the SOM is required for complicated reasons which are associated with orbital mechanics - suffice to note that Jupiter, due to its huge mass, would have to play a pivotal role in virtually whatever mission scenario destined for 'Oumuamua.

A Strategy for Success

Almost immediately OITS was generating optimal solutions. Those familiar with OITS will know that the MATLAB window to which the optimizer outputs its progress displays the most recent value of overall ΔV computed along the trajectory in units of m/s, thus one observes a gradually reducing sequence of numbers as the trajectories computed get closer and closer to the optimal one. For this trajectory scenario, the optimizer was converging on something around 18,300 m/s. This was a result!

Once the optimizer had completed its work, naturally I looked at the data corresponding to the optimal solution it had found and there was that launch date: 2021. There was a nagging doubt in my mind, how reliable were the results OITS had found?

This doubt was exacerbated when upon running OITS a second time, the optimal ΔV turned out to be much lower: around 14000m/s. I was initially rather stumped as to the explanation for this disagreement. However it soon occurred to me that the discrepancy was for the following reason. (Here it gets a bit technical, so feel free to skip the next paragraph if you prefer.)

The Intermediate Point, IP, for the SOM had to be, by definition, at the perihelion point of the spacecraft. Unfortunately for the latter result of 14000 m/s, the spacecraft trajectory was actually intersecting the sun because the perihelion was less ,than 1SR, both on the inbound (from Jupiter to the IP) and outbound (from the IP to 'Oumuamua) paths. There was an easy fix to this: my software already included the functionality allowing the user to specify minimum perihelia distances for the trajectory arcs in question. When I specified perihelia just lower than the distance the IP was placed from the sun (3SR), but way above the surface of the sun (ie > 1SR) the 14,000 m/s solution disappeared, and the 18,300 m/s mission became the winner for this scenario.

Discovering Something Only I Knew

Well I had clearly discovered something amazing, something no one else knew, but I didn't realise the full implications of these findings. To summarise - I had constructed some software, and it had, as a result of its computations, generated a number: 18.3 km/s, and a launch date: 2021. My naivety at this stage left me stumped on two counts: a) was this 18.3 km/s figure genuinely achievable by any existing or near-future propulsion system and b) was 2021 (at that time 4 years in the future) a realistic timeframe to build a spacecraft and prepare a mission. I concluded I needed assistance - and assistance was forthcoming.

