PRINCIPIUM

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SCIENTIA AD SIDERA | KNOWLEDGE TO THE STARS

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EDITORIAL

Welcome to issue 36 of Principium, the quarterly magazine of i4is, the Initiative and Institute for Interstellar Studies. The lead feature this time is *The Icarus Firefly Downlink*, looking at the approach suggested by the Firefly team in their 2015 JBIS paper, comparing it with the Daedalus work 40 years ago and contrasting the recent Starshot thinking for downlinks from gram-scale probes.

We have 8 pages of Interstellar News and our two IRG reporters, Bart Leahy & Joseph Meany bring us the informal part of the 7th Interstellar Symposium in Tucson, asserting that "The Hallway is More Important than the Podium…."

In addition to the summaries of recent peer-reviewed papers on interstellar studies in *The Journals* (*JBIS* and *Acta Astronautica*), we have, by kind permission of its editor, the 2021 Index of the BIS journal, JBIS.

As promised, you will find the second of two pieces covering papers of interstellar relevance at the 2021 congress of the International Astronautical Federation, IAC2021. And we have a brief on IAC2021 by our on-the-spot contributing editor, Samar AbdelFattah.

The capabilities of Adam Hibberd's OITS trajectory planning package are further described in - *Project Lyra: A Mission to 1I/'Oumuamua without Solar Oberth Manoeuvre* and in Adam's own piece - *Design of Interplanetary Missions to Jupiter Using Optimum Interplanetary Trajectory Software*.

As always we have the i4is members' page and another regular feature, *Become an i4is member*.

OUR NEW LOOK

Principium has been in need of a new design for some time and this issue brings you the vision of Andrée Wilson. We hope you like it - we do!
Find Andrée at www.andree-wilson.com.
Tell the editors what you think of this issue. We'll be making some minor tweaks to the design you see here and your input would be very useful.

The front cover image is the Bubble Nebula - NGC 7635 as used by a NASA report, *Taking a New Look at Searching for Life Beyond Earth*. The rear cover image is the iconic space station from *2001: A Space Odyssey*. More about both in *Cover Images* inside the rear cover.

The next issue, in May 2022, will include -

• A report on the summer 2021 course *Human Exploration of the Far Solar System and on to the Stars*, delivered by i4is for the Limitless Systems Institute (LSI) - by Patrick Mahon.

• A review of a new book, *Life, in the Cosmos - From Biosignatures to Technosignatures*, Manasvi Lingam (Florida Tech) & Avi Loeb (Harvard) - by Andreas Hein.

If you have any comments on Principium, i4is or interstellar topics more generally, we'd love to hear from you,

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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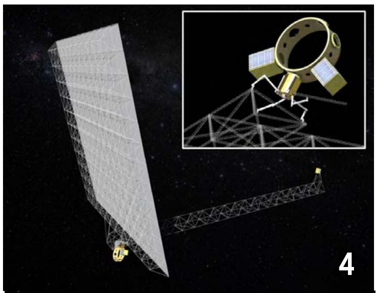

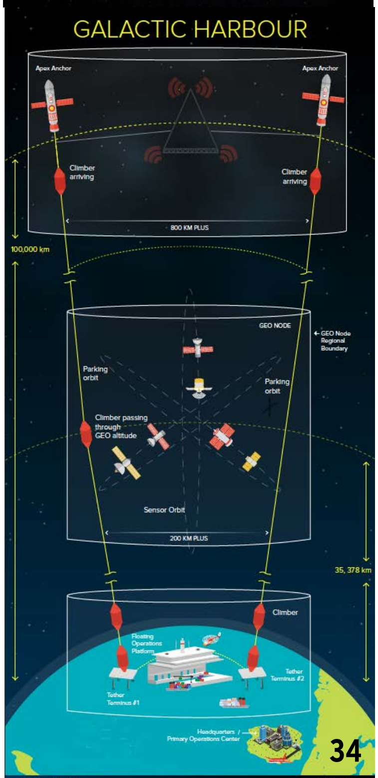

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The Icarus Firefly Downlink

John I Davies

In our last issue we outlined ***The downlink from swarming micro-probes: the "light brigade" of feasible interstellar probes***. This piece considers the "heavy brigade": communications from large fusion propelled probes. It is mainly based on the downlink envisaged from Project Icarus, the Firefly design. Comparisons with its predecessor, the downlink envisaged by the BIS Daedalus study are instructive.

John Davies looks at the Project Icarus work by Milne et al, 38 years later, on downlink communications for the "heavy brigade", fusion propelled probes.

Peter Milne made some very useful comments on a draft of this article.

However any errors or omissions remain the responsibility of the author.

1 Introduction

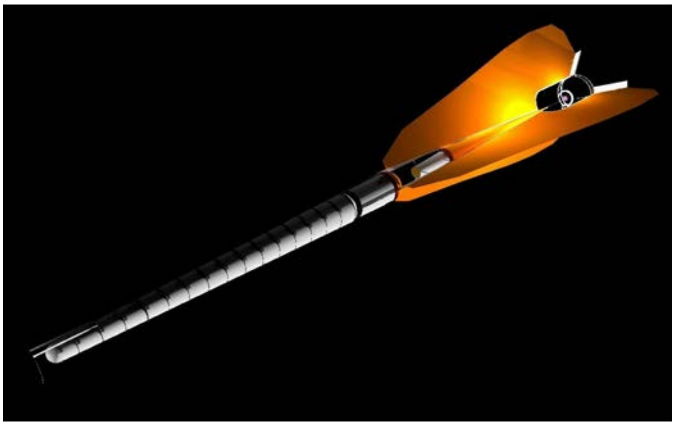
The downlink from an interstellar probe is the other most challenging issue alongside the propulsion required to achieve reasonable travel times. Earlier articles in Principium have mainly considered this challenge for the very small probes envisaged for laser-push propulsion - including early studies by Philip Lubin (UCSD) and i4is teams (projects Dragonfly and Andromeda). Here we consider the challenge for probes using the other reasonably feasible means of propulsion - a fusion rocket. This is mainly based on the 2016 paper *Project Icarus: Communications Data Link Designs between Icarus and Earth and between Icarus spacecraft* by Peter Milne, Michel Lamontagne and Robert M Freeland II [1].

The different probes and downlinks are directly compared below in *Table: The probes* and *Table: The downlinks*.

2 Daedalus and Icarus - The Downlinks

There is a long gap between the 1978 paper by Tony Lawton and Penny Wright on communications from the Daedalus probe, propelled by inertial confinement fusion [2] and the 2016 paper by Peter Milne, Robert M Freeland II and Michel Lamontagne on communications from their envisaged Icarus Firefly Z-pinch fusion propelled probe [3].

These are the "heavy brigade" of proposed interstellar probes and the communications downlink technology they have suggested to their designers differ very substantially from those proposed for the chipsats and chipsat swarms envisaged by Breakthrough Starshot.



Firefly Icarus, perspective view at main engine shutdown.
Michel Lamontagne, 2015

[1] Milne et al, JBIS, Vol. 69, pp.278-288, 2016

[2] *Project Daedalus: The Vehicle Communications Systems*, A T Lawton and P P Wright, Project Daedalus — Final Report, pp. S163-8171, 1978. in *Project Daedalus: Demonstrating the Engineering Feasibility of Interstellar Travel*, bis-space.com/shop/product/project-daedalus-demonstrating-the-engineering-feasibility-of-interstellar-travel/

[3] *Firefly Icarus: An Unmanned Interstellar Probe using Z-Pinch Fusion Propulsion*, R M Freeland II & M Lamontagne, JBIS, 68, pp.68-80, 2015 see also *Reaching the Stars in a Century using Fusion Propulsion - A Review Paper based on the 'Firefly Icarus' Design,* Patrick J Mahon, Principium 22 August 2018 i4is.org/reaching-the-stars-in-a-century-using-fusion-propulsion/

The tables below compare the two "heavy" studies with the Icarus Firefly study being the most explicit of the three sources. The rest of this article summarises its results, comparing the Daedalus study where there are clear similarities and differences. It's worth noting that Project Icarus spawned a number of studies, all based on fusion propulsion and requiring rendezvous at the target system.

There is a more detailed summary of the Starshot studies in *The Interstellar Downlink - Principles and Current Work* in Principium 31, November 2020 [1].

3 Three Downlinks compared - Daedalus, Icarus Firefly and Starshot .

3.1 Table: The probes

	Daedalus[2]	**Icarus Firefly[3]**	**Starshot[4]**
Study date	1978	2016	2020
Destination	Barnard's Star	Centauri System	Centauri System
Destination distance, light-years	7	4	4
Approximate journey time, years	40	100	20
Probe mass (metric)			
at launch	50,000 tons	23,550 tons	1 gram
at encounter	450 tons	2,200 tons	1 gram
Number of probes	1 (+subprobes)	1 (+subprobes)	thousands
Probe speed	12.2%c	4.7%c	20%c
Probe propulsion	Electron beam fusion	Z-pinch fusion	Laser-driven sail
Speed at destination	12.2%c	0	20%c
Approximate encounter duration*	8,197 seconds = 2 hours 17 minutes	indefinite	5,000 seconds = 1 hour 23 minutes

* For flyby missions I assume the useful encounter distance to be one Earth orbit diameter (2 AU) - so at speed of light, c, this is about 1,000 seconds.

Both Daedalus and Starshot are "flyby" probes with encounter duration in hours or days and there is therefore little benefit from a possible uplink to the probe since the link round-trip time is 8 to 12 years. The Daedalus study did not rule out an uplink but any useful traffic would need to have been sent during the decades of transit to the target system.

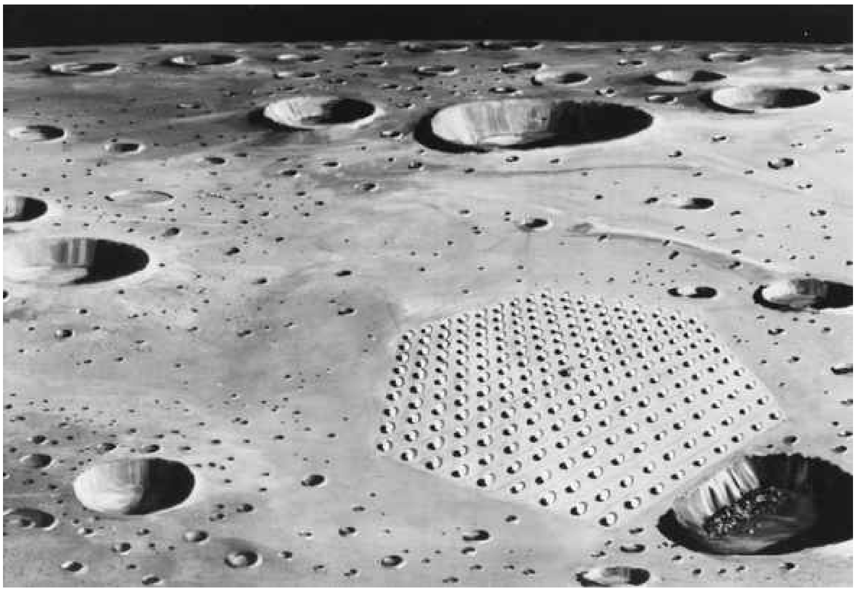
The Icarus studies require a deceleration to rendezvous and a usable encounter time limited only by reliability and availability of power. The Icarus Firefly study therefore included an uplink capability not discussed in this article but there are obvious advantages including target selection based on discoveries reported, software refinement and even instructions for hardware repair. The encounter duration would, of course, need to significantly exceed the minimum round trip communcations delay of about 8 years.

[1] *The Interstellar Downlink - Principles and Current Work*, John I Davies, in Principium 31, November 2020 i4is.org/wp-content/uploads/2021/08/The-Interstellar-Downlink-Principium31-print-2011291231-opt.pdf
[2] *Project Daedalus: Demonstrating the Engineering Feasibility of Interstellar Travel,* Alan Bond, Anthony R Martin et al, 1978, available in book form from the BIS website (http://www.bis-space.com/eshop/products-page/merchandise/books/)
[3] *Firefly Icarus: An Unmanned Interstellar Probe using Z-Pinch Fusion Propulsion*, R M Freeland II & M Lamontagne, JBIS vol 68 2015 see also *Reaching the Stars in a Century using Fusion Propulsion, A Review Paper based on the 'Firefly Icarus' Design*, Patrick J Mahon in P22, August 2018 - also - https://i4is.org/reaching-the-stars-in-a-century-using-fusion-propulsion/
[4] *The Breakthrough Starshot system model*, Kevin L G Parkin, Acta Astronautica Vol 152 November 2018 (https://parkinresearch.com/wp-content/uploads/2018/07/starshotmodel.pdf)

◀ 3.2 **Table: The downlinks**

	Daedalus[1,4]	**Icarus Firefly[2]**	**Starshot[3]**
technology	microwave	microwave	laser
frequency/wavelength	2.60 GHz / 0.115 m	32 GHz / 0.0094 m	293,914 GHz / 1.02 µm
power source	fusion 2.6 MW	fusion 2 MW	radioisotope (RTG) ?
transmit power	1.00 MW	2.00 MW (2*1 MW)	100 W
dbm	90	93	50
tx antenna diameter m	5.0	1,000	4.1
tx antenna area m^2	19.6	785,500	3.46
gain dbi	45	107.50	140
path loss db[5]	378.4 [4]	394.9	476
relativistic loss db[6]	negligible	negligible	3.5
rx antenna location	terrestrial/space	Earth-Moon L4/L5	terrestrial
rx antenna diameter m	3,160	15,000	30
rx antenna area m^2 [7]	$9.98*10^4$	$1.77*10^8$	707
gain dbi	98.7	131	156
rx power dbm [8]	not given	-257.4	-133
rx antenna noise loss db	3.1 [4]	3.1	complex analysis, no single figure
bit rate	864 Kbps	20 Gbps (2*10 Gbps)	260 - 1.5 Kbps

NOTE: db is log base 10 - ratio expressed as tenths - so 3 db is $10^{0.3}$ approximately 2.
dbm is milliwatts in the same log 10 form so 80 dbm = $10^{8.0}$ milliwatts = 100,000,000 milliwatts = 100 kW
dbi is db isotropic showing the ratio of power to/from a directional antenna versus a theoretical isotropic antenna which treats all directions as equal.



artist's rendering of a Project Cyclops hexagonal array on the far side of the Moon

NASA Report: https://ntrs.nasa.gov/api/citations/19730010095/

Image Credit:: fossilhunters.xyz

[1] Encounter phase values from - *Project Daedalus: The Vehicle Communications Systems*, A T Lawton and P P Wright in *Project Daedalus — Final Report*, pp. S163-8171, 1978. bis-space.com/shop/product/project-daedalus-demonstrating-the-engineering-feasibility-of-interstellar-travel/
[2] See especially tables 2 and 3 in *Project Icarus: Communications Data Link Designs between Icarus and Earth and between Icarus spacecraft*, Peter Milne, Michel Lamontagne and Robert M Freeland II, JBIS, Vol 69, pp278-288, 2016
[3] *A Starshot Communication Downlink*, Kevin L G Parkin, May 2020, arxiv.org/abs/2005.08940) - also Parkin, The Breakthrough Starshot system model, cited above
[4] Where the Daedalus study is silent I have used the Icarus Firefly values where they seem appropriate.
[5] Free space path loss = $(4*\Pi*\text{distance}*\text{frequency}/c)^2$
[6] Neither the Daedalus nor the Icarus Firefly studies include relativistic loss and I have assumed they are negligible within the much less challenging link budget for these very large probes - and at the lower encounter speeds.
[7] The Daedalus study assumes a Project Cyclops-based receiver. The NASA design study quotes "effective clear aperture diameter of 3.16 km." = $3.16*10^2$ m == area $9.98*10^4$ m^2; gain assumes 100% efficiency. Quote source: NASA Technical Report CR-114445 - Project Cyclops: A design study of a system for detecting extraterrestrial intelligent life.
[8] This appears to be the main omission from the Daedalus study. Corrections and comments would be very welcome.

▶

◀ **4 The Icarus Firefly Downlink**

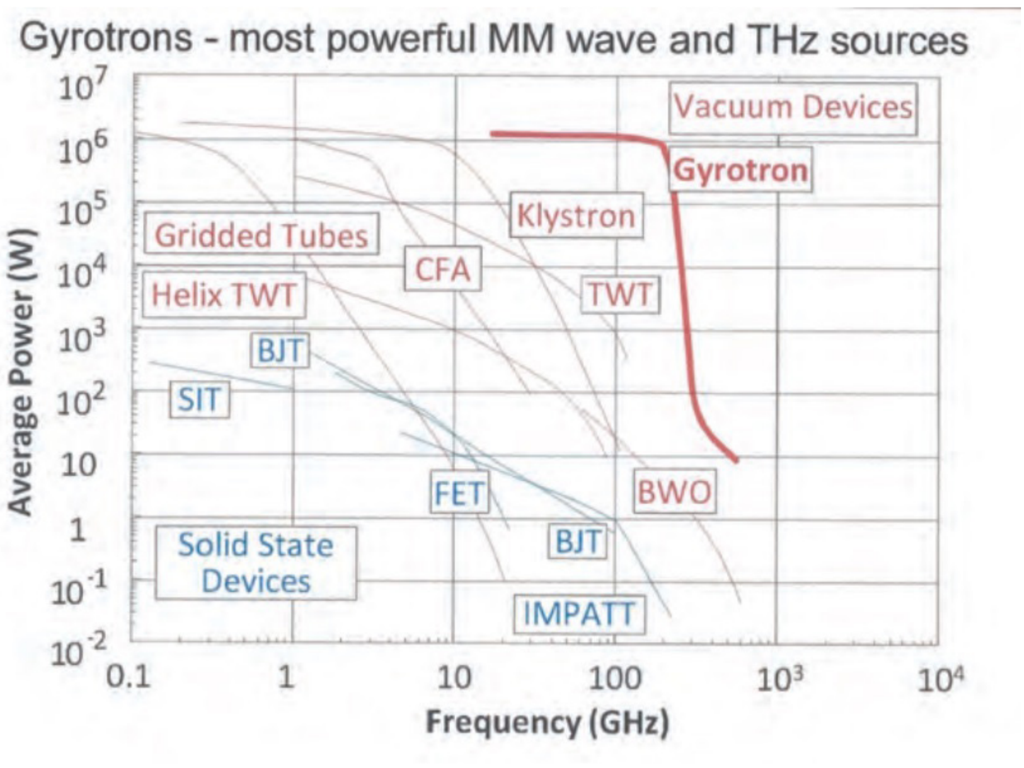
Here we deal mainly with the downlink from the probe to the receiving station (referred to as Gateway in the Milne et al paper) after arrival. This is the rendezvous phase. Milne et al set the rendezvous downlink requirement: "target 20 Gbps data rate between the Icarus probe and Earth, is the equivalent of 13 high definition TV channels (at 1.5 Gbps each)".

The paper also covers Gateway to Earth communication, boost phase and cruise phase communication, intercommunication with a variety of subprobes while exploring the target system and uplink communication (for example for software updates to the probe) during all phases of probe operation.

If and when we develop the capability to send large probes to the stars then the downlink challenge can be addressed using a correspondingly large transmit antenna. Daedalus proposed to use the second stage reaction chamber as a hemispherical reflector but the Icarus mission profile, intended to rendezvous with the target star system, would have time to deploy a larger, dedicated purpose, antenna. The Icarus Firefly team considered both a radio frequency (RF) and an optical downlink.

One thing which does not change whether the mission uses small probes (as in the Breakthrough Starshot studies and early i4is work) or large probes (as for the Daedalus and Icarus studies) or whether the target system encounter is flyby (as in Daedalus and Starshot) or rendezvous (as in the Icarus studies) is the enormous losses resulting for the inverse square law applied over multiple light year distances.

The Firefly study considered a number of RF transmitter options and settled on a developed version of a current technology, the Gyrotron [1]. The target device would yield an output power of 1 MW at 32 GHz over a bandwidth of 3 GHz.



Transmitter Technologies - from *High Frequency Gyrotrons and Their Applications*, R Temkin, Plasma Physics Colloquium, Columbia University 28 February 2014 [2]. Updated from Granatstein et al. Proc. IEEE 1999 [3]

Credit:, image and caption: Milne et al Fig. 1

[1] A type of free-electron maser (microwave equivalent of a laser) which generates high-frequency electromagnetic radiation by stimulated cyclotron resonance of electrons moving through a strong magnetic field. It can produce high power at millimetre wavelengths because its dimensions can be much larger than the wavelength of the radiation. This is unlike conventional microwave vacuum devices such as klystrons and magnetrons. More at en.wikipedia.org/wiki/Gyrotron

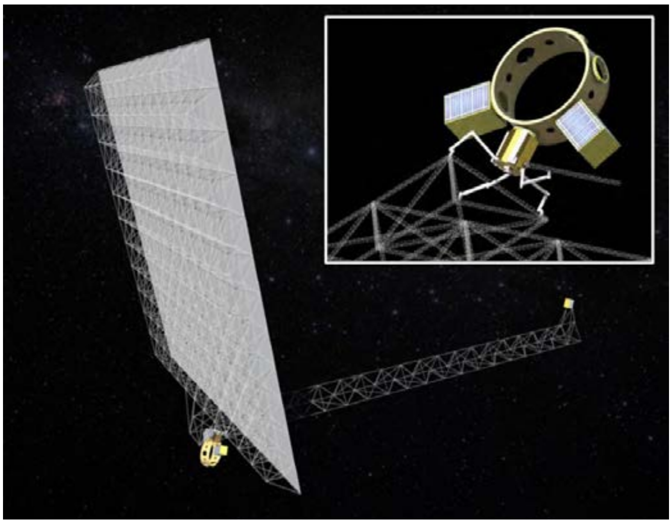
[2] Available as High Frequency Gyrotrons and Their Applications to tokamak plasma heating, K E Kreischer, January 1981, Journal of Magnetism and Magnetic Materials, Volume 11, Issues 1–3, April 1979, dspace.mit.edu/bitstream/handle/1721.1/93407/81rr001_full.pdf.