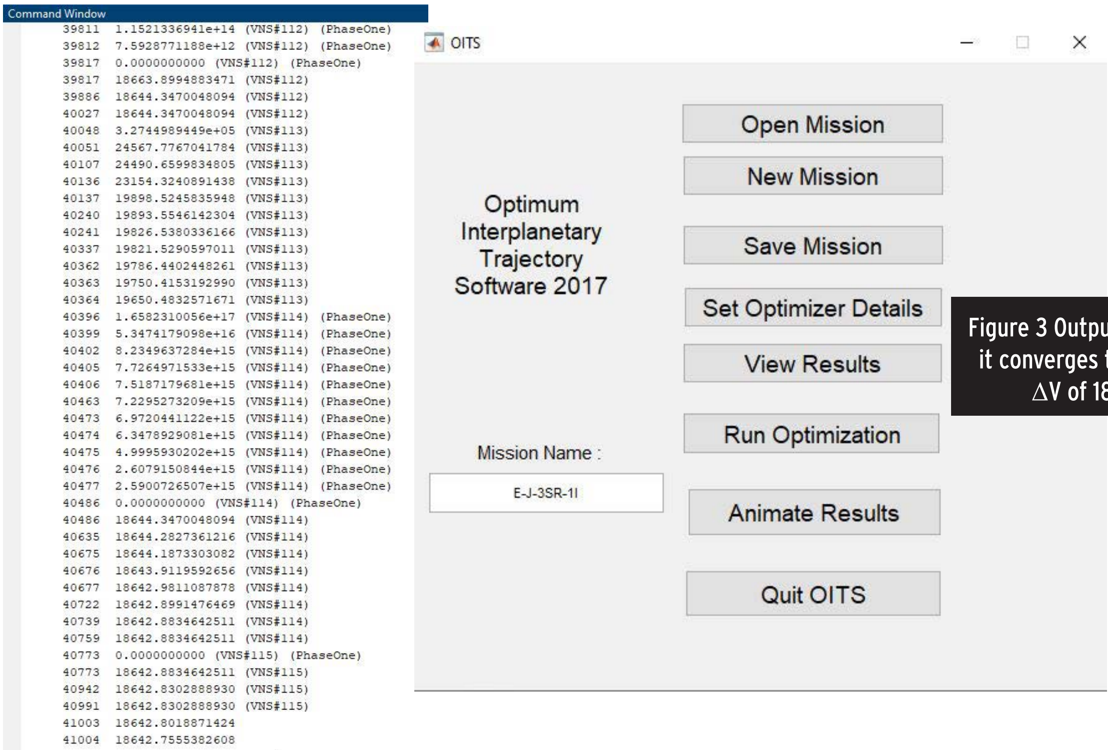

Figure 3 Output from OITS as it converges to a SOM with ΔV of 18.3 km/s

I should mention that while I was conducting my investigations, observations of 'Oumuamua were continuing, and its idiosyncratic nature was steadily unfolding before our eyes, with a steady flux of science papers on its unusual if not enigmatic properties. A long cigar-shaped object with aspect ratio 10:1 (from its light curve); no appearance of a coma or tail, for that matter no observable outgassing; unusually bright for its size; a reddish hue to its spectrum indicating space-weathering; a mysterious force as it sped away from the sun in inverse proportion to the solar distance or possibly the square of this distance. The latter finding led Avi Loeb [1] to suggest this could be an alien solar sail. The overall impact on scientists was one of bewilderment – what in the universe could this interloper to our celestial neighbourhood possibly be? Subsequently origin theories were plentiful and sometimes speculative but none of them seem satisfactory to everyone. Loeb has his own ideas as to the nature and origin of 'Oumuamua and is not averse to finding faults with those in conflict with his own [2].

Whatever the case, the relevance and importance of my findings in terms of resolving all this uncertainty and bewilderment was becoming increasingly persuasive. After all, what better way of discovering the true nature of this object, hitherto resolved as only a single pixel in telescope images – a speck of reflected sunlight - than by sending a mission and taking a close-up picture of it. In Loeb's own words: 'A picture paints a thousand words'.

[1] Professor Abraham Loeb, Harvard University, is a distinguished astrophysicist, former head of astronomy at Harvard and a prominent advocate of the probability of finding alien artefacts near or close to the Earth. He is the co-author of *Life in the Cosmos - From Biosignatures to Technosignatures*, reviewed in our previous issue, and author of *Extraterrestrial* reviewed in Principium 33. See also *News Feature: Loeb on an Artificial Origin for `Oumuamua* in Principium 35.
[2] Examples: *The mass budget necessary to explain 'Oumuamua as a nitrogen iceberg*, A Siraj & A Loeb, New Astronomy Volume 92, April 2022, 101730, www.sciencedirect.com/science/article/abs/pii/S1384107621001445. Open acccess at arxiv.org/pdf/2103.14032.pdf *Destruction of Molecular Hydrogen Ice and Implications for 1I/2017 U1 ('Oumuamua)*, Thiem Hoang & Abraham Loeb,
The Astrophysical Journal Letters, Volume 899, Number 2, iopscience.iop.org/article/10.3847/2041-8213/abab0c/meta Open accces at arxiv.org/abs/2006.08088

Project Lyra

I looked for help on the internet and found Project Lyra. The UK not-for-profit company known as the 'Initiative for Interstellar Studies' (i4is) had been founded several years previously with the noble ambition of research and education in the field of interstellar travel. Its Project Lyra initiative had been inaugurated quite expeditiously after the discovery of 'Oumuamua. Various scientists of world renown contributed to the content of the paper, which was eventually published as a preprint (without peer-review) only 10 days after 'Oumuamua's detection. To summarise, their work had slightly preceded mine and was independent of it, but its remit was to study the feasibility of spacecraft missions to 'Oumuamua, exactly the task I had undertaken with OITS.