[3] Vacuum electronics at the dawn of the twenty-first century, V L Granatstein, R K Parker and C M Armstrong, in Proceedings of the IEEE, vol. 87, no. 5, pp. 702-716, May 1999, doi: 10.1109/5.757251.(No public version found).

▶

Concept for demonstration of SpiderFab construction of a large RF aperture as a payload on an ESPA platform. SpiderFab technology can be validated on affordable secondary payload platforms prior to use in operational missions.

Credit: (image and caption) Hoyt et al, Figure 57



A deployable antenna is selected. This is a natural choice for a mission which decelerates. It need not operate at the cruise velocity of the mission, 4.7%c, with the accompanying hazard from the impact of high velocity interstellar dust particles. Both downlink and uplink are envisaged for the cruise phase but the requirements are restricted to telemetry and limited science data.

A 1 km diameter antenna could be fabricated using "spiderfab" robots [1]. The paper estimates that such a 1 km antenna would have mass 40 tons (40,000 kg). This is a fairly small fraction of the intended probe mass at encounter of 2,200 tons.

One or more receivers would be located at Earth-Moon L4 and L5 stable positions. The advantage in scale and power availability for such very much larger probes means that pointing accuracy of transmit and receive antennas can be enhanced by the downlink transmitter including a tracking signal which the downlink receiver can use to point its antenna more accurately using monopulse tracking (via multiple antennas or subarrays of an active electrically scanned antenna or phased array). Note also that the uplink can also include a tracking signal with similar enhancements of pointing accuracy for the antenna on the probe.

The paper includes a detailed link budget and a tradeoff analysis of the effects of different antenna diameters and transmit powers at both probe and receiving station. One striking result of this is that doubling transmitter power results in a 23% improvement in data rate (8.995 to 11.716 Gbps) while doubling the transmit antenna diameter (0.5 km to 1 km) results in a 58% improvement in data rate.

The paper addresses a number of other detailed issues including downlink implications of a possible Proxima Centauri Flyby. Proxima Centauri is not on the flight path between Earth and Alpha Centauri but the Icarus project objectives include the possibility of a subprobe to visit it without decelerating.

5 Possible Laser downlink

The proposed Starshot probes would use a (very small) laser as their downlink transmitter. Milne et al consider laser technology as an alternative to microwave. The basic physics and thus link budget is similar see - *Table: The downlinks* - above. The antenna accuracy requirements are inversely related to the wavelength - the difference is millimetres versus µm so the antenna needs to be around 1,000 times more accurate in shape. The paper gives a rendezvous phase link budget suggesting a 1 KW laser pulsing to 1 GW at 0.532 µm wavelength with a 10 m diameter transmit reflector. It would use pulse position modulation and achieve a 1 Kbps data rate. The data rate depends on the rate at which the laser source can be pulsed. The duty cycle sees a high power during the "on" period and then sufficient time for the device to cool before the next duty cycle begins. The need to dispose of waste heat limits the possible duty cycle of laser. An alternative downlink design utilising spread spectrum modulation (as in 3G mobile) was also considered, but although it could achieve a 12 Gbps data rate it would require a very large mirror with very high surface accuracy and synchronisation of multiple laser sources so that their outputs could be combined coherently. Those drawbacks were considered too difficult to overcome. Milne et al conclude that an RF link is preferable based on current technology but that in the likely timescales for such a heavyweight probe laser technology may have advanced to achieve comparable or better performance.

[1] *Spiderfab: Process for On-orbit Construction of Kilometer Scale Apertures*, R P Hoyt, J I Cushing and J T Slostad, "Tethers Unlimited Inc, NASA Innovative Advanced Concepts. ntrs.nasa.gov/api/citations/20140000422/downloads/20140000422.pdf

6 Citations

The Milne et al JBIS paper has been cited in these subsequent papers-

Interstellar communication. I. Maximized data rate for lightweight space-probes, Michael Hippke, International Journal of Astrobiology, Volume 18, Issue 3, June 2019, pp. 267 - 279, Open access: arxiv.org/abs/1706.03795.

Direct Exoplanet Investigation Using Interstellar Space Probes, Ian A Crawford, in *Handbook of Exoplanets*, ISBN 978-3-319-55332-0. Springer International Publishing AG, 2018, Open access: arxiv.org/abs/1707.01174.

See also *Communications vs isolation*, in *Worldship and self replicating systems*, Michel Lamontagne, Principium 32 February 2021, i4is.org/wp-content/uploads/2021/06/Worldship-and-self-replicating-systems-Principium32-print-2102221659-opt.pdf.

7 Other studies since Daedalus

A Starshot Communication Downlink, Kevin L G Parkin, May 2020, arxiv.org/abs/2005.08940.

Technological Challenges in Low-mass Interstellar Probe Communication, Messerschmitt D G, Lubin P and Morrison I, JBIS v73 #12 December 2020, Open access: arxiv.org/abs/2001.09987.

See also -

The Interstellar Downlink Principles and Current Work, J I Davies, Principium 31 November 2020, i4is.org/wp-content/uploads/2021/02/jid_20210201_principium.pdf - notably the final section - *6 References: Starshot and other related sources*.

8 Future work

The following are my own thoughts on where studies might usefully take us -

- A long duration rendezvous makes it feasible to consider retransmission if an error is detected in downlink data - remembering of course that means a round-trip delay of around eight years even for our nearest stellar neighbour.
- The assumption of a space based downlink receiver and continued use of constructor robots such as Spiderfab for the Gateway antenna means that it can be enlarged during all mission phases. In principle this would allow reduction of the error correction overhead for downlink data and thus a higher useful downlink data rate as the probe explores the target system.
- The massive $100m investment by Yuri Milner in the Breakthrough Starshot study programme includes a continuing effort to address downlink issues. While much of this aims to overcome the difficulties of downlink communication from gram scale probes, some of the results are likely to be applicable more widely.
- The transmit antenna could use three obvious sources of materials - purpose-designed components as in the Milne et al study, cannibalised elements of the probe and materials found in the target system - in-situ resource utilisation (ISRU).
- The life and capabilities of the probe may be extended by ISRU in other ways. Obvious applications include fusion fuel and powersat construction. ■

THE POSSIBLE OBJECTIVE?

Proxima b 3D Model - snapshot

Credit: NASA Visualization Technology Applications and Development (VTAD) exoplanets.nasa.gov/resources/2211/proxima-b-3d-model/

John I Davies reports on recent developments in interstellar studies

A real, albeit humble, warp bubble (continued)?

In our last issue, P35 November 2021, we reported on *A real, albeit humble, warp bubble?* based on a paper by Harold "Sonny" White et al [1].

In *Did scientists discover a warp bubble? Crunched up space-time, explained*} [2], Sarah Wells explains the ideas in the paper. She mentions parallel work by Erik Lentz (eriklentzphd.com) [3].

She also reports dissent. In *I wrote the book on warp drive. No, we didn't accidentally create a warp bubble* science communicator Ethan Siegel [4] says "the science doesn't check out". He describes the open access *European Physical Journal (EPJ)* (www.epj.org/} as "often dubious". Dr Siegel describes himself as "a scientist familiar with Dr White's grandiose claims surrounding physics-violating engines in the past". Not a fan then?

Warp drive is either a long way off or impractical but, like SETI, continues to attract the attention of scientists and engineers and of science journalists. Let's keep watching this plausible but difficult technology. There are many possible ways to the stars and all the serious ones deserve our attention. ■

Announcement from IRG - See what we heard at Tucson

The presentation videos from the 7th Interstellar Symposium that IRG held in Tucson, Arizona, September 25-27, 2021 are now beginning to be uploaded for viewing. There will be more as the editing is done until everything is online. You can see the videos in the 2021 Presentation Video Archive irg.space/2021-presentation-video-archive/. The 8th Interstellar Symposium will be in Montreal, in 2023; Come to Montreal - i4is will be there with IRG again! ■

Free-floating planets in the Upper Scorpius

In *A rich population of free-floating planets in the Upper Scorpius young stellar association*, published in Nature Astronomy Letters, 22 December 2021 (www.nature.com/articles/s41550-021-01513-x and open publication: arxiv.org/abs/2112.11999[1]), Nuria Miret-Roig, Laboratoire d'Astrophysique de Bordeaux & University of Vienna, Department of Astrophysics and colleagues from CNRS (France), University of Tokyo & National Institutes of Natural Sciences Tokyo, Institut d'Astrophysique de Paris, Depto. de Astrofısica Madrid, Universit Paris-Saclay, Depto. de Inteligencia Artificial UNED Madrid, Universidad de Cadiz, - identify a new population of free-floating planets (FFPs) - planetary-mass objects that are not bound to host stars. FFPs were first discovered in the 1990s but their nature and origin remain uncertain due to a lack of large homogeneous samples that would enable a statistical analysis of their properties. Micro-lensing surveys, using a foreground star to magnify the FFPs have detected them down to a few Earth masses. But the ephemeral nature of micro-lensing events prevents follow-up observations and thus better characterisation. This paper reports the discovery of between 70 and 170 FFPs in the region of Upper Scorpius and Ophiuchus relatively close to the Sun, the largest homogeneous sample of FFPs discovered to date. They suggest that ejections due to dynamical instabilities in giant exoplanet systems must be frequent within the first 10 million years of a system's life and thus account for the origins of significant numbers of FFPs.
Other authorities have suggested that these hard-to-detect bodies are likely to be our nearest interstellar neighbours and that internal heating by nuclear processes might make them capable of sustaining life. ■

[1] *Worldline numerics applied to custom Casimir geometry generates unanticipated intersection with Alcubierre warp metric* , European Physical Journal V81, #677 2021 epjc.epj.org/articles/epjc/abs/2021/07/10052_2021_Article_9484/10052_2021_Article_9484.html
[2] www.inverse.com/innovation/warp-bubble-space-time.
[3] *Breaking the warp barrier: hyper-fast solitons in Einstein–Maxwell-plasma theory*, Erik W Lentz, March 2021 *Classical and Quantum Gravity* V38,#7.
[4] bigthink.com/starts-with-a-bang/no-warp-bubble/ - author: https://bigthink.com/people/ethansiegel/.

▶

Capture of interstellar objects

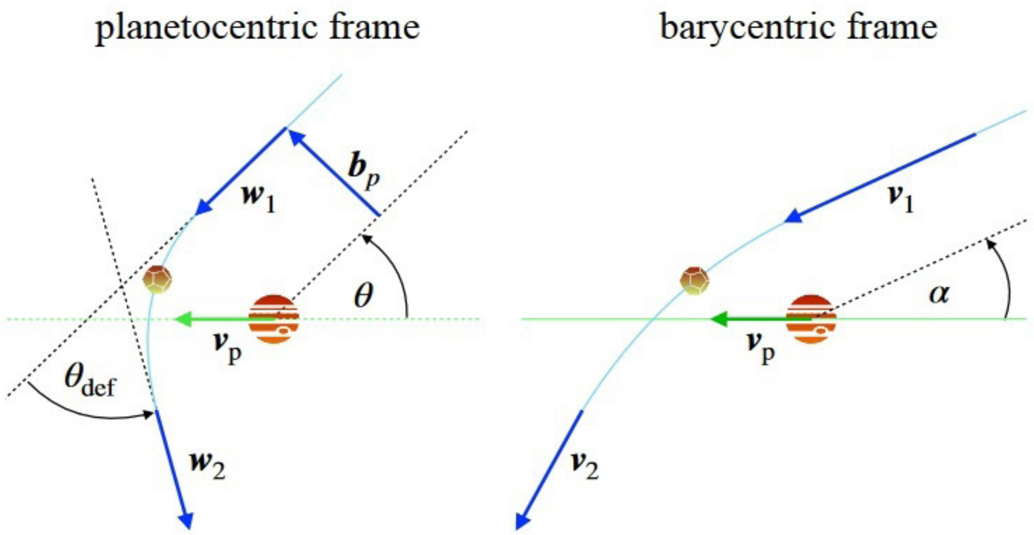
In *Capture of interstellar objects I: the capture cross-section*, researchers from Germany, UK and Switzerland examine how interstellar objects (ISOs) might be captured into orbits within the Solar System [1]. Since the only known ISOs, 1I/'Oumuamua and 2I/Borisov, are heading out on hyperbolic orbits, never to return, finding and identifying captured ISOs is currently the only other source of physical evidence from the rest of the universe.

The paper studies the capture of ISOs by a planet-star binary based on the mass ratio between planet and star, the size of the planet's orbit and its eccentricity. They use a mixture of analytic (roughly speaking "solve the equation") and numeric (roughly speaking "approximate using arithmetic") techniques. Theories of the ejection of ISOs from their birth systems imply interactions with giant planets (as in the slingshot manoeuvres used by the Voyagers and proposed by i4is Project Lyra missions) it might be expected that incoming ISOs can be perturbed into solar orbits by Jupiter or the smaller gas and ice giants in our own system.

They remark that "both the capture rate and the population of captive ISOs depend directly on the number density of these objects in interstellar space, which is not well known". We need to keep looking for both captured and hyperbolic ISOs if we are to learn directly about the rest of the galaxy before our probes can cross the almighty gulf to the nearest stars. ■

Solid core thermal antimatter propulsion

Acta Astronautica has published *Evaluation of solid core thermal antimatter propulsion concepts* [2]. No open access version of this paper seems to be available but the research organisation concerned, ThrustMe (www.thrustme.fr) has been widely published and the abstract is intriguing. Lafleur suggests that energy released during antimatter annihilation can be used to heat a working fluid to directly produce thrust (an "antimatter rocket") or run a thermodynamic cycle to generate power for conventional electric propulsion systems (antimatter power generation). The paper discusses different types of antimatter reactions and solid core reactors, different propellants (hydrogen, water, methane, and carbon dioxide) and electric propulsion technologies (arcjets, Hall thrusters, and gridded ion thrusters). ■



Swing-by of an ISO by a planet. In the frame moving with the planet (planetocentric frame) - the ISO is deflected by angle θ_{def} but retains its speed. If the ISO passes in front of the planet the outgoing barycentric speed (and hence energy) is smaller than the incoming speed enabling capture.

Credit: Dehnen and Hands [1].

The effect is identical to the drop towards the Sun required for a solar Oberth manoeuvre as in the earliest Project Lyra proposals for ISO interception.

[1] *Capture of interstellar objects I: the capture cross-section*, Walter Dehnen and Thomas O Hands, arxiv.org/abs/2112.07468.
[2] *Evaluation of solid core thermal antimatter propulsion concepts*, Trevor Lafleur, Acta Astronautica, Volume 191, February 2022, Pages 417-430

Feasibility of space solar power

The engineering consultancy Frazer-Nash has delivered a report on the feasibility of space solar power to the UK government [1].

The report envisages an orbital demonstrator by 2031 and an operational system by 2040 suggesting delivery of sustainable and clean energy at competitive prices. With input from John Mankins (Mankins Space Technology - using earlier concept, SPS Alpha) and Ian Cash (International Electric Co Ltd - using an earlier concept, CASSIOPei). The report envisages a ground station with a 6.7 km by 13 km elliptical rectifying antenna (converting microwave to DC power) receiving 245 W/m^2 RF power - only 25% of the intensity of the sun at the equator thus inherently safe for life on earth - and delivering 2 GW into the UK power grid.

The power satellite would be a monster 1.7 km across with solar reflectors of similar dimensions. It would be geostationary - thus giving 24 hour service and avoiding damage from proliferating in space debris in lower orbits. The power downlink would be at 2.45 GHz or 5.8 GHz which are industrial, scientific and medical (ISM) designated frequencies.

Power satellites like this could, of course, provide an ideal energy source for space-based beamers delivering laser push to small interstellar probes. The scale economics arising from their application to terrestrial power supply would inevitably alter the relative economics of ground-based versus space-based beamers.

More about the economics of beamers for interstellar missions in *UCSB on the Economics of Interstellar Flight* - elsewhere in this Interstellar News. ■

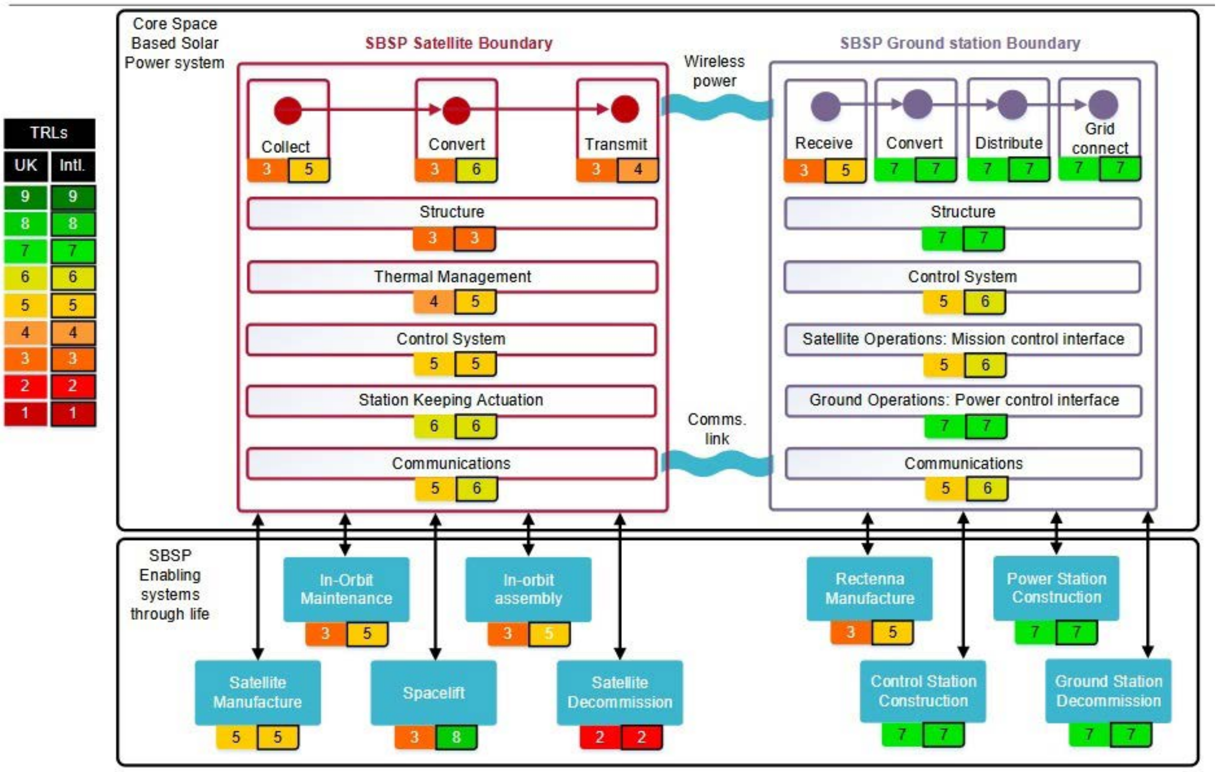


Figure 5: Visual summary of subsystem TRL assessment

Technology Readiness Levels (TRLs) [2]of subsystems from Space Based Solar Power as a Contributor to Net Zero - Phase 1: Engineering Feasibility Report https://www.fnc.co.uk/media/qkleyd5d/fnc-004456-51057r-phase-1-engineering-feasibility-issue-1-0.pdf.

Credit: Frazer-Nash

[1] Press release: *Frazer-Nash report for UK government shows feasibility of space solar power* 27/09/2021: www.fnc.co.uk/discover-frazer-nash/news/frazer-nash-report-for-uk-government-shows-feasibility-of-space-solar-power/, *Space Based Solar Power: De-risking the pathway to Net Zero - Executive Summary* www.fnc.co.uk/media/e15ing0q/frazer-nash-sbsp-executive-summary-final.pdf

[2] ISO 16290:2013 Space systems — Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment www.iso.org/standard/56064.html

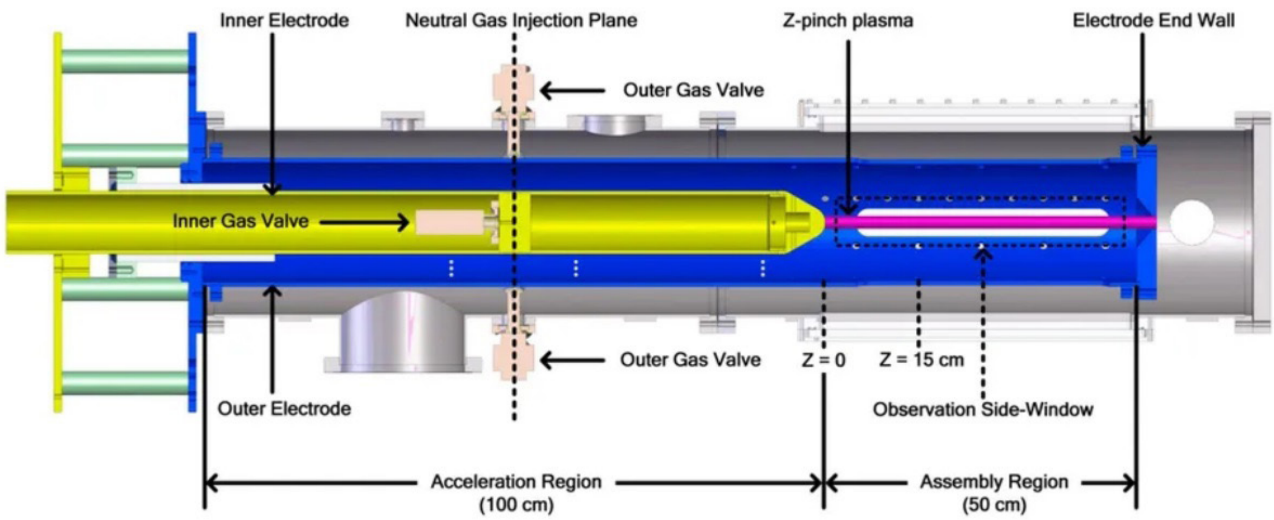
Hyper-Fast Positive Energy Warp Drives

Erik W Lentz of Pacific Northwest National Laboratory, USA (www.pnnl.gov/), has published a paper *Hyper-Fast Positive Energy Warp Drives* (arxiv.org/abs/2201.00652). He points out that travel at speeds beyond that of light has been associated with requirements for staggeringly large amounts of energy and "negative energy" too! In this article he summarises a new approach that identifies "soliton" solutions capable of superluminal travel while being sourced by purely positive energy densities based on his own paper, *Breaking the warp barrier: hyper-fast solitons in einstein-maxwell-plasma theory* [1].

Ever since Miguel Alcubierre's 1994 paper *The warp drive: hyper-fast travel within general relativity,* physicists and engineers have been attacking the mighty problems involved in turning his idea into reality. It seems we are still a long way from achieving this and there may still be things that make it infeasible but the possible effects of achieving superluminal travel can only barely be imagined. ■

IEEE reports - A Pinch of Fusion

The University of Washington work on Z-pinch fusion was mentioned in Rob Swinney's article *Extreme Deep Space Exploration* in Principium 25 May 2019. A recent IEEE Spectrum magazine reports on the spinoff company Zap Energy, aiming to move this work towards a commercial phase. They explain how sheared-flow stabilisation can overcome instability in the plasma stream [2].
Z-pinch fusion is the method explored in the Icarus Firefly study of Robert Freeland and Michel Lamontagne as explained by Patrick Mahon in Principium 22 August 2018, *Reaching The Stars in a Century Using Fusion Propulsion – A Review Paper based on the 'Firefly Icarus' Design* (i4is.org/reaching-the-stars-in-a-century-using-fusion-propulsion/).
Commercialisation of fusion for terrestrial use must inevitably assist its development for space propulsion and thus the possibility of heavyweight interstellar probes. ■



From IEEE article: As deuterium gas is injected into Zap Energy's FuZE-Q reactor, electrodes introduce synchronous pulses, which strip electrons from the deuterium atoms to create a plasma, or ionized gas. The plasma accelerates toward the assembly region, where the current creates a radial shear, or pinch, in the plasma flow. This magnetic field maintains stability as it simultaneously confines, compresses, and heats the plasma to fusion conditions.

Credit: (caption and image): ZAP Energy

[1] *Breaking the warp barrier: hyper-fast solitons in einstein–maxwell-plasma theory,* Eric W Lentz - in *Classical and Quantum Gravity* 38, p. 075015 (Mar 2021). arxiv.org/abs/2006.07125.
Solitons are single self-propagating waves - first observed in a canal by a Scottish engineer, John Scott Russell in 1834, www.mansfield.ox.ac.uk/solitary-waves-colin-please-maths. Russell went on to design the steamship *Great Eastern*, in collaboration with Isambard Kingdom Brunel.
[2] *Magnetic-Confinement Fusion Without the Magnets*, published in the January 2022 print issue of IEEE Spectrum as "A Pinch of Fusion." spectrum.ieee.org/zap-energy-fusion-reactor.

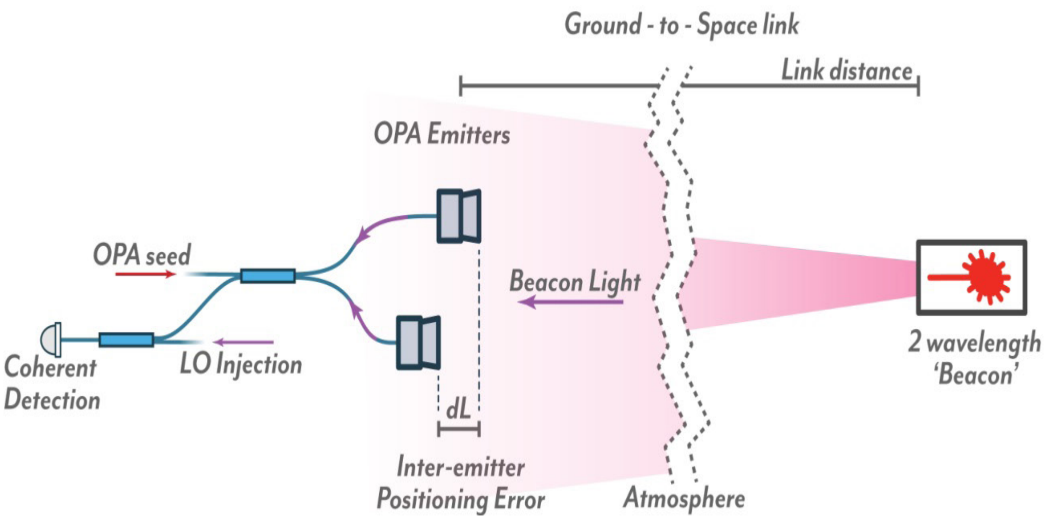
100 GW beamer by coherent combination of 100 M lasers

The Breakthrough Starshot ground-based laser array - order 100 GW of continuous wave optical power - requires coherent combination of many lasers into one beam to achieve a high optical power output. Bandutunga et al [1] propose a photonic solution for optical phase sensing and control to enable the coherent combination of order 10^8 individual lasers - to sense and compensate for atmospheric distortions.

Key points include -

- The system employs digitally enhanced heterodyne interferometry (DEHeI), using pseudo-random binary codes to uniquely identify and demodulate the interference signal from multiple lasers. This capability to uniquely identify optical paths (in effect a unique fingerprint) permits the measurement of the optical phase acquired along the non-common light paths to each emitter [2]. Bandutunga and Ward (B&W) propose a hybrid method that combines DEHeI multiplexed phase sensing with wavelength division multiplexing (WDM) to enable a multilayer hierarchical control scheme capable of individual phase control of an arbitrary number of optical emitters.
- They point out that any method that relies on back-reflected light from the sailcraft will have to deal with long delays due to light travel time at interplanetary distances.
- They propose to obtain the external phase measurements required for atmospheric pre-correction with a satellite-based laser "guide-star". The sensing beam covers the entire beamer array, perhaps a square kilometre with 100 million emitters.

Of course none of this system complexity would be necessary for a space based beamer - but it might take a bit longer to build! ■



From B&W Fig 4. Conceptual overview of the "Beacon" sensing approach. A two wavelength optical source within the isoplanatic patch of the optical phased array (OPA) is used to illuminate all emitter telescopes. Light from the Beacon is coupled into the OPA arms, combined, and then interfered with a local oscillator field (LO injection). Using the multiplexing technique digitally enhanced heterodyne interferometry, the Beacon wavefront, as seen by individual emitters, can be separately measured. Using a combination of emitter measurements at the two Beacon wavelengths, we reconstruct the phase correction required for the OPA wavelength enabling dynamic correction of atmospheric wavefront distortions as well as static phase offsets between emitters due to inter-emitter positioning errors.

[1] Photonic solution to phase sensing and control for light-based interstellar propulsion, Chathura P Bandutunga, Paul G Sibley, Michael J Ireland, and Robert L Ward - all Australian National University, Journal of the Optical Society of America B Vol. 38, Issue 5, pp. 1477-1486, www.osapublishing.org/josab/fulltext.cfm?uri=josab-38-5-1477&id=450064

[2] Modulating each beam with a unique pseudorandom code enables errors caused by spurious interference to be reduced by a factor inversely proportional to the PRN code length - see Shaddock, JPL, 2007 Optical Society of America, *Digitally enhanced heterodyne interferometry*, opg.optica.org/ol/abstract.cfm?uri=ol-32-22-3355

JWST - so far so good The launch of the Ariane 5 carrying the James Webb Space Telescope was a nail-biting Christmas present - with the unwrapping in the following two weeks. Enough has been written already but perhaps the most memorable moment following the main event was the fond goodbye between the Ariane upper stage and the JWST as it headed for Sun-Earth Lagrange point 2. Many fingers were crossed as the mirror segments were adjusted enroute and for the final insertion into its Lissajous orbit around L2 on 24 January. All remarkably smoothly done.
We have months to wait to see first results but let's offer congratulations to NASA, ESA, CSA, Arianespace and the JPL and other engineers - particularly for the mirror origami which seems to have worked flawlessly. ■

Separation of the JWST about 28 minutes after launch - from camera in Ariane upper stage. Credit: NASA and Arianespace

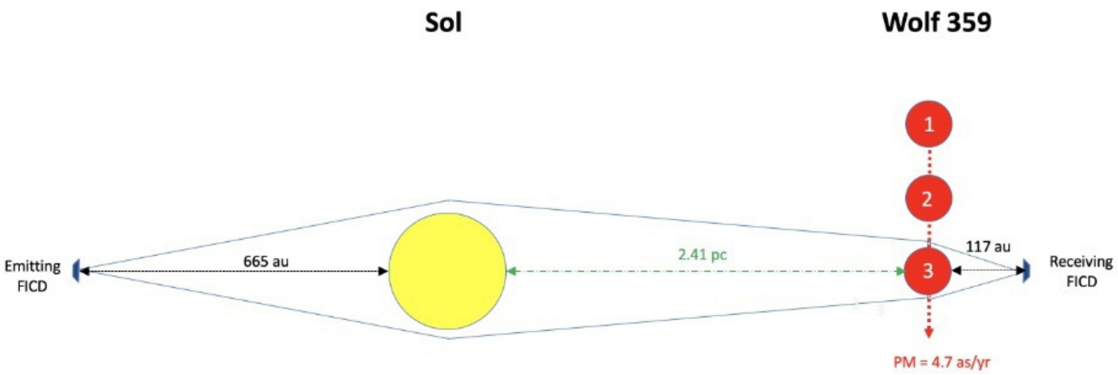
Interstellar communication from hypothetical alien probes

Michaël Gillon (Université de Liege), Artem Burdanov (MIT) and Jason T Wright (Pennsylvania State University) hypothesise that our Galaxy has been fully explored by self-reproducing probes forming an efficient communication network at the galactic scale by direct links between neighbouring systems, using the systems' host stars as Gravitational Lenses (GL). They describe their search for these focal interstellar communication devices (FICDs) in a paper *Search for an alien communication from the Solar System to a neighbor star* [1].

They suggest Wolf 359, the third nearest stellar system, as the best target for a search for interstellar communication from these hypothetical alien probes. Since Earth is a transiting planet as seen from Wolf 359, it would pass in a communication beam of the probe once per year.

They have made a first attempt to detect optical messages emitted from the Solar System to this star, using observations gathered by the TRAPPIST-South and SPECULOOS-South robotic telescopes. These would be sensitive enough to detect constant emission with emitting power as small as 1 W but the search was not successful despite searching for less optimally positioned transmitters within the ecliptic plane.

They are now extending their search beyond the ecliptic plane and for both transmitters and for reflections from a hypothetical solar sail which might be used to maintain the position of such a probe. ■



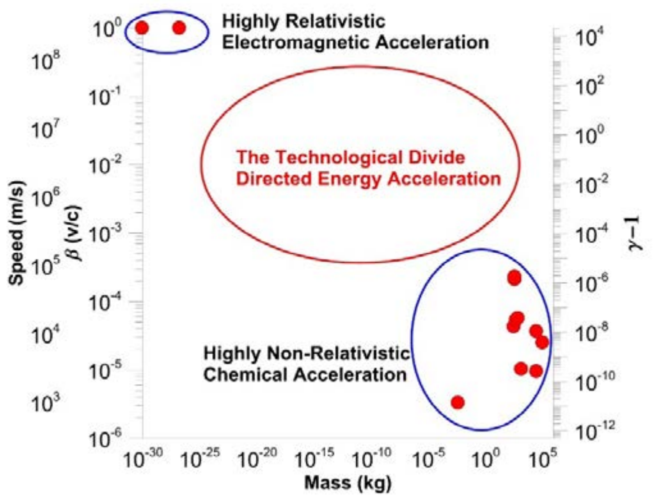
Geometry of the hypothesized communication link from the solar system to the Wolf 359 system (distances and stellar sizes are not to scale). The Wolf 359 system is shown at 3 different positions. Position 1 corresponds to the time of the emission of the photons that we receive from it now. Position 2 corresponds to its current position. Position 3 corresponds to the time it will receive the photons emitted now by the FICD. (caption based on Gillon et al Fig 2) Image Credit: Gillon et al

[1] Search for an alien communication from the Solar System to a neighbor star arxiv.org/abs/2111.05334

UCSB on Economics of Interstellar Flight

Thanks to our interstellar colleague, Paul Gilster, for drawing our attention to more excellent work by Professor Philip Lubin's team at the University of California - Santa Barbara. A paper *The Economics of Interstellar Flight [1]* will be formally published in a special issue of Acta Astronautica in early 2022. As part of the economic calculus for large scale directed energy (the beamers envisaged by Breakthrough Starshot and earlier studies by Professor Lubin and by members of the i4is team) he expands beyond interstellar missions to rapid interplanetary transit, long-range beamed power (for ion, ablation, and thermal engines), long-range recharging of distant spacecraft, long-range and ultra high bandwidth laser communications, remote composition analysis, manipulation of asteroids, and planetary defence. He sees this as an exponentially expanding growth area driven by diverse economic interests and requiring a fundamental change in system designs to deliver the cost reductions required. The paper outlines the physics that must drive the economics and derives an analytic cost model to support forward planning.

Challenges include exponential growth in some of the technologies but not in others resulting in complex dynamics of system costs and suggesting the need for an "interstellar roadmap" including photonics and electronics and a detailed understanding of other, non-exponential, factors.



Credit: (image and caption) Lubin and Cohen

Figure 1: Speed and fractional speed of light achieved by human accelerated objects vs mass of object from sub-atomic to large macroscopic objects. Right side y-axis shows $\gamma - 1$ where γ is the relativistic "gamma factor." $\gamma - 1$ times the rest mass energy is the kinetic energy of the object.

The paper contains a detailed analysis of many cost factors but energy cost dominates in most cases.

This suggests that directed energy propulsion technology will be largely a spinoff of other applications, like early space capability assisted by military application from Von Braun onwards. Lubin and Cohen point out the larger infrastructure costs of a space-based beamer but, despite the dominance of the cost of energy in this work, does not appear to consider the implications of space-based power sources, notably energy satellites, for example the solar power stations envisaged in UK government-sponsored research (see *Feasibility of space solar power* - earlier in this Interstellar News). A similar "spin-off" effect looks likely to decrease the cost of space-based power. Since earth rotation effects are eliminated, the continuous power required would be greatly reduced since thrust could be applied for hours and even days. ■

Beyond Solar System - beware dark matter

A recent paper by Edward Belbruno (Yeshiva University, NYC) and James Green (Princeton University) *When Leaving the Solar System: Dark Matter Makes a Difference* (arxiv.org/abs/2201.06575) suggests that, since the mass of our galaxy is predominantly dark matter, trajectories for spacecraft sufficiently far from the Sun will be affected. In fact has it already affected our existing trans-Neptunian probes? Can we devise a spacecraft to explicitly detect this force? And it would certainly affect interstellar probes if and when we launch them.

We only know (or think we know?) about the existence of dark matter because the galaxy seems to be rotating too fast for gravity from known objects (baryonic matter) to hold it together and that light is bent around external galaxies too much to be accounted for by what we see in them.

Dark matter is so weird that physicists have even suggested modified versions of existing gravity theories as an alternative explanation for what astronomers observe.

This paper calculates the force per unit mass, or equivalently, acceleration, on a particle due to the dark and baryonic matter of the galaxy using two different models.

[1] *The Economics of Interstellar Flight*, Philip Lubin, Alexander N Cohen, preprint at arxiv.org/abs/2112.13911

The two models used are developments of analytic approximations to real galaxies-

- the Hernquist model
- the Navarro-Frenk-White (NFW) model.

The trajectories of Pioneer 10 and New Horizons may give some insight into this likely effect. The lifetime of the RTG power source on Pioneer 10 may be a critical issue. The proposed Interstellar Probe of JHU-APL may have an even better opportunity to measure this effect.

Whatever the mass of our eventual probes to other star systems they will be affected. And since both laser-push and fusion rocket propulsion designs imply a boost phase and a long coasting phase it will be difficult to apply course corrections in mid journey. We therefore need to understand and measure this effect in the planning of these missions. ■

Conceptual illustration of the Wind Rider plasma magnet drive: Credit: Brent Freeze

Trappist 1 - Gravitational Lens in 8 Years

A paper at the December 2021 meeting of the American Geophysical Union, *Wind Rider Pathfinder Mission to Trappist 1 - Solar Gravitational Lens Focal Region in 8 Years* [1] proposes a pathfinder mission to 542 AU, within the Solar Gravitational Lens (SGL) focal region. This would provide -

- calibration data for instruments on a flagship interstellar probe
- initial optical measurements of a scientifically interesting target such as Trappist-1 (given selection of a suitable angle relative to the sun and plane of the ecliptic)

Practical Interplanetary Propulsion Study Group (PIPG) constructed a radial profile for the solar wind ranging from 1 AU through the foreshock at 83 AU, to a notional heliopause at 123 AU, and the near interstellar medium out to 1,800 AU. The resulting matrix of plasma parameters was applied to a trajectory model "seed code," to test flight paths for future probes leading to a proposed cubesat equipped with a Wind Rider propulsion system. Wind Rider is a suggested drag device primarily intended for fast trip times across the solar system. More in *Wind Rider: A High Performance Magsail*, (www.centauri-dreams.org/2021/11/19/wind-rider-a-high-performance-magsail/). They suggest a 1 year science campaign at the end of a total pathfinder mission time after launch of less than 8 years. They also suggest an option to gradually decelerate to a near stop at the end of the mission, using the Wind Rider to drag against the interstellar plasma. ■

Tailpiece: Wacky Scientists hire wacky vicars - or not?

The people at *Interesting Engineering* can't resist a quip - or in this case a missing one! They spotted a piece which originated in *The* (London) *Times - Heavens above: NASA enlists priest to prepare for an alien discovery* which announced that "The Rev Dr Andrew Davison, a priest and theologian at the University of Cambridge with a doctorate in biochemistry from Oxford, is among 24 theologians to have taken part in a NASA-sponsored programme at the Center for Theological Inquiry (CTI) in Princeton in the US to assess how the world's major religions would react to news that life exists on worlds beyond our own." Principium addressed what is a serious issue in a *Book Review: Religions and Extraterrestrial Life, David A Weintraub*, page 51 in Principium 29, May 2020 (i4is.org/wp-content/uploads/2020/05/Principium29-print-2005271554opt.pdf).

The Interesting Engineering piece was subtitled *A rabbi, an imam, and a priest walk into the NASA...* but the punchline was missing. A prize for the best joke with this first line! ■

KEEP AN EYE ON OUR FACEBOOK PAGE

Our Facebook page at **www.facebook.com/InterstellarInstitute** is a lively forum much used by our own Facebookers and others active in our subject area.

[1] *Wind Rider Pathfinder Mission to Trappist-1 Solar Gravitational Lens Focal Region in 8 Years* agu.confex.com/agu/fm21/meetingapp.cgi/Paper/796237

JBIS Index 2021 Volume 74

The Journal of the British Interplanetary Society (JBIS) is one of the two principal peer-reviewed publications covering all aspects of space.