It was a no-brainer, I contacted the Project Lyra team leader Andreas Hein providing him with some results of my research in an email. At this point a lesser scientist, indeed a lesser man, would have been wary of, ignored, or even discounted the information I had furnished him – I was after all only a BSc, and my previous experience of Optimum Trajectory Software had been 2 decades earlier when I worked as a software engineer for the Ariane 4 Project. However, instead Andreas was extremely accommodating and open-minded over my approach to him, suggesting he pass my findings on to the Project Lyra team. Thus history was made.

Welcomed into the Fold

At this stage the Project Lyra paper had already been published as a preprint, though had not yet been peer-reviewed. I was not privy to the conversations that were happening between Andreas and the other Project Lyra scientists, however I do know that Andreas eventually invited me to contribute to future versions of their paper. The obvious reasoning was that their research largely assumed direct trajectories from Earth to 'Oumuamua, and so there was a gap where indirect missions had not been studied in great detail. However I must credit Adam Crowl and Marshall Eubanks here and others, who had already done some useful work on missions with a SOM (also the aforementioned KISS workshop had studied SOMs for reaching the ISM). My software could readily fill this information gap, as I have already mentioned above. It seemed my studies would easily dovetail into those which Project Lyra had so far undertaken, bolstering, and contributing materially to the general conclusions and case for a mission to 'Oumuamua.

As far as my reservations were concerned, Andreas got to work on calculating a mass budget assuming rocket propulsion (chemical) corresponding to the ΔVs my software had calculated. The results of his analysis were unequivocal. A mission would indeed be feasible with significant spacecraft masses to 'Oumuamua, launching in 2021, particularly if one assumed the NASA super heavy-lift launch vehicle known as the Space Launch System (of course we now know that its maiden flight has been delayed time and again and it still hasn't launched as of the time of writing, June 2022).

Figure 4 Logos for Initiative for Interstellar Studies and Project Lyra

Reflection on the Initial Findings

You would think that would be the end of the matter. However the whole analysis I had conducted and results obtained using OITS left various questions unanswered. For instance, why did the optimal launch year happen to be 2021? What was so special about this time specifically? I concluded that there must be some special alignment of the celestial bodies involved – Earth, Jupiter, 'Oumuamua - which makes this departure date for some reason particularly propitious. Investigation of long-term missions to 'Oumuamua using OITS, looking forward decades into the future, indicated a 12 year periodicity in the feasibility of trajectories with this E-J-3SR-1I scenario. This was especially interesting on two fronts – first that there were indeed viable missions to 'Oumuamua beyond 2021, and second that these missions seemed to follow an approximate Jupiter year (11.9 Earth years) cycle. The latter observation indicated that viability must be dependent almost entirely on Jupiter, which must occupy a particular point in its orbit around the sun (a sweet spot) to allow missions to 'Oumuamua.

At the time I was distinctly underwhelmed by this finding because the flight duration for the 2021+12 = 2033 launch was what I considered exorbitantly protracted – 19 years – and actually significantly longer for 2033 + 12 = 2045 (26 years) and even longer for 2045 + 12 = 2057 (37 years).

Consequently I was extremely surprised when Andreas expressed consternation and excitement at this finding, suggesting it be written up in a further Project Lyra paper. In retrospect I now see he was correct and I can appreciate his perspective on multiple counts. Firstly, his view must have been that travel to another system beyond our own solar system would take tens of thousands of years using spacecraft with chemical propulsion, and here we had with this interstellar object the possibility of conducting just such an examination in the space of as little as 20 odd years. Secondly the findings indicated that viable missions to 'Oumuamua allowed launch dates years if not decades into the future, so plenty of opportunity to organise and prepare a mission. Finally the Voyager missions are still operating 45 years since their launch in 1977 and have now travelled well beyond the heliopause, so comparatively speaking these protracted flight durations might not actually be all that protracted.

A Difficult Time

I had carried out all this work – development of OITS and Project Lyra research - in an ordinary semi-detached house in Coventry on a Dell laptop. My father was struggling with all kinds of health issues and I found a good deal of my time was spent caring for him. Unfortunately he was to pass away with only a vague idea of my achievements re Project Lyra, despite his endless efforts to try and understand. What was particularly sad was that he had been extremely intelligent in his prime. I was also experiencing severe mental health difficulties throughout this period, I look back in wonderment that I was able to achieve anything at all. I therefore can be forgiven, perhaps, for not involving myself proactively in the field of science in which I had found myself.

It was second hand then – via communications with Andreas and other volunteers for i4is – that I was to learn of the scepticism by Avi Loeb of the Project Lyra findings. It is possible therefore that his own hypothesis on the nature of 'Oumuamua as alien technology will neither be proven nor disproven or at least the resolution would have to be kicked into the long grass, when propulsion technology allowed. Waiting for another interstellar object and then sending a mission to that would be another option, but who knows when such an unusual object like 'Oumuamua and such a wonderful opportunity will arise in our system again?

Make no bones, 'Oumuamua was an invitation for humanity to take its first serious steps into interstellar space and embark on travel beyond our own solar system, on to the stars. Put starkly, will humanity die out on its home planet or will it extend its outreach and establish a long-term presence in the universe? Maybe the reality of the Covid pandemic is timely, perhaps this is an opportunity for humanity to regroup, rethink and decide what exactly it wishes to achieve by its precious existence in this universe.

Further Work

Spurred on by Loeb's scepticism of Project Lyra, I decided to investigate the effects of changing the perihelion distance of the SOM, in particular increasing it to a longer, safer distance away from the sun, to see how it would influence the viability of missions. Indeed my decision to investigate further turned out to be rather fruitful and I was pleasantly surprised at the results.

It seems that larger perihelion distances are actually not only viable but in certain respects beneficial in terms of reducing the overall ΔV budget associated with the mission - so in other words taking into account the burn at Jupiter perijove (closest approach to Jupiter) as well as that needed at the SOM. The baseline mission I discovered utilising OITS had a launch in 2030 and a SOM perihelion of 6SR but even larger perihelia were possible, markedly reducing the complexity of the mission by enabling heat shield technology to be deployed by Project Lyra identical to that used by the very real NASA mission designed to study the sun close up, the Park Solar Probe (PSP).