JBIS was first published in the 1930s, published its first interstellar papers in the early 1950s and has continued to publish on all aspects of interstellar studies since then. The Principium feature, *The Journals*, and its predecessor in our Interstellar News section has identified these papers since Issue 26, August 2019.

With the kind permission of the editor we reproduce the annual Index published in the final 2021 issue.

Contents by subject

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72nd International Astronautical Congress 2021 The Interstellar Papers

edited by John I Davies

In this second of two pieces likely to be of special interest to Principium readers we again cover explicitly interstellar topics and others important in contributing to our interstellar goal. See also *A brief on IAC2021: Inspire, Innovate and Discover For the Benefit of Humankind* by i4is Contributing Editor Samar AbdelFattah elsewhere in this issue.

Reports are by - Adam Hibberd, Paul Campbell, Michel Lamontagne, Cassidy Cobbs, Angelo Genovese, Alan Cranston, Robert W Swinney, Patrick Mahon & John I Davies. Please contact john.davies@i4is.org if you have comments, find discrepancies or have additional items to suggest.

Contents

In these reports you will find -
Code - the unique IAC code and a link to the Abstract
Paper title, Speaker, Institutional Affiliation, Country, Reporter
And Links to papers and videos on the IAF website (login required) and to open publication (where found) with each Report on the paper.

IAC-21-C4-9-10-x61782	The Comet Interceptor Mission — Making a Case for Solar Electric Propulsion	Mr Henrique Costa	GMV Innovating Solutions	Portugal/Spain

IAF cited paper:
iafastro.directory/iac/proceedings/IAC-21/IAC-21/C4/9/manuscripts/IAC-21,C4,9,10,x61782.pdf
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iafastro.directory/iac/proceedings/IAC-21/IAC-21/C4/9/presentations/IAC-21,C4,9,10,x61782.show.pdf
IAF cited presentation video: none
Open paper: none found
Reported by: Adam Hibberd

Most readers I'm sure will be aware of the planned ESA Comet-Interceptor mission which will launch towards the end of this decade and will spend up to three years waiting at the Sun/Earth Lagrange 2 point for a suitable dynamically new comet (a comet new to the inner solar system and in pristine, un-eroded condition). It will then be sent on an intercept trajectory to study it.

By necessity, the intercept point will coincide with either the comet's Descending or Ascending Node, the two points at which the comet's path intercept with the ecliptic plane. 'By necessity' because the Sun Earth L2 point rotates around the sun in the ecliptic plane, hence all the spacecraft's velocity will lie in this plane and any applied thrust out of this plane will amount to wasted effort.

The baseline system will employ Chemical Propulsion (CP) implying high thrust, and which can be approximated by assuming an impulsive initial application of ΔV (velocity increment). The mass of propellant required for this burn is given by:

$M_p = M_I - M_f = M_I (1-\exp(-\Delta V/g/I))$

The paper reviewed here is concerned with the investigation of an alternative propulsion system, Electric Propulsion (EP), which comes under the general category of 'low thrust propulsion'. For CP, the trajectory arcs can be treated as approximately ellipses, with the main influence from the sun's gravity and none from the CP system, excepting the impulse at dispatch.

In the case of EP, the probe's orbit is continuously being altered by what amounts to a consistent small perturbing acceleration generated by the EP system, leading to trajectories which deviate significantly from conic sections. For Solar Electric Propulsion (SEP), the mass of propellant is determined by the rate of mass ejection, dm/dt which is dependent on available wattage from the power supply, which in turn depends on the distance from the sun (if solar panels are used).

There are two approaches in the field of trajectory optimization – indirect and direct. The indirect method generally involves application of Pontryagin's Maximum Principle and a Hamiltonian formulation, the direct one involves parametrisation of the control variables (like pitch and yaw for

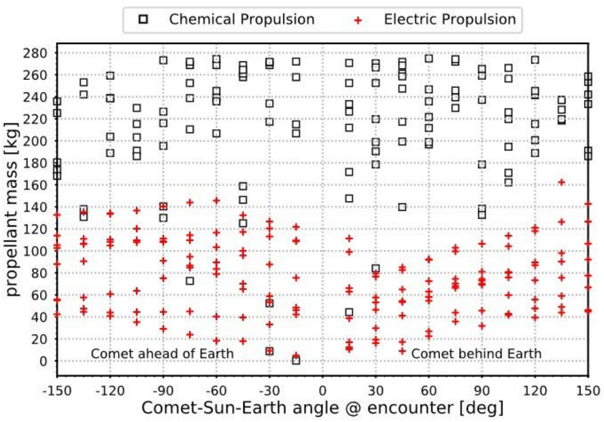

Fig. 4. Superimposed EP and CP m_p maps for minimum m_p trajectories

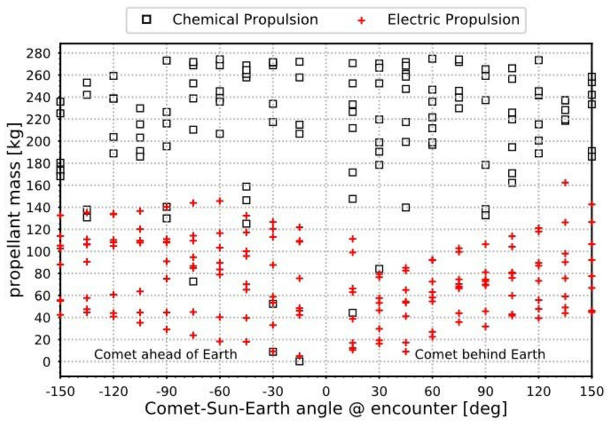

Fig. 5. Superimposed EP and CP m_p maps for minimum Δt trajectories

Electric propellant (EP) and chemical propellant (CP): Minimum propellant mass Mp (left) versus minimum transfer duration Δt (right).

Credit: Costa et al

example in rockets), and usually the application of a Non-Linear Programming (NLP) solver.
The approach here is the latter, direct method, but not only are the controls parameterised but the trajectory itself which is approximated by Chebyshev Polynomials, with the coefficients calculated to satisfy a) the initial position and velocity, b) the final position (the intercept point) and c) the equations of motion.
The problem is formulated as motion in the ecliptic plane with the initial position of the spacecraft located at distance R_{L2} from the Sun and with initial solar longitude $\theta = 0°$ with respect to Earth. Various target values of sun-radial intercept distance R_c and longitude θ_c were selected where $0.9 \leq R_c \leq 1.2$ and $-150° \leq \theta_c \leq 150°$. Values of θ_c near to 180° were neglected to avoid an intercept at conjunction. Furthermore multiple cycles around the sun were modelled where appropriate.
There were two optimization criteria (objective functions) for these trajectory calculations, i) minimum propellant mass, and ii) minimum time. (Reasoning this out and we find these routes are indeed not equivalent for SEP: a time minimum trajectory may use a route which is high wattage – closer to the sun – and therefore require more propellant mass.)
The results were that for SEP there were significant savings in propellant mass, for situation i) above - SEP required max160 kg as opposed to a CP of 280 kg max. In the case of ii) above, the difference is not quite so clear, SEP requiring 260 kg against CP of 280 kg.
Analysis was also performed on the back-up target which is the short period comet 73P/Schwassmann-Wachmann.
To conclude, the SEP system saves 125 kg of propellant mass for 50% of the comet encounter locations, and 75% of the encounter locations required no additional time-of-flight. For 73P/Schwassmann-Wachmann, SEP can reach it with only 16 kg of propellant.

Authors:
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IAC-21,D4,1,14, x66313	Selection of Asteroids Which Are Suitable For Collision With Mars For The Purpose of Terraforming	Neelabh Menariaa, Aditya Balasubramania, Dhruthi Bhatc	Ramaiah Institute of Technology	India

IAF cited paper: iafastro.directory/iac/proceedings/IAC-21/IAC-21/D4/1/manuscripts/IAC-21,D4,1,14,x66313.pdf
IAF cited presentation: iafastro.directory/iac/proceedings/IAC-21/IAC-21/D4/1/presentations/IAC-21,D4,1,14,x66313.show.pptx
IAF cited presentation video: None
Open paper: None found
Reported by: Michel Lamontagne

The writers propose the use of asteroids as impactors for the Mars terraforming process. They propose the use of volatile rich asteroids such as C-complex asteroids from the main asteroid belt. Asteroid deflection methods are described but not calculated. They suggest a runaway greenhouse effect can be started with an artificial 4K rise of the martian atmosphere temperature created by the impact, requiring a 1/200 of the engineering effort for a full 55K rise as originally proposed by Zubrin*. This can be provided by 5-20% of the energy from the impact of a single C-type asteroid of sufficient dimension, somewhere between 150 m to 380 m in diameter ($1{,}9 \times 10^9$ kg to $2{,}96 \times 10^{10}$ kg).
Four candidates are proposed for this purpose, 259P/Garradd (P/2008 R1), P/2013 R3, 238P/READ and 101955 Bennu.

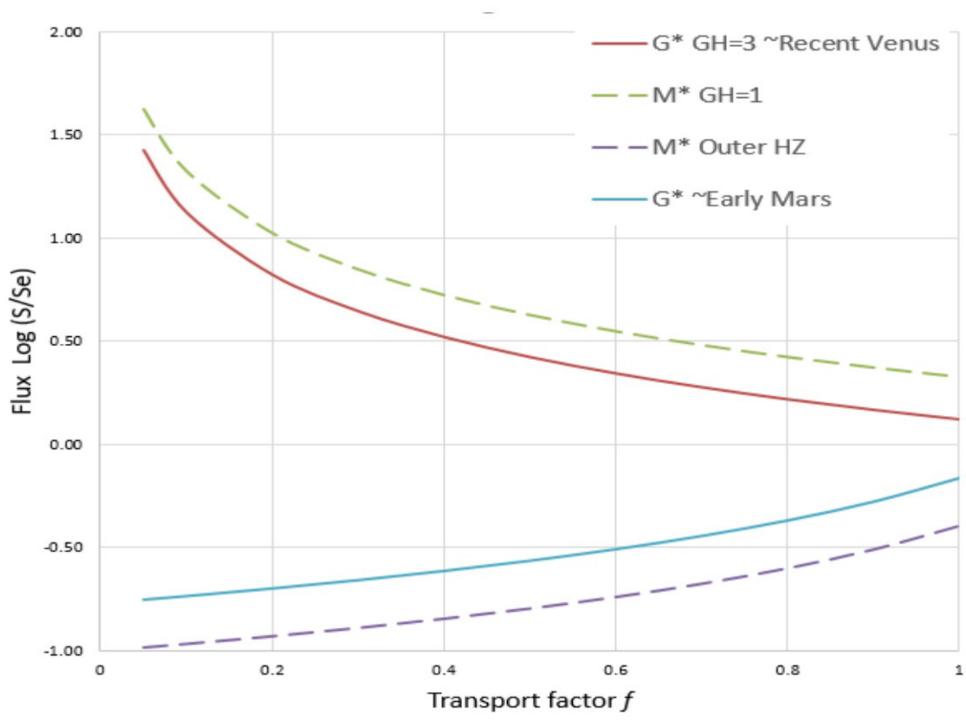
*Zubrin, Robert, and Christopher McKay. *Technological requirements for terraforming Mars* 29th Joint Propulsion Conference and Exhibit. 1993.

Authors:
Neelabh Menariaa, Aditya Balasubramania, Dhruthi Bhatc, all from the Ramaiah Institute of Technology

IAC-21-A1.6.1,x63282	Extended Habitable Zone of M-dwarf planets	Amri Wandel	The Hebrew University of Jerusalem	Israel

IAF cited paper: iafastro.directory/iac/proceedings/IAC-21/IAC-21/A1/6/manuscripts/IAC-21,A1,6,1,x63282.pdf
IAF cited presentation: iafastro.directory/iac/proceedings/IAC-21/IAC-21/A1/6/presentations/IAC-21,A1,6,1,x63282.show.pptx
IAF cited presentation video: none
Open paper: none found
Reported by: Cassidy Cobbs

Wandel expands on the implications of previously reported models (Wandel, 2018 and Wandel and Gale, 2020) of atmospheric properties of planets which are locked, in synchronous orbit, or slowly rotating around M-type stars. This report shows that these atmospheric models, which reduce the surface temperature distribution estimations to a function of host star irradiation, heat transport/reflection, and greenhouse effects, imply a wider Habitable Zone around M-type stars than previously assumed.
Wandel identifies a "heating factor" by combining the Bond albedo, fraction of radiation reaching the planet's surface, greenhouse factor, and insolation (as defined by the host star's luminosity and its distance from the planet) relative to Earth. Thus, the minimum and maximum surface temperatures on a given planet with a defined heating factor can be plotted across latitudes to identify what percentage of the surface falls in the habitable range for temperature.
Further, Wandel plots potential sources of variability in the model, including horizontal heat transport, determined by the atmospheric conditions and rotation speed of the host planet; greenhouse heating; and atmospheric composition and density. This model demonstrates that the HZ for M-type stars may be broader than previously assumed, and that atmospheric conditions can lead to a wide range of estimated surface temperatures by latitude on closely orbiting planets of these stars.



Wandel Fig 4. Minimum and maximum flux values of locked planets as a function of the transport factor. Solid curves show the early Mars-recent Venus HZ of a G-type star, while the dashed curves show the inner (upper curves) and outer (lower curves) HZ-boundaries of an M-type star, for a locked or slowly-rotating planet. Credit: (image and caption) Amri Wandel

IAC-21,C4,6,7,x64788	Progress in Research and Development of Superconductor-Based Applied-Field Magnetoplasmadynamic Technology	Marcus Collier-Wright	NeutronStar Systems UG, Köln 50674	Germany

IAF cited paper: iafastro.directory/iac/proceedings/IAC-21/IAC-21/C4/6/manuscripts/IAC-21,C4,6,7,x64788.pdf
IAF cited presentation: iafastro.directory/iac/proceedings/IAC-21/IAC-21/C4/6/presentations/IAC-21,C4,6,7,x64788.show.pptx
IAF cited presentation video: none
Open paper: none found
Reported by: Angelo Genovese

The low thrust produced by current electric propulsion (EP) devices has created a large gap between the applications for which they are suited and those where chemical propulsion is more fitting. For example, crewed missions prioritise short travel times, and thus, the large thrust produced by chemical systems is needed even at the expense of payload mass. However, with more power, EP systems may produce enough thrust to break into this niche, while retaining the propellant efficiency characteristic of this class of propulsion. As a result, there is continuing research into scaling EP devices to higher power and exploring new concepts that may excel at > 100 kW.

MPDT (Magneto-Plasma-Dynamic Thruster) is a form of electromagnetic propulsion as it employs electromagnetic fields to accelerate a propellant and generate thrust. In an MPDT, a cylindrical anode is located concentric to a central cathode. An arc is struck between these electrodes, ionising the propellant and forming a plasma. This plasma conducts the current radially between the electrodes, inducing an azimuthal magnetic field. The combination of this magnetic field with the electric field generates a Lorentz force which accelerates the plasma out of the thruster to produce thrust.

There are two types of MPD Thruster: Applied-Field and Self-Field. In self-field designs, only the self-induced magnetic field contributes to the plasma acceleration. Applied-Field designs make use of a second, external magnetic field which is typically generated with either permanent magnets or electromagnets. This field is applied in the axial direction, resulting in an overall helical magnetic field configuration due to the interaction of the axial and azimuthal fields. The result is two additional acceleration mechanisms: a Hall-effect acceleration, and a swirl acceleration. As self-field designs require significantly higher currents to operate effectively, today MPDT research has mainly focused on Applied-Field designs (AF-MPDT).

The generation of the applied magnetic field can be achieved through applying a current on a copper coil. For the high field strengths required, this leads to extremely bulky and heavy electromagnets. High-Temperature Superconductor (HTS) technology provides a way of generating the required magnetic field using a much smaller and lighter coil, thereby solving a fundamental issue with conventional AF-MPDT.

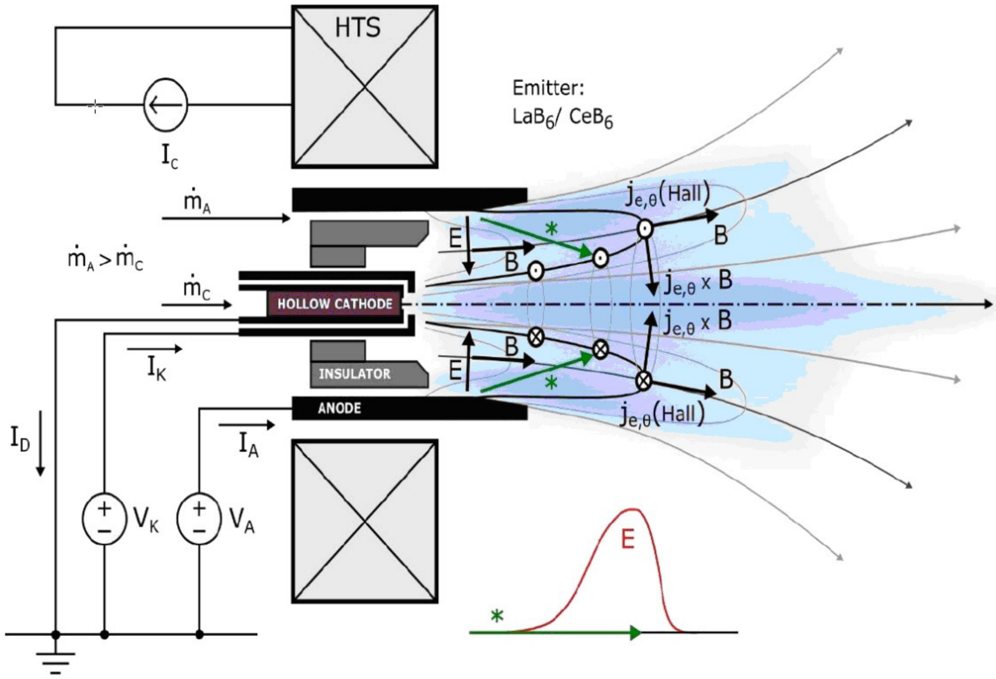
This paper reviews the latest advances in AF-MPDT and HTS developments and presents the SUPREME design concept, an effort to commercialize HTS-based AF-MPD technology currently underway in Germany, led by Neutron Star Systems (NSS) and the University of Stuttgart.

The 100 kW SX3 AF-MPDT developed by the Institute of Space Systems (IRS) of the University of Stuttgart has shown gradual improvements in efficiency up to 62%, a thrust of 2.75 N and a specific impulse close to 4700 s using Argon as propellant. This high performance and high thrust density are very attractive for high-power interplanetary missions, but there are still formidable technical challenges to be solved.

The main challenge is the present poor lifetime, which makes MPDT not competitive against other more mature EP technologies.

The HTS electromagnetic coils which are needed to increase the flight feasibility of this technology present a number of engineering challenges which NSS is currently addressing.

Furthermore, MPDT performance is poor at power levels <100 kW. Hence, any high-performance MPDT design is currently impractical due to the lack of in-space >100 kW power systems. NSS is addressing this issue with the SUPREME concept; it is defined by an operating mode which considers voltage regulation and high voltage operation, alongside with very strong HTS applied magnetic fields, in order to maximize the Applied-Field acceleration mechanisms, namely the Hall and Swirl accelerations.



Operating principles of AF-MPDT Thrusters.

Operating principles of AF -MPDT Thll1sters.

Credit: Collier-Wright et al

The authors note that the AF-MPDT topic has seen an increased traction worldwide with strong national funding, in particular in Russia and China in order to develop high-power EP systems for their joint Lunar and Martian programs. It is then essential to support research efforts in Europe and USA in order not to lose ground with respect to these antagonist space superpowers.

Authors: Marcus Collier-Wright (marcus@neutronstar.systems), Elias Bögel, Manuel La Rosa Betancourt, NeutronStar Systems marcus@neutronstar.systems.

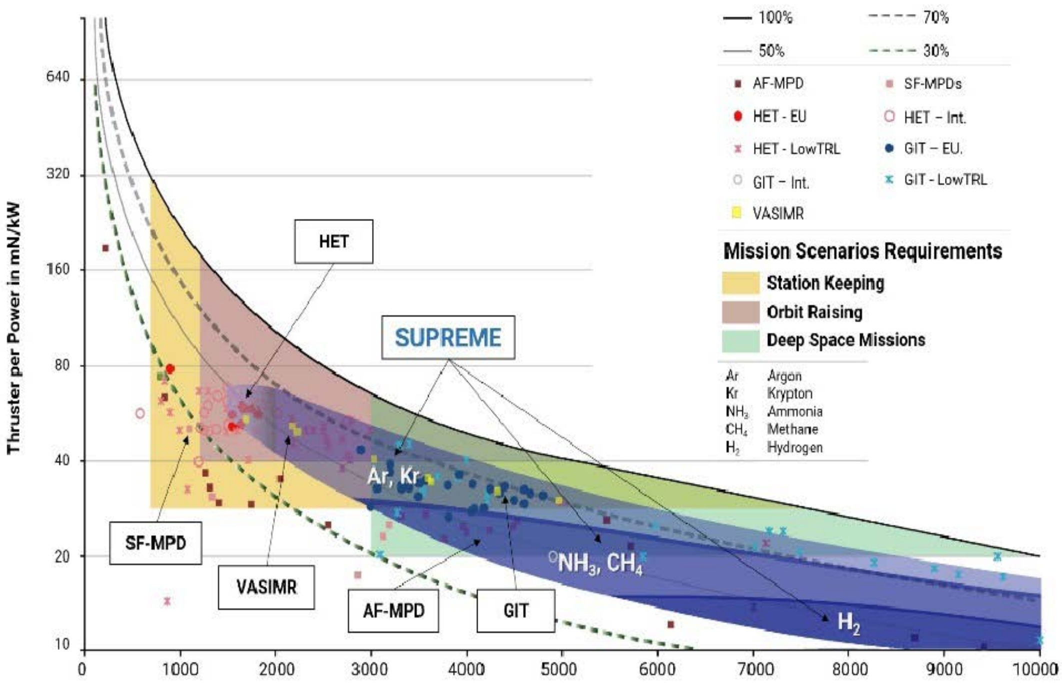


Fig 1. Comparison of Thrust-to-Power ratio and Specific Impulse of different EP technologies.

Credit (image and caption): Collier-Wright et al / M Peukert and B Wollenhaupt [1])

[1] M Peukert and B Wollenhaupt, "OHB-System's View on Electric Propulsion Needs," in EPIC Workshop Brussels, Brussels, 2014. (www.researchgate.net/profile/Markus-Peukert/publication/330082426_OHB-System's_View_on_Electric_Propulsion_Needs/links/5c2c89fe92851c22a3547bc7/OHB-Systems-View-on-Electric-Propulsion-Needs.pdf)

IAC-21, A4,2,10,x65430	Benedict XVI and SETI	Dr Paolo Musso	University of Insubria	Italy

AF cited paper: iafastro.directory/iac/proceedings/IAC-21/IAC-21/A4/2/manuscripts/IAC-21,A4,2,10,x65430.pdf
IAF cited presentation: iafastro.directory/iac/proceedings/IAC-21/IAC-21/A4/2/presentations/IAC-21,A4,2,10,x65430.show.pptx
IAF cited presentation video: none
Open paper: none found
Reported by: Alan Cranston

What does the Pope think about extraterrestrial life? Well, you could always ask him, and that is exactly what Paulo Musso did. As he says, "the discovery of other civilisations in the universe would clearly have deep religious implications." So he wrote to Pope Benedict XVI (then Pope Emeritus) with some questions: and got some answers. His paper discusses what the Pope had to say.

The encounter between Pope Benedict XVI and Dr Paolo Musso in 2015, after their exchange of letters.

Credit: Musso

Perhaps I should start by saying that I am pretty much an atheist whereas I think Dr Musso makes clear in the paper that he is a believer. That might make him more interested in a detailed exegesis of the Pope's view than I am, but we can all recognise the importance of the question as about more than just religious doctrine. It is about human culture and belief systems, which we all have whether we recognise it or not. The discovery of other civilisations in the universe would surely have a profound effect on how most people, whether religious or not, see humanity's place in the universe. It's probably part of the job description for Pope to have thought deeply about these matters or to be willing to do so.

So what did the Pope have to say? On the main question, Benedict suggests that the implications of extraterrestrial life can't seriously be discussed until there is actual evidence of it. Dr Musso recognises that we might be disappointed by this answer (and to be honest I am) but he explains its importance as not dismissing the idea as heresy, as remaining open-minded. It is not only prudent not to speculate, he argues, but scientific. I am more convinced by the former than the latter, but it is surely a psychological truth that most people find it easier to contemplate matters when they are in some sense real to them rather than theoretical constructs. (Anyone who has watched the film 'Don't Look Up' will understand that to many people the comet only became real when they could see it.)

Dr Musso's other questions to the Pope were about how the existence of extraterrestrial life might bear on three aspects of Christian belief: the origins of humankind (Adam and Eve), original sin, and redemption via Jesus Christ. I didn't find the paper very clear on how the existence (or otherwise) of extraterrestrial life bears on the first two of these. However Benedict seems clear that "the triumph of Christ embraces the whole cosmos". In this context, that seems to me to be an extraordinarily forceful view. Christ was born to save all of the beings of the universe, not just the inhabitants of planet Earth. So were we to achieve communication, should we send missionaries? It's interesting that, in an interview quoted at the end of the paper, Pope Francis (Benedict's successor) seems to differ "I am sure that Jesus Christ died on the Cross to *save us human beings* from sin, and resurrected by overcoming death". (I've abbreviated and the italics are mine.) That seems more like a view that Christianity is for humans and stands in a particular relationship to the human condition. But an omnipotent God would still have a view on the whole universe, so there are perhaps conflicts in Francis's view that Benedict avoids. If God thought that extraterrestrials needed the offer of redemption, would he have sent a Christ figure to them too? Perhaps the Church's stance of not having a view until it is needed is the right one.

I found this an interesting paper raising some interesting questions. But for myself I found Dr Musso wanting to dive deeper into specifically Catholic theology than I wanted to go, and I would have valued more discussion about views of other faith systems on these profound matters.

IAC-21-E2.2.9.x65326	A first step towards interstellar fusion propulsion	Mewantha Aurelio Kaluthantrige Don	Department of Mechanical and Aerospace Engineering, University of Strathclyde	UK

IAF cited paper: iafastro.directory/iac/proceedings/IAC-21/IAC-21/E2/2/manuscripts/IAC-21,E2,2,9,x65326.pdf
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Open paper: None found
Reported by: Robert W Swinney

Over recent years many theoretical options for fusion propulsion have been proposed. Fusion is often seen as one of the few candidate technologies that might meet the extreme requirements of interstellar travel using rockets. The lack of definitive experimental evidence has kept the field wide open for a multitude of potential alternatives and it has been difficult to conclude which might win out.

Don highlights the Inertial Electrostatic Confinement (IEC) method which among many others was first studied in the 1960s [eg ref 3] and now being given new life in the intensifying race for fusion power and propulsion. He describes some first practical steps for physically modelling the 'non-fusing' behaviour of IEC along with mathematical modelling.

IEC uses strong electrical fields to confine a plasma in a concentric configuration that accelerates the ions toward the centre of the system. It is conceived that at high enough electrical potentials, eventually, the kinetic energy obtained by ions drawn to the centre will cause fusion by collision of the nuclei. With manipulation of the electrical fields the fusion products could be ejected for thrust akin to current electrostatic propulsion systems.

This paper in reality describes initial attempts to build non-fusing IEC plasma-type drives, noting recent attempts at the Institute of Space Systems [13] and also Kentucky University [15]; Don's test programme is based on a Farnsworth-Hirsch fusor [16] placed in a vacuum bell.

Although the lab results were fairly inconclusive due to leaks and other issues, along with the analytical work it seems that there is potential for a small-scale plasma confining propulsion system that Don considers could even conceivably be applied to a 6U CubeSat. At the range of potential of the anode, the specific impulse of the IEC type devices described varies from 1,000 to 12,000 sec. As he alludes, it is just a first step to building a fusing IEC on a much larger scale.

The work was undertaken at NASA Ames in the Technological and Educational Nanosatellite department under the direction of Marcus Murbach of the Space Technology division.

References (numbers as given in original paper):

[3] Hirsch, R L, 1967. Inertial-Electrostatic Confinement of Ionized Fusion Gases. Journal of Applied Physics, 38 (11).
[13] Chan, Y-A and Herdrich, G, 2018a. Breakthrough of Inertial Electrostatic Confinement Concept for Advanced Space Propulsion. 69th International Astronautical Congress.
[15] Winter, M and Koch, H, 2017. Inertial Electrostatic Confinement Plasma Devices - Potential thruster technology for very accurate attitude. 35th International Electric Propulsion Conference, pp.1–17.
[16] Makezine, 2016. nuker_diagram, i1.wp.com/makezine.com/wp-content/uploads/2013/10/nuker_diagram_v4.jpg?w=1200&ssl=1, (accessed 20.08.21)

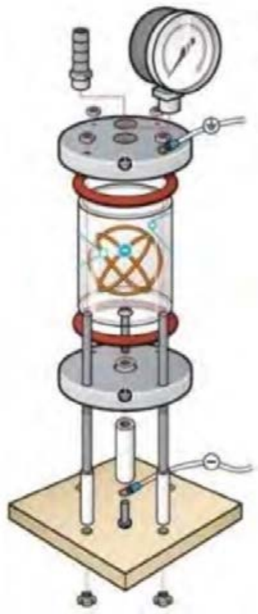

Figure 1. Farnsworth-Hirsch fusor [16] Credit: [16]

IAC-21,A3,3A,10,x66846	Colonizing Mars: In-Situ Resource Utilization of Martian Moons	Vipul Mani	Energy Acres, Uttarakhand	India

IAF cited paper: iafastro.directory/iac/proceedings/IAC-21/IAC-21/A3/3A/manuscripts/IAC-21,A3,3A,10,x66846.pdf
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Open paper: None found
Reported by: John I Davies

Phobos is 27 km across at its widest point. Deimos is even smaller. This paper discusses a possible Mars colony via In-Situ Resource Utilization (ISRU) of these moons. It identifies the overall requirements for such an enterprise, identifies additional research required to better characterise the moons, discusses possible landing sites and identifies the project risks.
Authors: Vipul Mani (M.Sc. Space Engineering, TU Berlin), Harshit Goel, Lawanya Awasthi, Dushyant Singh, Adwait Sidhana (all Department of Aerospace Engineering, Energy Acres)

C4,10-C3.5,5,x66797	Overview of the High Performance Centrifugal Nuclear Thermal Propulsion System	Jimmy Allen	Dynetics	USA

IAF cited paper: none available
IAF cited presentation: none available
Open paper: local.ans.org/ne/wp-content/uploads/2021/02/OverviewCNTR-ANS-Winter-2020-summary-paper.pdf (note this link may be insecure)
Reported by: John I Davies

The Centrifugal Nuclear Thermal Rocket (CNTR) is designed to enable advanced space exploration missions while minimizing engine development risk. This paper gives an overview of the concept, an initial design and an evaluation of its benefits with next steps to implementation. Differing from earlier Nuclear Thermal Propulsion (NTP) it uses liquid fuel, with the liquid contained in rotating cylinders by centrifugal force to deliver a specific impulse of 1,800 seconds using hydrogen propellant, and of 900 seconds using passively storable propellants such as ammonia, methane, or hydrazine. For comparison earlier NTP rockets delivered around 800-900 seconds using hydrogen propellant.
Hydrogen propellant passes through a neutron reflector, a regeneratively cooled section of the nozzle, neutron moderator, and into the main reactor keeping moderators and structural materials at a relatively low temperature (< 800 K). Propellant flows radially into each of 19 Rotating Fuel Elements (see schematic of 19 cylinder CNTR and cross-section of CNTR Rotating Fuel Element) via the porous rotating cylinder wall, passes radially through the molten uranium fuel and exits axially through a central channel into a

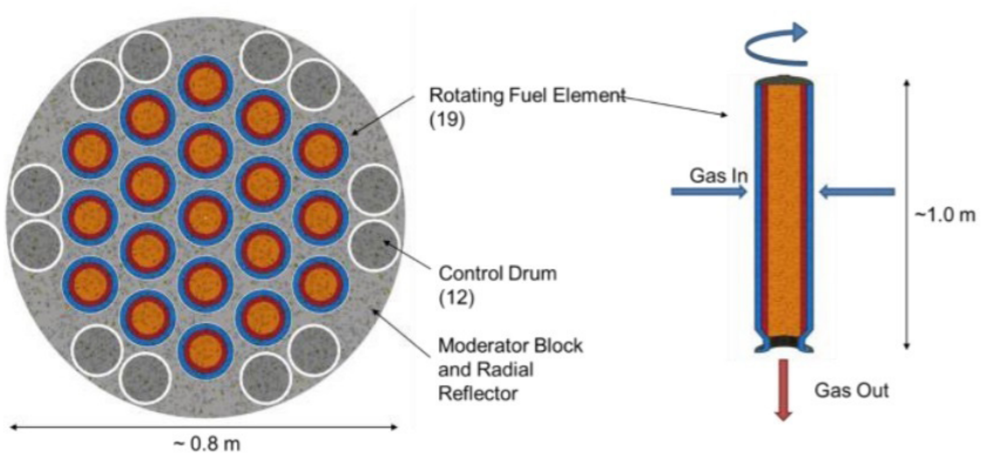


Fig. 1. Schematic of 19 cylinders CNTR

Credit: Allen et al

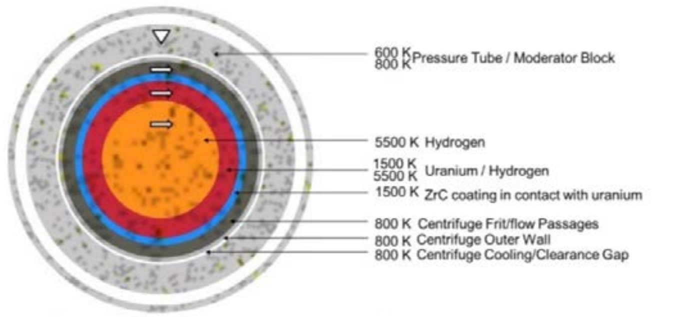


Fig. 2. Cross-section of CNTR Rotating Fuel Element

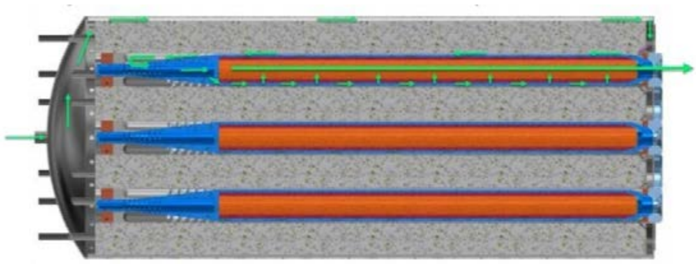


Fig. 3. Propellant Flow Path in the CNTR

Fig 2+3 Credit: Allen et al

common plenum prior to being accelerated through a converging/diverging nozzle. Liquid uranium only contacts the propellant and does not contact any structural material. The liquid uranium is kept under about 34 bar (atmospheres) pressure to prevent the uranium boiling.

The paper claims a number of potential advantages for the CNTR design -

- Only the metallic uranium fuel and a coating on the inside of the rotating cylinder wall exceeds 800 K.
- No thermal stresses in the fuel and no significant compatibility issues between fuel and propellant.
- Hydrogen gives highest specific impulse but propellant can be any volatile material.
- Metallic liquid uranium gives high uranium density using only Low Enriched Uranium while still maintaining acceptable system mass.
- Iodine-135, a fission product, can be exhausted during the engine burn, meaning Xenon-135 poisoning will not restrict engine restart.
- Other fission products exhausted during the engine burn would mitigate shutdown decay heat removal.
- High specific impulse (~1,800 s) at high thrust, which may enable round-trip times to Mars in around 420 days.
- A lower specific impulse storable propellant would enable long-term in-space storage.

The paper identifies a number of design risks and technologies and engineering approaches that are needed for the CNTR-

- Adequate heat transfer between the metallic liquid uranium and the propellant must be demonstrated.
- The porous rotating cylinder wall must allow propellant to flow into the cylinder while not allowing molten uranium to be forced out (by the centrifugal force) via the propellant flow.
- The porous wall must help ensure adequate mixing between the propellant and uranium.
- The coating for the inside of the rotating cylinder wall must be compatible with liquid uranium and any potential propellants at ~1,500 K.
- Rotating cylinder design and fabrication with transpiration and film cooling to avoid potential hot spots.
- Developing rotating cylinders at several thousand RPM with toleration of failure of individual cylinders.
- Methods for startup and shutdown must minimise loss of uranium and avoid vibrational instabilities
- The reactor and cylinder exit must keep the uranium (HALEU) loss rate acceptable, <0.01% of the propellant mass.
- Methods for replenishing HALEU.
- Optimised neutronic design of the core.
- Use experience from previous (lower temperature) liquid reactor development to ensure stable operation during startup, operation, and shutdown.
- Methods for incorporating the CNTR reactor into an NTP engine must be devised.
- A rapid, affordable CNTR development program is required including early proof of concept experiments.

The paper concludes that a high thrust propulsion system capable of providing 1,800 seconds specific impulse could enable 420-day round trip human Mars missions and other advanced space missions.

Authors: Jimmy Allen (Dynetics), Michael Johns & Mark Patterson (Southern Research, Birmingham, AL), Michael Houts (NASA Marshall), Florent Heidet (Argonne National Laboratory), Nicholas V Smith (Idaho National Laboratory), John E Foster (University of Michigan)

IAC-21,A4,1,10,x67003	From Dust to Technosignatures: Searching for Stellar Occulters with Machine Learning	Dr Daniel Giles	SETI Institute	USA

IAF Cited Paper: iafastro.directory/iac/paper/id/67003/abstract-pdf/IAC-21,A4,1,10,x67003.brief.pdf
IAF cited presentation: iafastro.directory/iac/proceedings/IAC-21/IAC-21/A4/1/presentations/IAC-21,A4,1,10,x67003.show.pptx
Open paper: none found
Reported by: Paul Campbell

Over the last decade the Kepler telescope and the Transiting Exoplanet Survey Satellite (TESS) have monitored millions of stars' cadences. These fading events have been hypothesised as being anything from artificial megastructures to transiting exocomets [1]. Utilising machine learning this work looks to identify more of these rare fading events in light curves from the TESS raw dataset to identify the most unusual for follow-up with ground-based observation.

The approach taken is based around anomaly detection. First the TESS dataset is filtered retaining only the most significant outlying light curves to reduce the size of the dataset for the next stages using a user defined threshold relative to the mean. The outlying light curves are then scored using a machine learning model based on 60 dimensions (a dimension in machine learning is an individual property of an input). The output of this is a score relative to how similar each light curve is to the others.

Having scored the individual light curves the research group are using the model to identify the most anomalous curves. Their future work will focus on investigating any dips in the most anomalous curves to identify occulters' similar to Boyajian's Star.

The scored dataset will also be made available to others for further research based into anomalous light curves.

[1] Boyajian T S, et al., 2016, Monthly Notices of the Royal Astronomical Society, 457, 3988

Authors: Daniel K Giles (Carl Sagan Center, SETI Institute), Ann Marie Cody (SETIwTESS Collaboration - Organized by the Breakthrough Listen group at UC Berkeley).

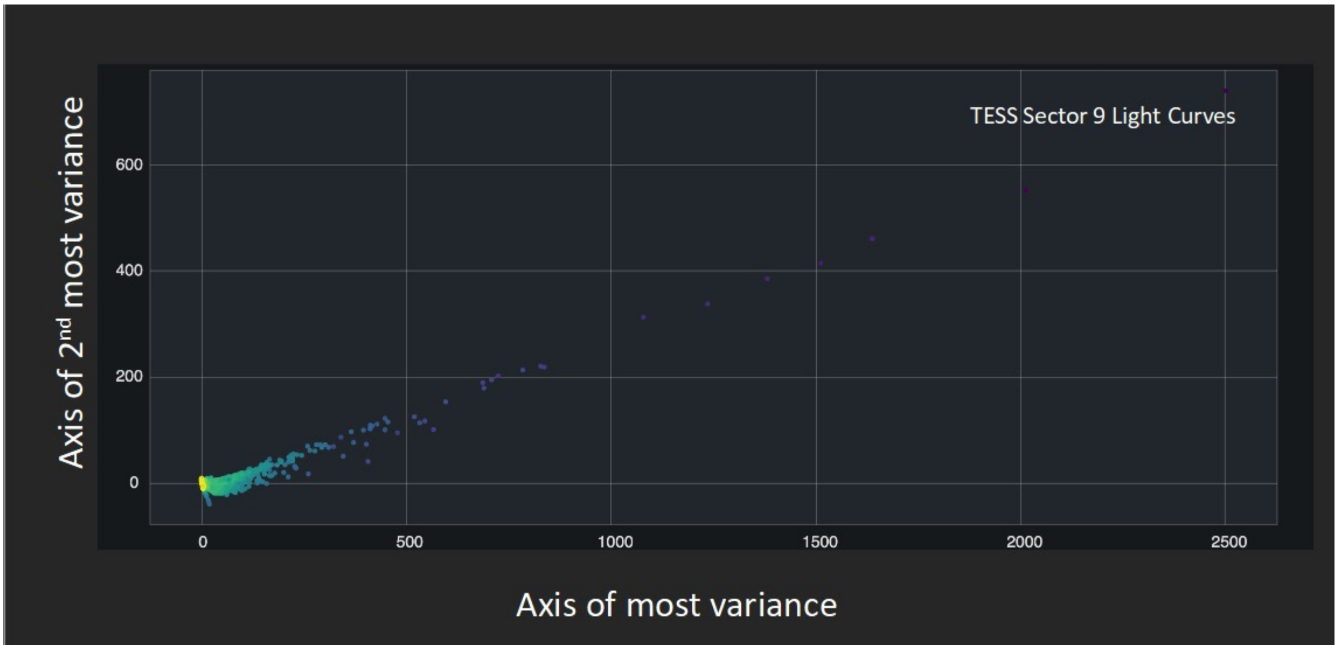


Chart showing two dimensions but, with additional dimensions the model is shown in 3D space. Credit: Giles/Cody

IAC-21,A4,1,1,x65248	Breakthrough Listen: Green Bank Telescope Observations, Analysis, and Public Data	Steve Croft	University California Berkeley	USA

IAF Cited Paper: not available
IAF cited presentation: iafastro.directory/iac/proceedings/IAC-21/IAC-21/A4/1/presentations/IAC-21,A4,1,1,x65248.show.pptx
IAF cited paper: IAC-21,A4,1,1,x65248.pdf
IAF cited presentation video: none found
Open paper: Not found
(background: http://seti.berkeley.edu/listen/)
Reported by: Patrick Mahon

In this presentation, Steve Croft outlines recent progress on the Breakthrough Listen-funded SETI work at the 100-metre diameter Green Bank steerable radio telescope in West Virginia, USA.