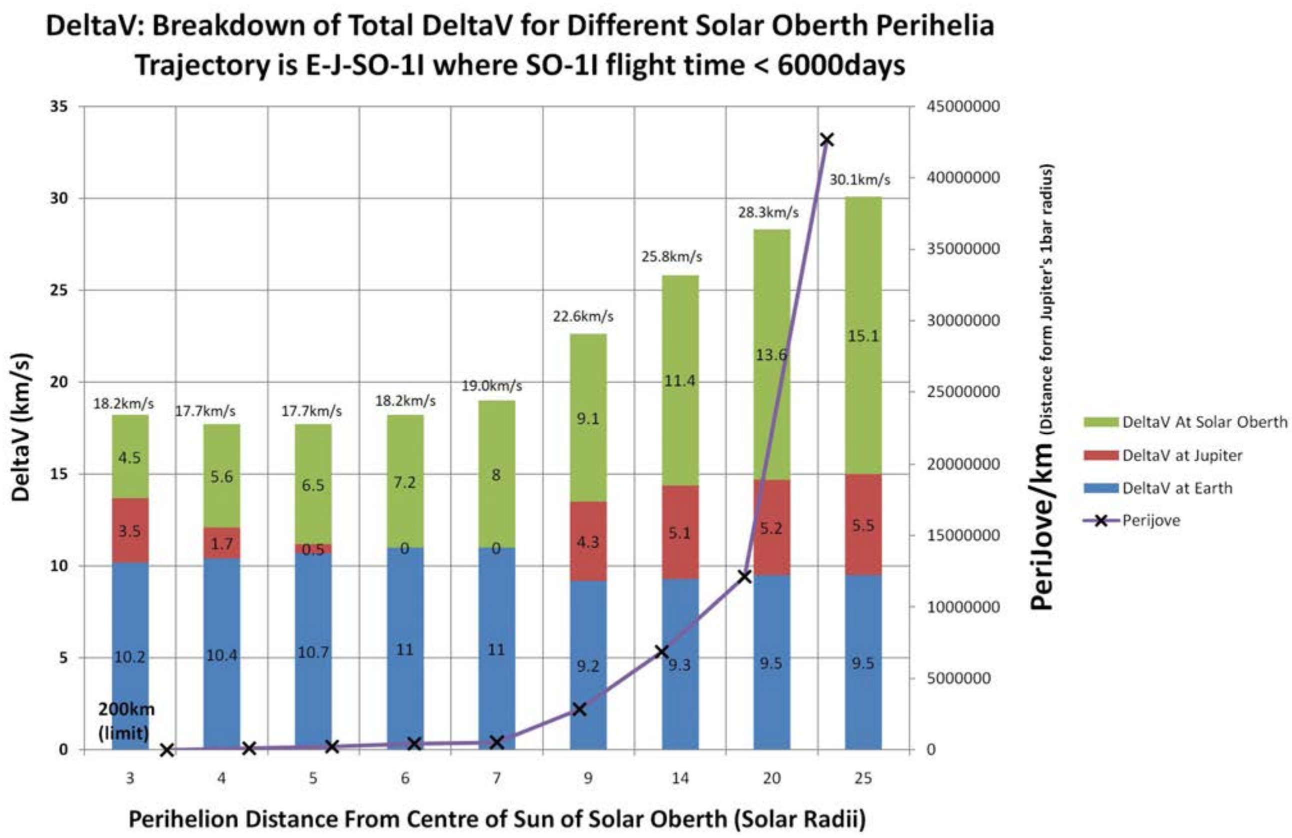

Figure 5 Bar Chart Indicating Optimal ΔV at around 5SR/6SR for Project Lyra (see Bibliography # 1)