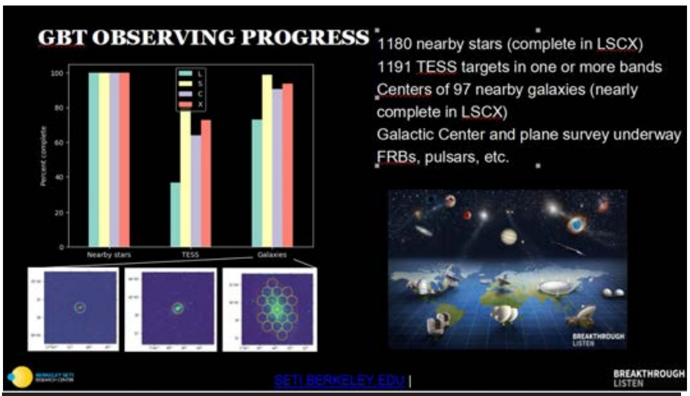
A summary of their previous work, based on Croft's presentation at IAC 2020, can be found in Principium issue 32, page 82.

They are now using the telescope for five hours a day for SETI work, which leads to them capturing hundreds of Terabytes of raw data each day, so data storage capacity is a major issue.

The Green Bank Telescope continues to have three main SETI targets: 1,180 nearby stars, 1,191 targets selected from the Transiting Exoplanet Survey Satellite (TESS) catalogue of 'Targets of Interest' (stars with potential exoplanets orbiting them), and the centres of 97 nearby galaxies.

The survey of nearby stars is now complete, and the survey of nearby galaxies is over four-fifths complete, while the TESS candidate survey is around half-completed. To date, they have found no technosignatures.

They are also undertaking a survey of the centre of our own Milky Way galaxy, recognising that the density of stars is relatively high there, providing more targets to observe per square degree of sky. They have now surveyed it comprehensively across a bandwidth of 1-93 GHz, and found no transients



Progress at Green Bank / *Credit: Croft / Breakthrough Listen*

Green Bank telescope *Credit: Croft*

within their limits of detectability.

Finally, Croft provides an update on their use of machine learning techniques to automate the analysis of their massive datasets, looking to find

Galactic Centre Summary *Credit:* Gajjar, Perez, et al (2021)

new features that may be missed otherwise. This includes working with the 'Kaggle' data science and machine learning online community to run a competition with a $15,000 prize for the team that develops the best machine learning algorithm for detecting anomalous signals in the Breakthrough Listen datasets.

For anyone who is interested in using this data to do citizen science, there is over 2 Petabytes of public data available to interrogate at seti.berkeley.edu/opendata.

Authors: Dr Steve Croft, Dr Andrew Siemion
Berkeley SETI Research Center.

IAC-21,C4,5,2,x63347	A Superconducting EmDrive Thruster: Design, Performance and Application	Roger Shawyer	Satellite Propulsion Research Ltd	UK

IAF Cited Paper: iafastro.directory/iac/proceedings/IAC-21/IAC-21/C4/5/manuscripts/IAC-21,C4,5,2,x63347.pdf
Presentation video: vimeo.com/641220207
Open paper: www.emdrive.com/IAC20212Gpaper.pdf
Reported by: Patrick Mahon

The EmDrive is a widely reported concept for an electrically-powered spacecraft thruster which appears to enable propulsion without the use of reaction fuel. Many observers are sceptical about the entire concept, since at first glance it appears to violate the principles of conservation of energy and momentum [1].

The basic design of the EmDrive is shown in Figure 1. It is a cavity in the shape of a truncated cone, into which microwaves are injected. At the resonant frequency (eg where the length of the cavity is equal to precisely 1.5 times the wavelength of the radiation) a standing wave is set up. The microwave beam transfers momentum to each of the end plates, but because one is larger than the other, and because the beam velocity varies across the cavity, there is a net thrust.

The inventor of the EmDrive, Roger Shawyer, insists that it is consistent with the laws of physics, and continues to develop the EmDrive design. Last year, he presented a paper at the virtual IAC 2020 which set out detailed design specifications for an EmDrive thruster suitable for use on a CubeSat, purportedly enabling a flight time from Low Earth Orbit to Mars in 8 months, or to Pluto in 4.3 years.

In this latest paper, he describes experiments aimed at significantly increasing the level of thrust produced from the CubeSat EmDrive [2] by coating the internal surface of the microwave cavity with a superconducting thin film. This is done because the thrust generated by the device is predicted by Shawyer's theory to be proportional to the 'Q-factor', or Quality factor, a standard feature of resonant cavities defined as the ratio between the energy stored in the cavity and the energy lost.

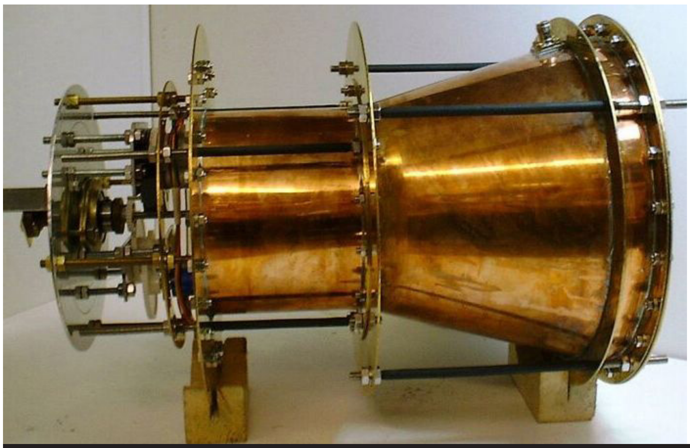
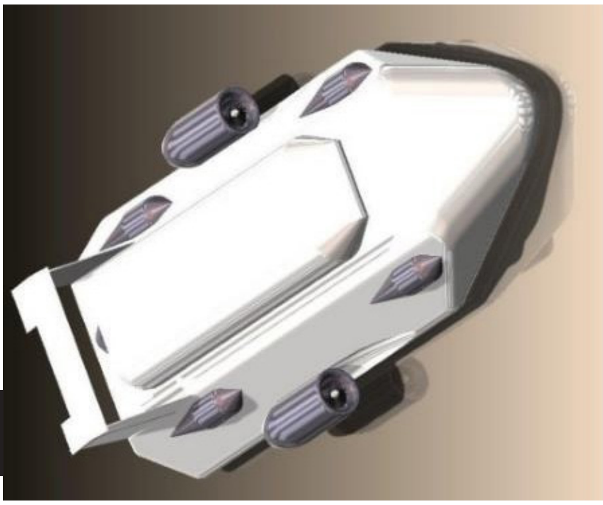


Figure 1. EmDrive / *Credit* - www.emdrive.com/

In his experiments, when the thin-film superconductor (made from Yttrium Barium Copper Oxide, which becomes superconducting below around 93 Kelvin) is cooled to 77 Kelvin with liquid Nitrogen, the Q factor and thus the available thrust increases by two orders of magnitude. Another two orders of magnitude improvement in thrust is predicted from cooling the equipment down to 20 Kelvin with liquid Hydrogen.

Using liquid Nitrogen, a specific thrust of 12.3 Newtons per kilowatt has been achieved in the experimental set-up. If reproduced at an operational scale, Shawyer suggests that such thrust levels could enable rapid missions to the outer planets, or even interstellar precursor missions.



Shawyer has wider ambitions - Hybrid Spaceplane Concept / *Credit:* Shawyer *[3]*

[1] P Sutter (2021), In a comprehensive new test, the EmDrive fails to generate any thrust. phys.org/news/2021-04-comprehensive-emdrive.html
[2] R Shawyer (2020), An EmDrive thruster for CubeSats, paper C4.6.9, IAC 2020. Open paper: www.em rive.com/IAC20paper.pdf
[3] The impact of EmDrive Propulsion on the launch costs for Solar Power Satellites - IAC-21,C3,1,5,x62540
Roger Shawyer www.emdrive.com/IAC2021spspaper.pdf

IAC-21, C4.10-C3.5.11,x65142	Toward the Engineering Feasibility of the Centrifugal Nuclear Thermal Rocket	Dale Thomas	University of Alabama in Huntsville	USA

IAF Cited Paper: iafastro.directory/iac/proceedings/IAC-21/IAC-21/C4/10-C3.5/manuscripts/IAC-21,C4,10-C3.5,11,x65142.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-21/IAC-21/C4/10-C3.5/presentations/IAC-21,C4,10-C3.5,11,x65142.show.pdf

Related open paper: local.ans.org/ne/wp-content/uploads/2021/02/OverviewCNTR-ANS-Winter-2020-summary-paper.pdf (note this link may be insecure)

Reported by: Patrick Mahon

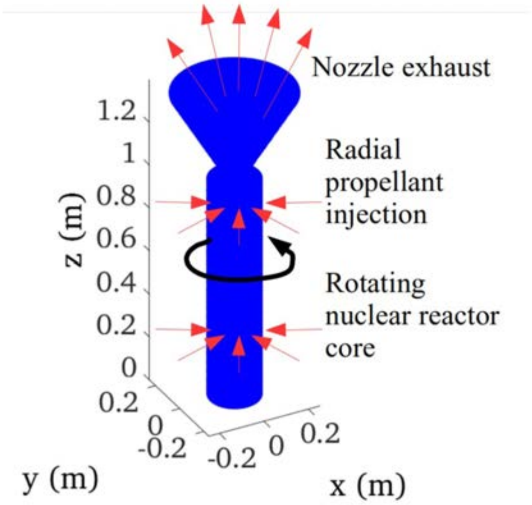
If we want to be able to reach the stars in a reasonable timeframe, we need to develop advanced propulsion systems that will enable our spacecraft to reach much higher velocities.

Amongst the many different technologies under investigation, Nuclear Thermal Propulsion (NTP) is one that seems closer to reality than most, having been studied since NASA's Nuclear Engine for Rocket Vehicle Application (NERVA) programme in the 1960s.

In a standard NTP rocket, a liquid propellant such as hydrogen is pumped through the core of a nuclear reactor, conceptually similar to the type used in nuclear power stations worldwide. The reactor generates huge amounts of heat through the fission of uranium atoms, and this heats up the hydrogen propellant, turning it into a gas which is expelled at high velocity through the exhaust nozzle to produce thrust. Such a rocket is predicted to be roughly twice as efficient as the best chemical rockets in turning propellant into thrust, as measured by the specific impulse: around 450 seconds for the Space Shuttle Main Engine, versus around 900 seconds for standard NTP [1].

In an effort to develop even more thrust per unit of propellant, researchers are investigating more complex types of NTP design, such as the one explored in this paper. The Centrifugal Nuclear Thermal Rocket (CNTR) differs from more standard NTP designs in that it uses liquid reactor fuel, rather than the solid uranium fuel rods found in a normal nuclear reactor. This enables the propellant to be directly heated to the extremely high temperature of the molten fuel, doubling the specific impulse once more, up to 1,800 seconds for hydrogen. This would, for example, enable a crewed mission to Mars in a round trip duration of 420 days, significantly reducing the travel time and thus the crew's exposure to cosmic radiation.

In order to keep the propellant as close as possible to the nuclear fuel, a further innovation in this design is that both are held in rotating cylinders, using centrifugal force to keep them together (see C4,10-C3.5,5,x66797, *Overview of the High Performance Centrifugal Nuclear Thermal Propulsion System* - earlier in this IAC21 report).



Notional elements of a 3D centrifugal nuclear thermal propulsion simulation.
Credit: Thomas Fig 7

While the fundamental physics is well understood, there are several major engineering challenges to be overcome before the CNTR concept can become a reality. These include optimising the heat transfer between the metallic liquid uranium fuel and the hydrogen propellant, designing the porous wall of the rotating cylinders so that the propellant can get in without the uranium fuel getting out, designing and manufacturing the rotating cylinders themselves, and minimising the loss rate of the uranium fuel to an acceptable level. Another six challenges are listed in the paper.

The early-stage research to address these challenges (analysis, modelling and experimentation) is being undertaken at five institutions in parallel: University of Alabama in Huntsville, MIT, University of Michigan, Penn State and NASA Marshall. While they admit to being some considerable way from developing a prototype CNTR engine, their research programme will take them towards that destination.

[1] Office of Nuclear Energy (2021), 6 Things You Should Know About Nuclear Thermal Propulsion. www.energy.gov/ne/articles/6-things-you-should-know-about-nuclear-thermal-propulsion

C4,10-C3.5,1,x63502	Thrust Measurements of Microwave-, Superconducting- and Laser-Type EMDrives	Oliver Neunzig, Marcel Weikert, Martin Tajmar	Technische Universität Dresden	Germany

IAF cited paper: iafastro.directory/iac/proceedings/IAC-21/IAC-21/C4/10-C3.5/manuscripts/IAC-21,C4,10-C3.5,1,x63502.pdf
IAF cited presentation video: none available
Open paper: none found
Reported by: Dan Fries, PhD

Using thrust measurements capable of nanoNewton resolution, Neunzig, Weikert and Tajmar assess the thrust generating capabilities of different EMDrive, or propellantless cavity-based, propulsion concepts. The EMDrive concepts encompass the classical microwave setup, an infrared laser type setup, and a superconducting configuration. The research is part of ongoing efforts to develop and test advanced space propulsion systems at the Institute of Aerospace Engineering at TU Dresden. Past tests had not shown any real thrust being produced by EMDrive devices. The current study re-assesses these results after implementing a range of external suggestions, increasing the reliability of the performed measurements. The most important developments for the new thrust measurements are summarized as follows:

• Environmental influences on thrust measurements were minimised and noise levels lowered to that of photon pressure thrust measurements.
• Ability to cryogenically cool the thrust balance setup for superconducting propulsion devices.
• The figure of merit is a thrust value exceeding the photon pressure of equivalent power, for a propulsion device to be of interest.
• The thrust balance developed is an inverted counterbalanced double-pendulum configuration.
• Deflections of the balance are measured with an optical interferometer. Thus, thrusts as low as 1.67 nanoNewton from a 0.5 W continuous laser can be measured with a signal-to-noise ratio of 10.

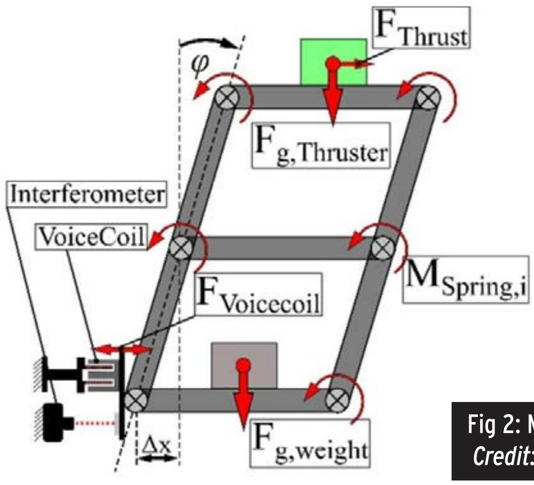


Fig 2: Measurement principle of the inverted double-pendulum thrust balance. *Credit: Neunzig et al*

In the case of the classical microwave EMDrive, no measurements exceeded the noise floor nor the equivalent photon pressure at a given operating power. Neither predicted force values nor operating conditions were reached by the device. The superconducting EMDrive measurements presented challenges due to nitrogen boil-off and temperature variations, increasing the noise floor. Testing of this device in different orientations led to the conclusion that thrust measurements, while present, are most likely experimental artifacts. Finally, thrust measurements for optical cavity concepts, in all cases, resulted in pure photon thrust or balance noise only, with no enhancement as predicted by a certain theory of quantised inertia. Thus, the results reported in this study confirm previous findings, ie none of the EMDrive devices represent a "breakthrough in space propulsion". Nonetheless, the impressive sensitivities and capabilities of the developed thrust measurement approach will be useful in future studies.

Authors: Oliver Neunzig, Marcel Weikert, Martin Tajmar, all Technische Universität Dresden ■

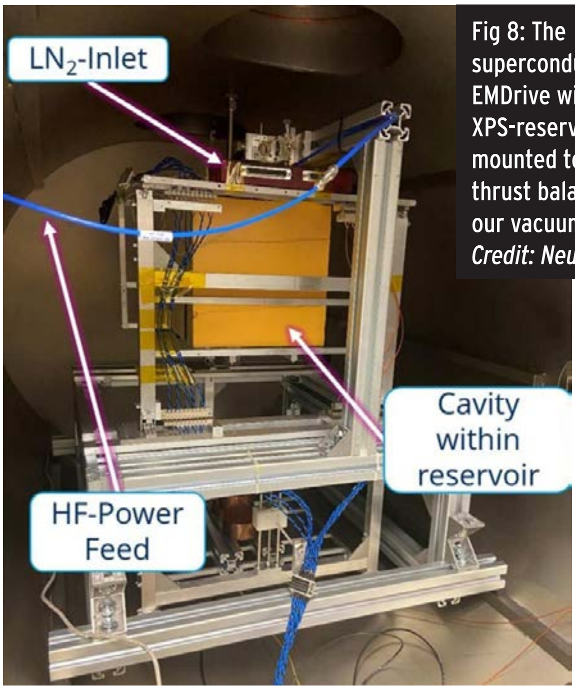


Fig 8: The superconducting EMDrive within the XPS-reservoir mounted to the thrust balance inside our vacuum chamber. *Credit: Neunzig et al*

A brief on IAC2021: Inspire, Innovate and Discover For the Benefit of Humankind

Samar AbdelFattah

Principium Contributing Editor Samar AbdelFattah was the i4is representative at the 2021 International Astronautical Congress (IAC21) in Dubai. Reports on interstellar papers given at the Congress are in our last issue and this one. Here Samar gives us her impressions of the event.

IAC2021 was a source of inspiration for all. From the desert of the UAE, where for the first time in history, the IAC is happening in the Middle-East, to this year's programme addressing the commercialization of space exploration and the expected unique growth in the space industry. Driven by this vision, the scheme of IAC this year focused on space exploration, towards the Moon, to Mars and beyond our Solar System.

In addition to the potential and expansion of commercial space services, another critically important topic was discussed this year, which is the use of space exploration to study climate change and Earth sustainability. As a result, sustainable space utilization was one of the essential components in most use cases and missions outlined. Whether it's an LEO satellite, lunar or Martian exploration, or even an interstellar mission, sustainability was a key element to measure the expected success or even the audience interest in the discussed mission or project. In this article, we covered the relevant interstellar topics that were presented this year. Followed by the interstellar-relevant brief we will walk you through the most recent trends in the space industry that were discussed and can influence the progress and growth of deep space missions and interstellar travel.

The second day technical agenda carried a very interesting series of discussions (oral presentations) around the Space Elevator proposals. The sessions, which were led by Dr Peter Swan- president of International Space Elevator Consortium ISEC, held a portion of approaches towards enabling masses to GEO and beyond. With the masses enablement as a main function, the discussions continued under the main theme of "Green Road to Space" that was established by the ISEC team.

Figure 1. IAC2021 Opening, Dubai, UAE

Figure 2. Dr Peter Swan introduces ISEC Space Elevator Sessions

◀ With their Galactic Harbour architecture they aim to incorporate two space elevator systems,for the transportation and for the enterprise. Basically, the Galactic Harbour will be the volume encompassing the Earth Port and stretching up in a series of cylinders to include two tethers and the region just beyond the Apex Anchors (Figure 3). Such that, customer products/payloads will enter the Galactic Harbour at the Earth Port and exit at some point along the tether. Along the way, there will be tremendous enterprise development such as easy assembly at GEO, refuelling operational satellites and construction, among other things, and release from the Apex Anchor for trips to interplanetary destinations.

In summary, ISEC are trying sustainable and complementary solutions that can address -on an application layer- space solar power to placing masses for industrial purposes in orbit in an eco-friendly manner. However, the concept still faces some technical challenges that the ISEC team addressed during their sessions. For example, space debris as an obstacle for the elevator construction and operations. Also, the lightning effect on the initial 50 km from earth at least.

Finally, they discussed how space elevators can complement current launching systems and integrate with them, so there is more to understand on the "Green Road to Space". More details about the Space Elevator functions and operations schemes can be found on the ISEC website.

Another highlight was on the fourth day that included a series of sessions on the Interstellar Probe mission by the Johns Hopkins team, Figure 4. The excitement was on all attendees' faces when the team introduced their spacecraft interstellar mission, especially after all the effort placed in the past almost six decades to send a spacecraft to the Interstellar Medium. So far only five spacecraft have achieved that, Pioneer 10 and 11, Voyagers 1 and 2, and New Horizons.

The Interstellar Probe 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 1000 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.

The spacecraft used New Horizons as a baseline for their design and more details on the model and payload design can be found here.

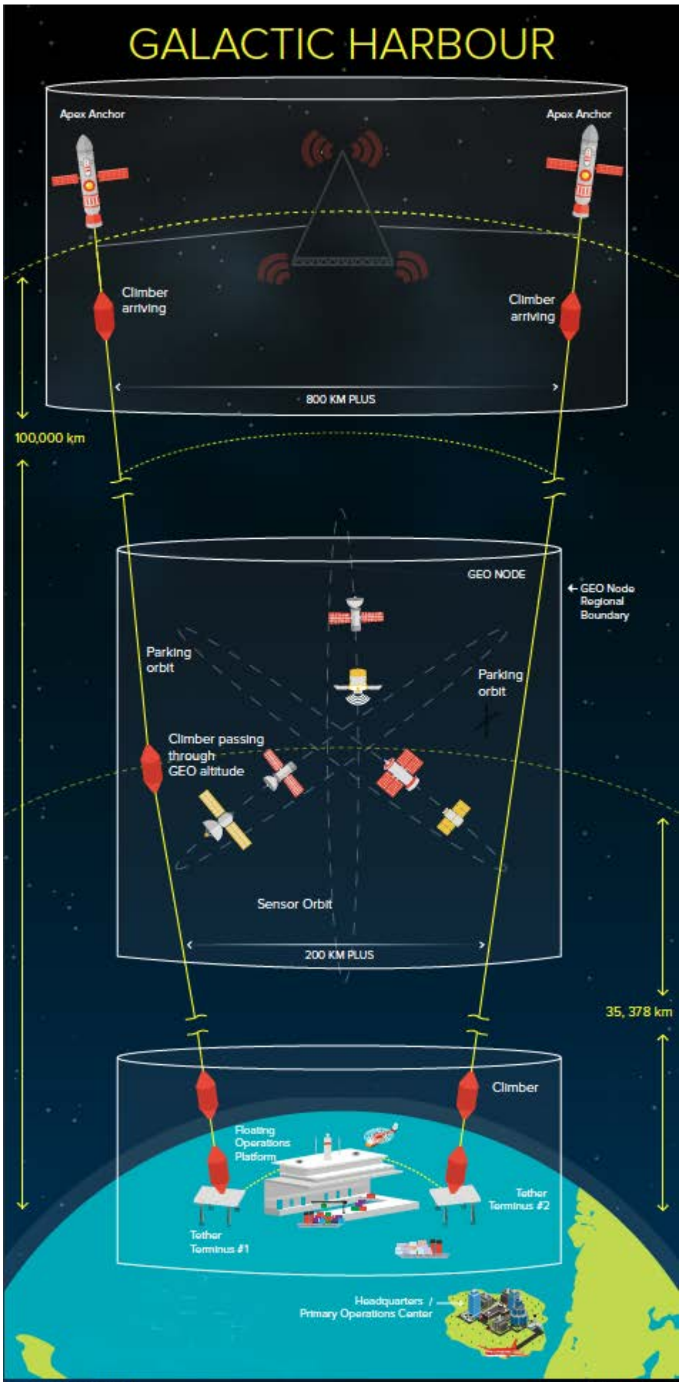


Figure 3. Galactic Harbour Scheme by ISEC

▶

Figure 4. Interstellar Probe Campfire Session: HUMANITY'S FIRST DELIBERATE STEP INTO THE GALAXY BY 2030

With the ambition to fill in the gaps and answer the already existing and recently generated questions by different disciplines, the Interstellar Probe mission will seek to understand more and elaborate on

- Our Heliosphere as a Habitable Astrosphere and its Place in the Galaxy.
- The Origin and Evolution of Planetary Systems.
- How Early Galaxies and Stars were formed.

To penetrate this unexplored territory the Interstellar Probe is planned and expected to flyby Jupiter in less than a year (expectedly by 2030). The ISP report can be very useful to learn more about the mission: interstellarprobe.jhuapl.edu/uploadedDocs/papers/588-ISP-Study-2019-Report_PR.pdf.

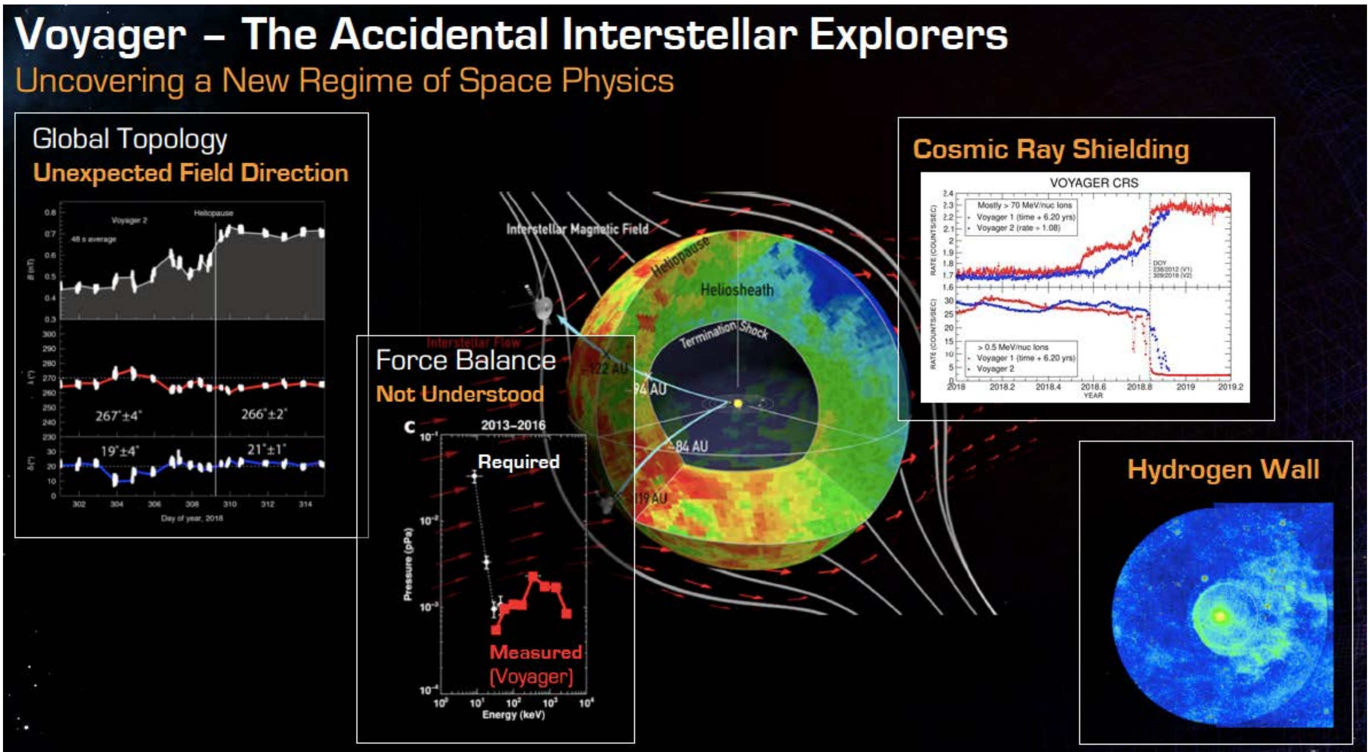


Figure 5. Voyager Unexplored Regime, Copyright: ISP- JHUAPL

One of the most trending keywords during IAC this year has to be access to investments. With the rapid growth of commercial applications of space technologies and introducing space tourism in a more feasible structure, an exponential growth in access to funds can also be expected. Enabling projects like the Space Elevator and missions like the Interstellar Probe comes with their ability and adaptability to integrate with the space industry's future needs. However, the financial challenges facing missions planned to explore our Heliosphere and beyond are exclusively higher, especially at early stages of research and development.

A key solution for that can be associated with another trending keyword during this year's IAC as well, which is Inclusion in Space. The location of this year's event in itself is a step forward to address inclusivity in the space industry.

In fact, inclusion in the space industry will not only lead to more ideas and perspectives of space exploration in our solar system and beyond, it will also participate in increasing access to funds by engaging governments to release contracts and launch national space programmes. Which will also naturally lead to the growth in private businesses developing space technologies, solutions and services.

However, some challenges are expected to arise at early stages of this growth, for example commercial applications will take longer time to penetrate these new markets, where the space exploration race was not part of their economic positioning for a very long time. Thus, creating lack of awareness about space potential use cases like tourism or entertainment.

These commercialization challenges will not only face new markets but rather exist in most projects or missions that haven't displayed their expected Returns Of Investments (ROIs) clearly. Which is expected to be a concern at very early stages with most research investments focusing on the technical feasibility rather than the business ROIs. Some commercial applications however have paved the way with successful business models like Zero-Gravity flights, LEO Tourism, ISS site visits and soon to join the Orbital Reef project that was exclusively announced during the second day of IAC2021.

Orbital Reef is the first of its kind commercial space station by Blue Origin and Sierra in collaboration with NASA and RedWire. The project took commercial applications beyond the trending scheme of space tourism to enable space deeper space explorations missions and giving access to in space testing and manufacturing. Similarly, Interstellar missions have to work on getting their own breakthrough by empowering commercial applications of their missions.

In conclusion, a lot of work still needs to be done and the presence of Interstellar Technologies will have to go beyond ideas and dreams to Only explore! The industry already moved from commercializing space technologies into commercializing space missions. With this disruptiveness in the ecosystem, the interstellar dream can turn into reality faster than we think. ■

Figure 6. Orbital Reef Official Announcement, IAC2021

The Future is closer than we think

7th Interstellar Symposium - The Hallway is More Important than the Podium...

Joe Meany and Bart Leahy

In our last issue Bart Leahy & Joe Meany reported on the 2021 symposium of the Interstellar Research Group (IRG) in Tucson, Arizona. Here Joe tells us about the informal part of the event. Experience teaches that it's often the personal side of conferences where a lot of the significant results are achieved.
We hope that the International Astronautical Congress in Paris this year and the 8th Interstellar Symposium in Montreal 2023 can be even more productive.

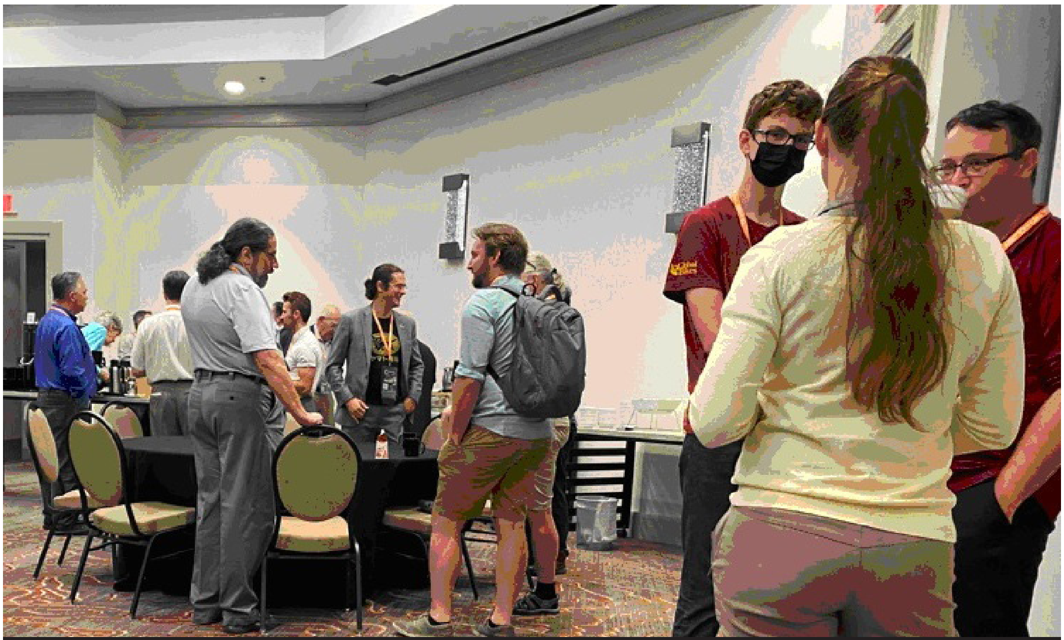
…as the saying goes. Lots of information is shared at the podium, years of work among teams of people putting considerable effort into the breakthroughs that define careers. But the dynamic is always the same: a lead researcher lecturing in a one-way transfer of information to an audience of (let's be honest) varying attention spans and topical understanding.

One of the high purposes of the IRG Interstellar Symposia is to catalyze the discovery process by breaking down that monolithic communication model.

The IRG Symposia are designed purposefully to facilitate information exchange. By limiting the number of speakers, IRG intends to build in multiple opportunities for informal conversations over the coffee breaks, catered meals, and the "Hospitality Suite," a purposeful carryover from the entertaining con suites found at classic sci-fi conventions. What are some of the things that happened in these spaces, which underscore the importance of in-person meetings?

Opening Reception participants wondering what the author was up to.

All images & captions Credit: Bart Leahy



Chatting room only at one of the daily IRG coffee breaks

Coffee breaks, strategically situated to stimulate both the legs and the mind, give the audience a designed opportunity to query presenters with in-depth discussion before the memory fades. Lectures are designed within static time constraints, and we all know that the truly interesting questions can't be addressed within the confines of a quick Q&A. I had one such discussion with Jeff Greason and Andrew Higgins about their design for the accelerated particle beam. Having a background in materials science, particularly one focused on carbon-based nanomaterials, I was struck by their suggestion to use ionized fullerenes (balls of electrically conductive carbon) in their design. We had a lovely back-and-forth, and I got to shine a little by pointing out other possible material candidates based on ionization energies and how efficient different materials might be to use based on their mass-to-charge ratios. The conversation wrapped neatly within the 30 minutes of the break, and we still got to have our coffee and brownies during the chat.

The catered lunch (and walk over to it) are also a perfect time to hold discussions, catching up with old collaborators or just getting to know the other folks at the conference. Lunch spent networking with new colleagues is one of those benefits, and I had the pleasure of meeting Colin Warn, an interesting fellow from Washington state who wants to work on publicity with IRG in the near future. I also had the pleasure of catching up with Brent Ziarnick, who has finally returned from a hiatus from IRG while his career required all of his professional energies. Brent was the lunch speaker so he had to eat quickly, but the rest of the discussions around the table were professionally lively.

The atrium of this particular Marriott was well-suited to collaborative conversations, as comfortable padded seats with high backs were situated around tables to seat four to five individuals. Groups of tables clustered nearby enabled small groups of individuals to overlap nearby conversations as chance allowed it. I saw this happen no less than three times over the course of the symposium, where nearby conversations would meld together (akin to a reverse osmosis) from small groups into larger, more energetic, exchanges. The height of the atrium carried laughter to the rafters well into the evenings. Even with the muted public attendance, the conversations were engaging. Attendees regaled others with tales about their early careers in aerospace research; suggested job or business opportunities; coached junior researchers about how to grow as professionals in the field; and genuinely shared in the dreaming that makes interstellar enthusiasts of us all. Gerald Jackson, founder of HBAR Technologies, was particularly generous with his advice and guidance. I greatly appreciated the opportunity to spend as much time with him as I did.

This year, the Hospitality Suite was home to a reception for the multitude of volunteers who came together to make the convention a success. Local students sat down to local pizza and snacks to refresh from their labors, mingling with IRG staff and each other. At the session I was able to refresh my connection with Robert Freeland, a long-time contributor to IRG and Project Lead with Icarus Interstellar. After the technical tours, the Hospitality Suite provided a nice quiet place to relax and refresh. I sat with Yvonne Mayfield and Mark Prusten. Mark shared episodes from his long career in computer modelling for both the sciences and special effects industry. It was absolutely fascinating to hear about early graphics processing, something completely outside of my experience. As a mere consumer of art, I certainly take special effects rendering for granted. Yvonne and I also had a useful conversation, suggesting where IRG could improve in its inclusivity efforts, particularly with students. I'm glad she brought up the subject, as it reminded me why I came to the IRG board in the first place: if IRG is to last as an organization, it needs to include a growth model that accentuates student involvement.

When I attended my first Symposium with the IRG (then, the TVIW), TVIW co-founder Robert Kennedy had asked me to attend something I'd never heard of before. He asked me to come along to a "dead-dog" session. It was a phrase I'd never heard of before, but as a plucky graduate student who was still rather enthralled with being asked to tag along with these fun spacey folks, I obliged. In the dead-dog session we broke down what went wrong and what went right with the session. Much of the discussion centered on pre-planning logistics which I'd not been privy to, so that conversation went a little over my head. But then the attention of the room turned to me. What did I, someone unfamiliar with the history of the organization and the context out of which it sprung, think of the conference? Did I get anything out of it? What could have been done better? Even though my leadership position within IRG was still several years off, the leadership was taking careful notes of the feedback I provided for the next symposium.

Bart Leahy reports out on the "Targeting a Habitable World" working track

This year's dead-dog session proceeded in that same spirit. Colin Warn attended along with Martha Knowles, Ken Roy, Doug Loss, Andrew Higgins, and Andrew's graduate student assistant Matthias. While there was certainly plenty of feedback solicited from Colin and Matthias, we also geared the conversation toward our next goal: Montreal in 2023! This month, IRG and Andrew Higgins are getting underway to plan the 8th Interstellar Symposium to be held in summer 2023. Looking forward to seeing everyone there! ■

IRG President Doug Loss delivers closing remarks for 2021

The Journals

John I Davies

Here we list recent interstellar 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

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

JBIS VOLUME 74 NO.11 NOVEMBER 2021	**General Interstellar Issue**	
RELATIVISTIC BRAKING AND POWER GENERATION through stellar magnetic fields via Eddy Current forces	Colin Warn	Washington State University
A highly conceptual method of braking a spacecraft moving at relativistic speeds by means of circulating Eddy Current forces in a metal is proposed. As an example calculation using a sail made from the 'wonder-material' graphene, it is hypothesized that an approximately 500 m2, 1 g sail can be decelerated completely from 8% the speed of light in 127 seconds using a planetary system's stellar magnetic fields, while generating around 26 W of power. This method, if experimentally shown to be feasible, can be improved by increasing the melting point of the spacecraft materials, as well as the maximum deceleration rating of spacecraft electronics and payloads.		
SETI AND EVOLUTIONARY POPULATION DYNAMICS	Stephen Ashworth	
The number of loci at which extraterrestrial intelligence might be found in the Milky Way Galaxy is conventionally thought to be roughly constant over time, having already arrived at a steady state some billions of years in the past. But the scenario of interstellar colonisation implies a radical transformation of the prevalence of intelligent activity in the Galaxy: an evolutionary big bang. Observations indicate that such a big bang has not yet happened, or is still at an early stage. Writers on the subject have hitherto shied away from this implication, preferring to conclude that it is possible to reconcile an already well populated Galaxy with the current lack of observed signs of intelligent activity in our immediate galactic neighbourhood. But whenever a radically new evolutionary innovation has appeared in the past history of life on Earth, it has spread as widely as it is physically possible for it to do in a brief period compared with the total time available. There are no grounds to believe that the evolution of technology-enabled life, if it goes through to its logical conclusion, will be different in this respect. Evolutionary population dynamics will therefore drive the occupation of the Galaxy by industrial species to saturation in a short period of time on the cosmic timescale.		