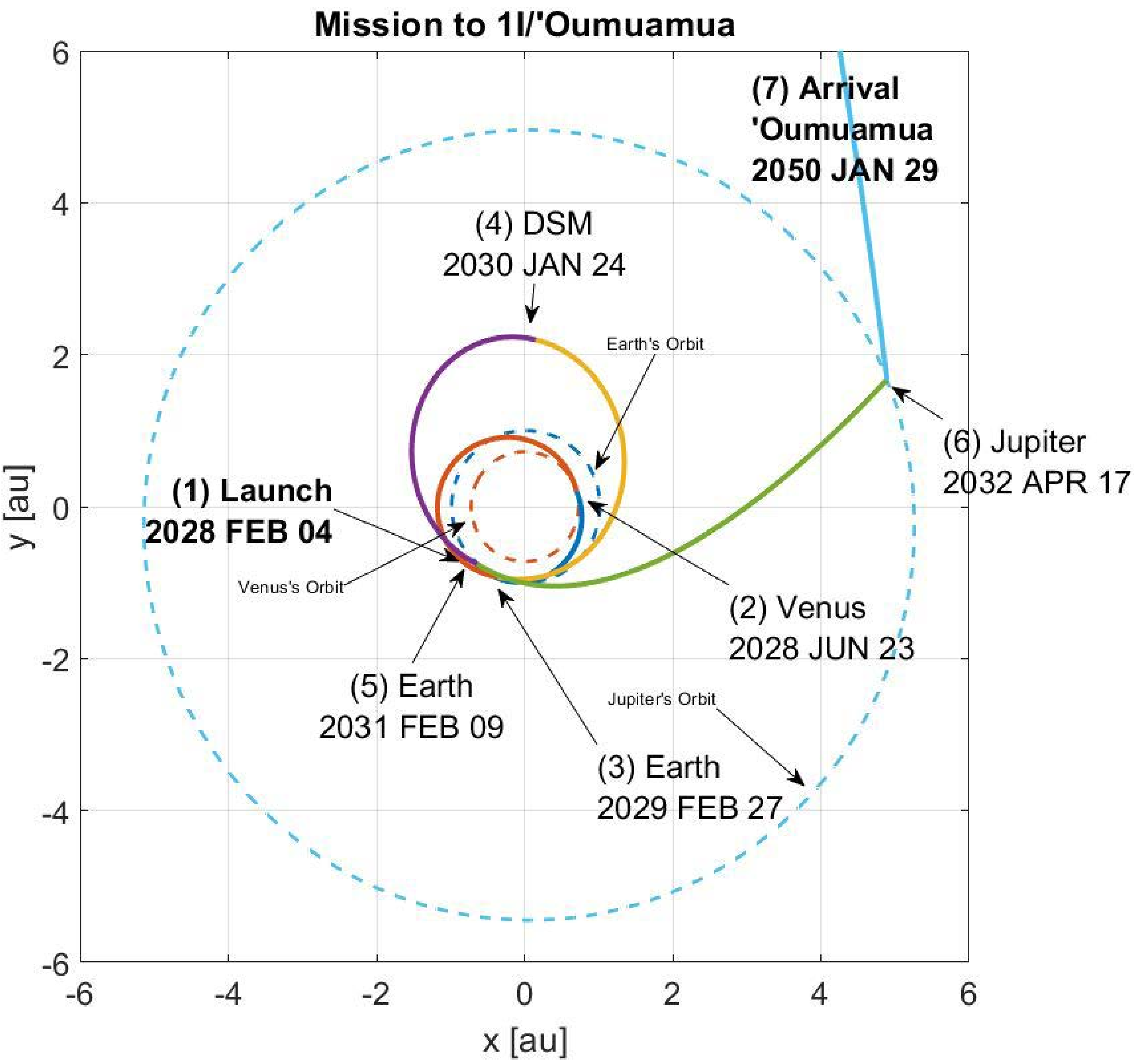

Figure 6 Project Lyra, using a JOM, an alternative to a SOM (see Bibliography #2)

An Encounter with Jupiter

At this juncture, let us embark upon a spot of time travel and leap forward to December 2021 and the publication of the 'Interstellar Probe' Concept Report by The Johns Hopkins University (JHU) Applied Physics Laboratory (APL). The Interstellar Probe project is all to do with sending a mission to the Very Local Interstellar Medium (VLISM). This VLISM is not entirely virgin territory for humanity as the Voyager 1 and Voyager 2 probes have both broken out of the heliopause – the boundary layer between the solar wind and interstellar wind - placed at approximately 122 AU from the sun. In its goal to reach and study the VLISM very quickly, APL had effectively dumped the theoretical benefits of a solar slingshot (SOM) for the far more practically achievable benefits of a Jupiter slingshot. As their baseline mission they selected a passive Jupiter gravitational assist (without a rocket burn at Jupiter). The second mission scenario they considered was a powered Jupiter gravitational assist, ie a Jupiter Oberth Manoeuvre (JOM), the SOM being the least preferred option.

However one might wish to argue the case one way or another for a SOM/JOM, the fact remained that I had not yet exhaustively considered the case for a Jupiter slingshot. The publication of the Interstellar Probe Concept Report inspired and stimulated me to reconsider a mission to 'Oumuamua in the context of a JOM rather than a SOM.

My research was fruitful in that I was able to discover an efficacious route to Jupiter – the VEEGA sequence of gravitational assists – and then conducting a JOM at Jupiter. Although the route was not as effective as the SOM, it nevertheless circumvented the solar shield requirement, thus contributing to the overall mass of the payload eventually arriving at 'Oumuamua.

Conclusion

After the paper on missions to 'Oumuamua using the VEEGA sequence had been published as a preprint, with contributions from my colleagues and co-authors Andreas M Hein, Marshall T Eubanks and Robert G Kennedy III, the popularity of the paper was somewhat of a surprise, even outshining the initial Project Lyra paper, completed 4 years before. The paper was widely reported in the global media.

It seems that an appetite to resolve the 'Oumuamua conundrum had not abated to any extent since that first paper and certain social media activists were even extolling the virtues of dedicating a NASA Space Launch System (SLS) as a priority over their moon Artemis plans, their logic being that a mission to the moon would happen eventually and there was no cause for hurry, whilst the realisation of a mission to 'Oumuamua was pressing and required urgent attention due to the near-future launch opportunities.

In 2022, I have written two further papers about missions to 'Oumuamua. The first elaborates a different trajectory, also without a SOM but with a JOM, which requires virtually no burn from the spacecraft at any of the planetary encounters on the way to Jupiter. For various reasons this makes for a very attractive proposition, although the launch date, in 2026, is a mere 4 years away at the time of writing. The second paper details the notion of 'Intermediate Points' as a means of modelling SOMs for example, so that missions to exit the heliosphere and chase ISOs can be investigated.

My contribution to all this has been one of a volunteer. Where before there was some degree of uncertainty and speculation, my work has brought order and engineering know-how to the task of resolving the problem of 'Oumuamua. It would be such a shame if this work and this opportunity were to go to waste, but there lies the folly of humanity.

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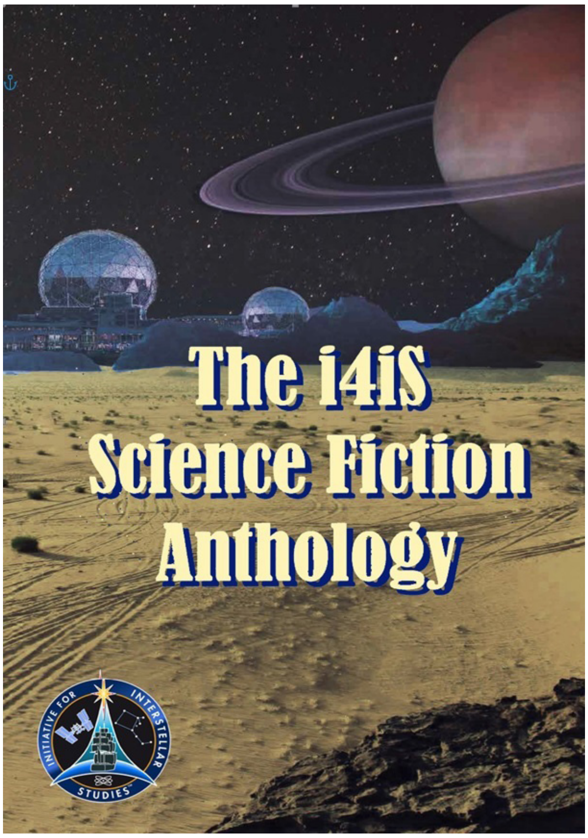
2. HIBBERD, A et al Project Lyra: Mission to 1I/'Oumuamua without Solar Oberth Manoeuvre arXiv, January 2022. Open publication: arxiv.org/abs/2201.04240

Adam Hibberd is the lead astrodynamicist for i4is. He has been an author of many papers in this and related topics in the past four years, many of them published in leading journals including Acta Astronautica, Advances in Space Research, The Astrophysical Journal Letters and the Bulletin of the American Astronomical Society. Adam was educated at a UK state school, Stoke Park Comprehensive School and Community College, in Coventry. He has a joint honours degree in physics and maths from the University of Keele. He worked in the '90s as a software engineer on the on-board flight program for the European Ariane 4 launch vehicle. He is also a pianist and composer. More about Adam's music and space research - adamhibberd.com. He developed his Optimum Interplanetary Trajectory Software, in 2017 as a personal challenge to learn the MATLAB programming environment and language.

i4is Science Fiction Anthology

A new i4is collection

Sarah Margree and Jean Asselin



The Project

One of the roles of i4is is to inspire a new generation to think beyond the present and actively look to the future. We all have that childhood imagination within us somewhere, and there is nothing better to encourage it than science fiction. If you ask many of the world's leading scientists they will tell you that they were motivated by what they read and watched on TV and in movies. Do you have a story in you that could help to inspire the next generation?

To that end, i4is are putting together an anthology of science fiction stories on an interstellar theme and are calling for contributions from members, and those willing to become members. We are looking for stories about interstellar travel. The editors of the anthology, Sarah Margree and Jean Asselin, are keen to read work from both established authors and those new to the field.

After a successful workshop in Lincoln in October, they are looking to run further workshops for those who would like to develop their work or who are struggling to start, or complete, a story. The workshops would initially be run via Zoom, with follow ups in person depending on demand and availability.

To further the aims of this venture, we will also be starting a science fiction book club. Due to the nature of the group, with members around the world, we will hold the book club once a month on Zoom. Initial book will be picked by the editors and will showcase the kind of writing we are looking for in the anthology. Further books will be voted on by the members of the club.

Get involved!

To express your interest in submitting a story, signing up for the workshops and/or joining the book club, please email Sarah or Jean, the Editors.

Sarah Margree holds an MA in Creative Writing and a Postgraduate Certificate in Space Science and was the first Executive Secretary of i4is. She is a member of i4is, the BIS and a fellow of the Royal Astronomical Society (RAS). Sarah is a first reader for James Gunn's Ad Astra (www.adastrasf.com/) and is setting up her first writing retreat. Contact Sarah at sarahmargree@i4is.org.

Jean Asselin holds an MSc in Structural Geology (Imperial College) and has been editor-in-chief of the SF journal James Gunn's Ad Astra since 2015. He is a member of i4is and BIS. He is also a regular workshop leader and attendee. Contact Jean at jean.asselin.qc@i4is.org.

THE i4iS MEMBERS' PAGE

JUST SOME OF YOUR i4is TEAM

Angelo, Adam, Conor, Dan, Gill, John

Nikolaos, Paul, Marshall, Tam. Samar, Robert

Recent members' newsletters and preprints

Just one edition of the members' newsletter has come out since the last issue of Principium. Issued on 25 August, it concentrated on *The i4is Science Fiction Anthology: First Workshop* (i4is.org/the-i4is-science-fiction-anthology/). We know that some of our members write science fiction and we aim to provide a platform for more fiction on themes such as travel to the stars or preludes to it, related technologies such as propulsion, communication, probes, cryonics, robotics, etc, who or what we might meet there, even faster-than-light travel. More about this in *i4is Science Fiction Anthology* on page 83 in this issue.

Getting more actively involved

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

Schools outreach is something we have been doing since our beginnings and we have delivered to schools in both UK and USA this year. We would like to deliver more and to a wider variety of countries - especially to the non-English speaking world.

i4is Members' newsletter team

Our i4is Members' newsletter team are Conor MacBride (Delivery editor) and Dr Olivia Borgue (Content editor). Olivia is stepping down due to pressure from her academic work at the University of Luxembourg.

We are looking for volunteers to take on her role. Here's a summary of the job -

- Job title: Content editor
- Pro Bono: like all i4is team members we pay expenses only.
- Role: Monitoring the web and email newsletters for news relevant to interstellar Studies, Receiving suggested content from Principium editor
- Deliverable: Formatted news summary ready to go into our email newsletter
- Tools; Subscribe to several relevant news feeds and newsletters
- Time commitment: Typically about two hours per week
- Partnered with: Delivery editor - who will receive your news items and transmit them - and Principium editor - who will share items being gathered for our quarterly Principium Interstellar News.

Preprints

We have published preprints of 14 Principium articles specifically for members this year so far.

NEXT ISSUE

youtu.be/b7if22TZJB4

- **Human Exploration of the Far Solar System and on to the Stars:** A report on our summer 2021 courses, delivered by i4is for the Limitless Space Institute (LSI) - reporter: Patrick Mahon -postponed from this issue
- **Search for an Alien Message to a Nearby Star:** response to News item *Search for an Alien Message to a Nearby Star* - in this issue - Rob Swinney
- **IAC22:** International Astronautical Congress 2021 - The Interstellar Papers - part 2
- **Three News Features:** A new way of finding out what's happening in interstellar studies, a major i4is project in communications and a new venture from one of the i4is team

\- **plus**, of course, *Interstellar News* and interstellar papers in *The Journals*.

COVER IMAGES

Our cover images for this issue look to our immediate past and our near future - with a bit of artistic license thrown in!

FRONT COVER

Composite of early covers
To celebrate the 10th birthday of i4is we took some of our early covers and created a mosaic of them. You can see them full size where you will find all our back issues (i4is.org/publications/principium/).
Tell us your favourites (and maybe the ones we should have left on the cutting room floor!).

BACK COVER

Black solar sail
Our executive and technical director, Dr Andreas Hein, is a man of two cultures. Here he shows his broader cultural qualities with an image of a black solar sail which he created using an AI. But we know that current AI is still not truly intelligent - we suspect that our robot overlords, if and when they arrive, will need true artificial general intelligence. Nevertheless it is remarkable what a creative human can do with a little assistance from current machine learning software.

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.

SCIENTIA AD SIDERA
KNOWLEDGE TO THE STARS

Front cover:Composite of early covers
Back cover: Black solar sail
Credit: Andreas M Hein

I4IS.ORG

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

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

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