AN EXAMINATION OF THE FERMI PARADOX by modelling the use of self-replicating probes	Alista Fow	University of Waikato, NZ
The Fermi Paradox was first presented in 1933 and asks, "If extra-terrestrial space faring civilisations are common in our galaxy, why have we not observed them?" A common proposed expansion method is the use of self-replicating space probes. In ideal circumstances, if civilisations could send such probes, they would expand to cover our entire galaxy in less than ten million years. To test this hypothesis, a model was constructed and several possible failure modes that would affect such an expansion were examined. The results of the modelling demonstrates that expansion across the galaxy would not occur in all circumstances. This implies that one possible reason that humans have not observed such a probe could be because no civilisation has reached a technological level sufficient to overcome these failure modes.		
THE SEARCH FOR DELIBERATE INTERSTELLAR SETI SIGNALS MAY BE FUTILE	John Gertz	Zorro Productions, Berkeley, California
For more than 60 years, the predominant SETI search paradigm has entailed the observation of stars in an effort to detect alien electromagnetic signals that deliberately target Earth. However, this strategy is fraught with challenges when examined from ET's perspective. Astronomical, physiological, psychological, and intellectual problems are enumerated. Consequently, ET is likely to attempt a different strategy in order to best establish communications. It will send physical AI robotic probes that would be linked together by a vast interstellar network of communications nodes. This strategy would solve most or all problems associated with interstellar signaling.		
THE IMPACT OF NATURAL SELECTION ON CREW SIZE AND HUMAN EVOLUTION during interstellar travel	Sano Satoshi	Japan Aerospace Exploration Agency
In this work the Monte Carlo code named EVOLVE has been updated to simulate the impact of natural selection on crew size and human evolution during multigenerational interstellar travel. Designing multigenerational interstellar ships requires defining the capacity of a spaceship, which includes many variables, including the space required for one person, food production, closed-ecosystem design and propulsion. EVOLVE version 1 (Sano, 2021) provided a critical crew size of 1,900-2,000 for interstellar travel and estimated the rate of human evolution, including population genetic parameters such as mutation and genetic drift, based on the neutral hypothesis (no natural selection). However, deleterious mutations reduce fitness (reproductive success) and could decrease population size. On the other hand, beneficial mutations, which may occur occasionally, would increase the rate of evolution. Thus, natural selection could be an important factor for multigenerational interstellar travel. Therefore, EVOLVE was updated to version 2, which includes the effect of natural selection on multigenerational interstellar travel. This paper shows that the impact of deleterious mutations on crew size is small and that a critical crew size to maintain a genetically healthy crew during interstellar travel is also approximately 2,000 even if there are deleterious mutations. Finally, this paper shows that human evolution during multigenerational interstellar travel can occur through beneficial mutations, which should be taken into consideration for the design of interstellar spaceships. The evolution rate of space flight is approximately 10 times higher than that of Earth.		

COULD THE INTERSTELLAR OBJECT 'OUMUAMUA BE A SOLAR THERMAL PROPULSION VEHICLE?	Todd Sheerin & Abraham Loeb	The Aerospace Corporation, California
The first interstellar object, 'Oumuamua, featured extreme geometry, excited rotation, and comet-like acceleration without detectable outgassing. Recent natural explanations contemplate objects that have never been observed before, including hydrogen and nitrogen icebergs, but these explanations are unlikely. Thus far, only a solar sail has been proposed as an alternative hypothesis, but there are other possibilities. This study investigates whether ‘Oumuamua could have been a solar thermal propulsion vehicle. Given the constraints obtained by the Spitzer Space Telescope on infrared radiation emitted by 'Oumuamua, upper limits are derived for size and temperature of a notional exhaust hot spot, constraining its diameter to be smaller than one meter for temperatures above 800 K. These results may inform observational capability needs for future interstellar object transit events.		

Acta Astronautica

Title	Number+date	Author	Affiliation
Abstract/Précis/Highlights			
Navigation and star identification for an interstellar mission	#192, March 2022	Paul McKee, Jacob Kowalski, John AChristian	Rensselaer Polytechnic Institute/Georgia Institute of Technology
Interstellar missions are expected to rely on star observations as part of their navigation system. Interstellar missions require 3D star catalogs, which represents a departure from conventional star catalogs. If stars in the galaxy must be modeled as 3D points, there are no pose invariant descriptors that can be used to index star patterns. We may obtain star pattern invariants by constraining the allowable motion of the interstellar spacecraft.			
Interstellar space biology via Project Starlight	#190, January 2022	Stephen Lantin et al	University of Florida/ University of California - Santa Barbara
NASA Starlight program details a path to send small relativistic spacecraft to interstellar space. Relativistic spacecraft can transport seeds and live organisms to characterize and expand life. Biological and technological challenges of interstellar space biology are outlined. Guidelines for species selection based on research practicality and survivability are offered. Current planetary protection regulations cannot address ethics of extrasolar biology missions.			

<table>
<tr><td>Navigation evaluation for fast interstellar object flybys</td><td>#191, February 2022</td><td>Declan Mages, Damon Landau, Benjamin Donitz, Shyam Bhaskaran</td><td>Jet Propulsion Laboratory</td></tr>
<tr><td colspan="4">Rapid response spacecraft to interstellar objects encounter high solar phase angles.
High relative velocities severely limit ground-in-the-loop navigation accuracies.
Autonomous navigation can enable successful close flybys and tracking.
Autonomous navigation enables impactor guidance, though limited by high phase angles.</td></tr>
<tr><td>The Fishback ramjet revisited</td><td>#191, February 2022</td><td>Peter Schattschneider, Albert A Jackson</td><td>TU Wien Austria, Triton Systems, Houston, USA</td></tr>
<tr><td colspan="4">Fishback’s proposal of magnetic scooping for a Bussard ramjet is physically feasible.
Absurdly long solenoids are needed.
The cut-off speeds are orders of magnitude lower than thought before.Visiting the galactic center in a Bussard ramjet within a lifetime is unrealizable.
NOTE: See also - Al Jackson: The Interstellar Ram Jet at 60 (Principium 29, May 2020) and IAC-20,D4,4,11,x58592, A Feasibility Analysis of Interstellar Ramjet Concepts, Gupta (P31, November 2020)</td></tr>
<tr><td>SETI in 2020</td><td>#190, January 2022</td><td>Jason T Wright</td><td>Pennsylvania State University</td></tr>
<tr><td colspan="4">A subjective survey of nearly all of the literature in SETI in 2020.
A categorization of the kinds of papers in the field.
A look ahead to 2021.</td></tr>
</table>


JBIS
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VOLUME 74 NO.11 NOVEMBER 2021
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SETI AND EVOLUTIONARY POPULATION DYNAMICS
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www.bis-space.com
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Credit: British Interplanetary Society

The red colour has distinguished Interstellar Issues of JBIS for many years

Project Lyra: A Mission to 1I/'Oumuamua without Solar Oberth Manoeuvre

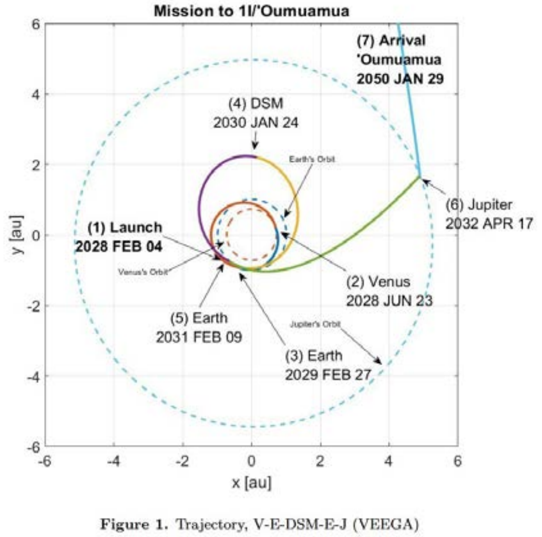
John I Davies

The Project Lyra team, noting the challenges involved in a close approach to the Sun to execute a Solar Oberth Manoeuvre, have now proposed a less challenging strategy using a Jupiter Oberth Manoeuvre in a paper available as open publication (arxiv.org/abs/2201.04240). Forbes magazine has featured its recommendations [1] and phy,org went into much more detail [2]. We also appeared in Interesting Engineering [3] and even The Sun newspaper - have they ever cited an arxiv.org publication before?

The proposed mission would launch in 2028 with a total time of flight of around 26 years implying an intercept around 2054. I would be 108 years old but it's still nearer to us in the future than the Voyager missions are in our past - they launched in 1977 - 45 years ago. The mission would slingshot around Venus then Earth, make a Deep Space Manoeuvre then again around Earth and out to Jupiter - firing a rocket around closest approach to exploit the Oberth effect (V-E-DSM-E-J). The intercept velocity would be only slightly more than half of that for an equivalent mission based on a Solar Oberth Manoeuvre - giving more time for examination of the 1I object. The mission can be achieved with a near term launcher, the NASA SLS Block 1B or a successor. The probe would reach its target at arrival speed relative to 1I/'Oumuamua of approximately 18 km/s, about 40% slower than for the Solar Oberth Manoeuvre with a consequent improvement in useful observation time.

Adam Hibberd's Optimum Interplanetary Trajectory Software (OITS) again proves it worth. Adam explains its application to a purely solar system mission elsewhere in this issue of Principium.

As the paper remarks, the possible scientific return



Trajectory, V-E-DSM-E-J (VEEGA), Credit: Adam Hibberd

from such a venture makes this an unmissable opportunity. The 1I object remains unique and, though the strong scientific consensus is that it is a natural object, the possibilities for its composition remain numerous and all of them have significant objections which cannot now be resolved without an intercept mission. The mystery might be resolved soon if a similar object is found but it is now well over four years since 1I was discovered [4] and we cannot reason from a single instance to predict the frequency of such objects. Principium and the i4is Project Lyra team have been making this point since a few weeks after its discovery. We are well overdue for investment in detailed mission planning. As the Forbes story says "In short, we ***must*** take a closer look." More on the i4is Project Lyra page *Project Lyra – Exploring Interstellar Objects* [(i4is.org/what-we-do/technical/project-lyra/](i4is.org/what-we-do/technical/project-lyra/).

Adam has set up a launch countdown to both ways of executing the Lyra mission - (adamhibberd.com/project-lyra-launch-countdown/). ■

[1] *NASA To 'Oumuamua? The New 22 Year Mission To The Extraordinary Object Said To Be An 'Alien Solar Sail',* Jamie Carter, Jan 18 2022, www.forbes.com/sites/jamiecartereurope/2022/01/18/nasa-to-oumuamua-the-new-22-year-mission-to-the-extraordinary-object-said-to-be-an-alien-solar-sail/
[2] If launched by 2028, a spacecraft could catch up with 'Oumuamua in 26 years phys.org/news/2022-01-spacecraft-oumuamua-years.html
[3] interestingengineering.com/scientists-want-to-send-a-probe-to-catch-up-with-oumumua-by-2054 - but beware their confusion about solar sails!
[4] 19 October 2017 by the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS1), Hawaii

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Stephen Hawking, *Brief Answers to the Big Questions*, 2018 (published after his death)

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- Optimising solar sail trajectories to Alpha Centauri using evolutionary neurocontrol;
- Guidance of the Ariane 4 launch vehicle; and
- Visions of our interstellar future.

Coming soon: videos from our 2021 summer course *Human Exploration of the Far Solar System and on to the Stars*, delivered by i4is on behalf of Limitless Space Institute.

More details on the i4is members' page in this issue of Principium.

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Design of Interplanetary Missions to Jupiter Using Optimum Interplanetary Trajectory Software

Adam Hibberd

When Adam Hibberd developed the first version of his 'Optimum Interplanetary Trajectory Software' (OITS). He has, as its name implies, intended it for interplanetary missions. The appearance of Oumuamua and his contact with i4is gave it a new and unforeseen purpose. Here he explains an application of OITS to its original purpose.

In 2017 I developed the software application 'Optimum Interplanetary Trajectory Software' (OITS). By the time the first interstellar object 1I/'Oumuamua was discovered passing through our solar system, I had completed most of the work. Inspired by the Arthur C Clarke novel 'Rendezvous with Rama' I decided to exploit OITS to perform research into missions to 'Oumuamua. I was soon generating interesting and important results and decided to contact the UK non-profit, the 'Initiative for Interstellar Studies' (i4is), becoming a member of the 'Project Lyra' team, and collaborating with them on various papers on the subject.

The article here is not related to anything interstellar. I had originally intended OITS to study missions to bodies belonging to our solar system, and indeed if used judiciously, OITS can be a powerful tool for preliminary interplanetary mission design.

Recently I conducted a little research into missions to Jupiter as this is relevant to two missions which will be launched later in this decade. The research was on a small scale, so not really worthy of a paper (and actually a paper already exists on the subject anyway), nevertheless what follows is intended as an education as to how to use OITS, as well as an invitation to you to try it out for yourself.

Two spacecraft will be launched in the next couple of years or so bound for the gas giant Jupiter, the largest planet in our solar system and approximately 1,000th the mass of the sun. As far as the interplanetary missions are concerned the target is Jupiter. However, because most of the attention of these spacecraft will be directed on three of Jupiter's moons, Europa, Ganymede and Callisto, the planet Jupiter will actually just be the background setting. The spacecraft in question are the European Space Agency's (ESA) JUICE mission (a clumsily constructed acronym of JUpiter ICy moon Explorer) and the NASA Europa Clipper.

Mission planners will be crossing their fingers that everything will be ship-shape, however both these probes owe their existence to a previous Jupiter mission which was a partial failure, the Galileo spacecraft launched some time ago, in 1989 by space shuttle Atlantis. Space enthusiasts may recollect that the high-gain antenna of the Galileo craft failed to deploy, and consequently the low-gain antenna had to be used in its stead, significantly hampering the scientific return garnered from the mission.

Nevertheless despite this setback, Galileo was still able to use its onboard instrumentation, and, as a result of the measurements and images it took of Europa, scientists now believe there to be a subsurface ocean of salty liquid water present in the

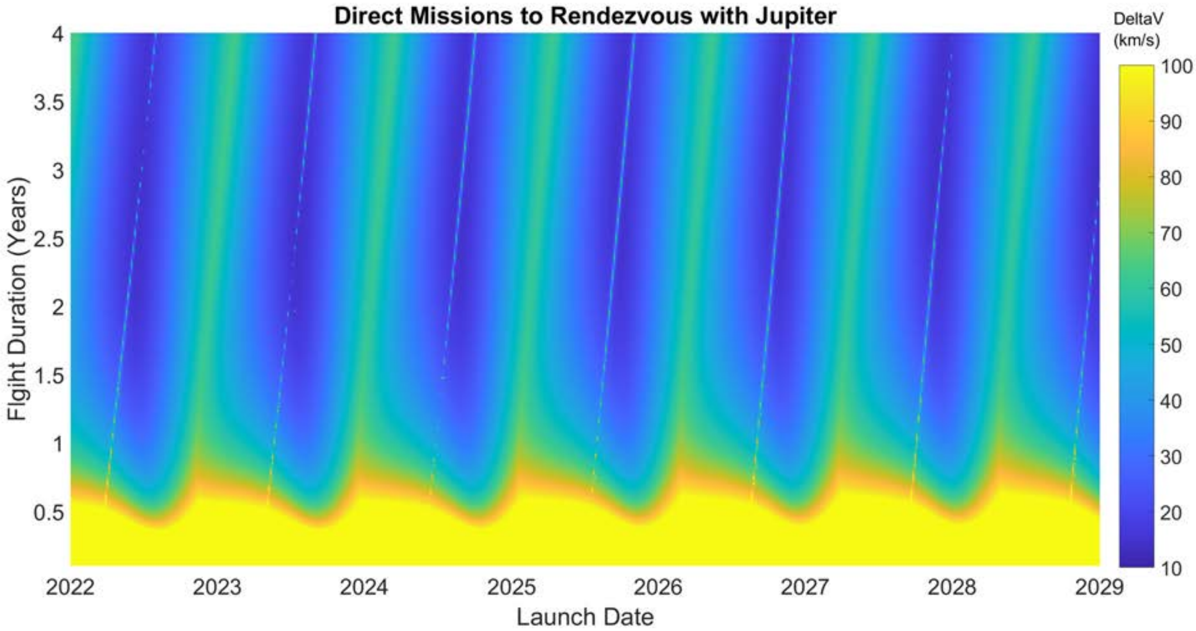

Figure 1

interior of this Galilean moon. Furthermore, hydrothermal vents may exist which are known to support an abundance of life on Earth.

In addition to Europa and Enceladus, a moon of Saturn must in my view be considered a high priority for in-situ research. Also two further moons of Jupiter, Callisto and Ganymede (the solar system's largest moon) may support similar subsurface environments and indeed the JUICE mission is set to explore these three Galilean moons.

Before we begin, there are certain assumptions which OITS adopts, the overarching one is of a series of instantaneous applications of ΔV placed at the closest approach (the periapsis point) of the spacecraft at each of the planets encountered and in line with the spacecraft's apsidal velocity. This assumption amounts to infinite thrust which may seem rather outrageous. However chemical propulsion does indeed have high thrust compared to many other propulsion schemes. Furthermore when one compares the rocket burn time with the long durations of interplanetary orbital arcs between planetary encounters, this assumption of impulsive thrust is really quite realistic, yielding results more than satisfactory for preliminary mission design of the kind we shall conduct here, comparing favourably with NASA's online Trajectory Browser for instance.

OITS makes no coplanar assumption nor one of circularity, this is because it uses position and velocities of celestial bodies generated by the NASA JPL NAIF SPICE toolkit which is linked in with OITS as third party software. Consequently the 'ephemerides' calculated are extremely accurate and factor in all the major forces exerted on the planets as they 'wander' around the sun.

So that the analysis here is relevant to the JUICE and Europa Clipper missions, we shall analyse launch opportunities no earlier than January 2022 and no later than January 2029, and determine whether we can find any promising interplanetary mission profiles. We may discover a combination of GAs (gravitational assists) superior to those which ESA or NASA have selected. This superiority could manifest as either a lower ΔV or alternatively a reduction in the flight time needed.

Firstly the 'direct scenario'. This is the simplest option, also the reference for alternative indirect routes – if the total ΔVs with GAs are higher than this most direct and simplest of cases, then such trajectories can be discounted as inferior and irrelevant. For the direct case, a colour contour – or 'pork chop' plot is extremely useful (and most visually satisfying) as it neatly illustrates in patterns of colour, the alignments of the two planets - refer to Figure 1. Referencing the numerical results, we find the total ΔV (which we define as the sum of the hyperbolic excess speed at Earth, V∞, and the

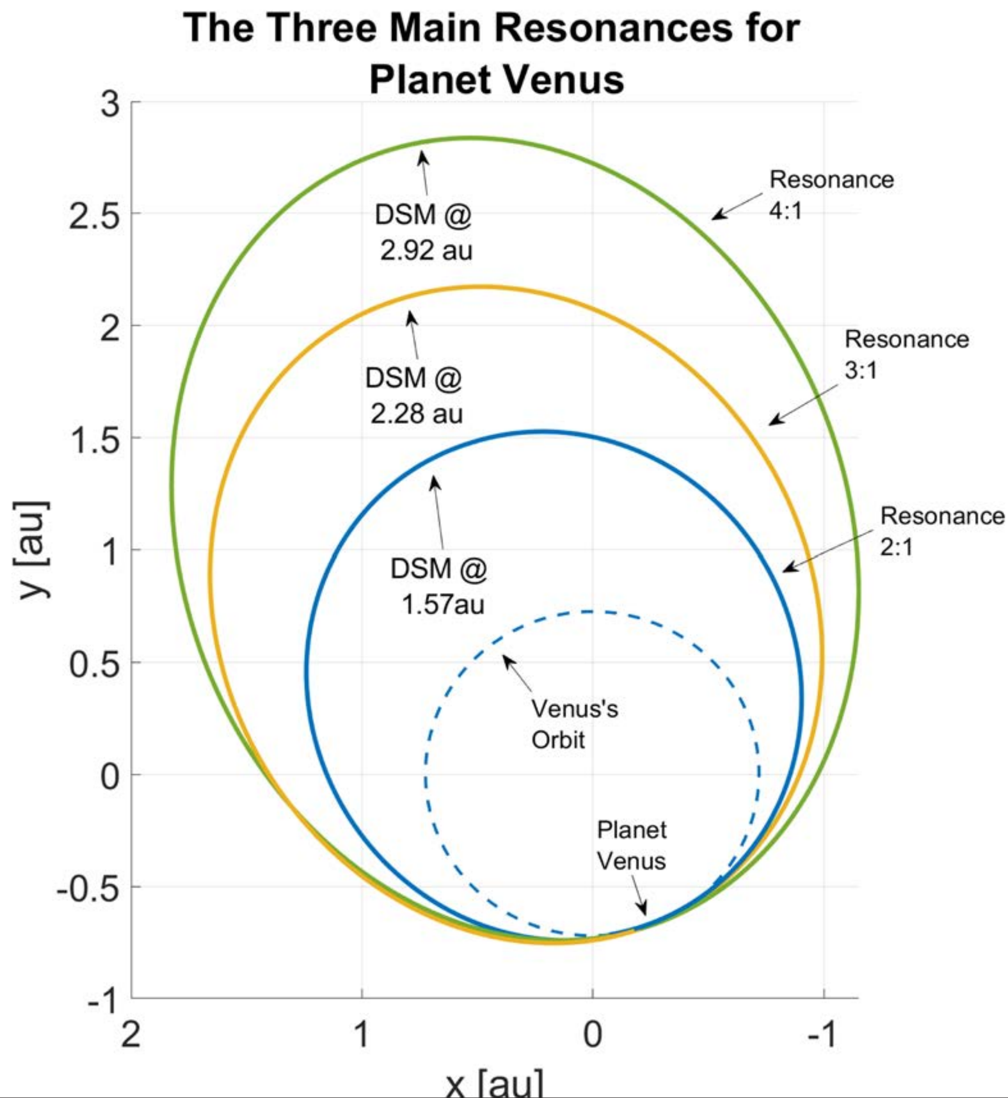

Figure 2

arrival speed relative to Jupiter, Varr) has a minimum of 8.7+5.7=14.4 km/s and the flight duration is around three years. In the following we shall study some GA scenarios which might bring this ΔV down, but on the other hand might extend the flight duration.

We can first attempt a single GA of Venus and compare it with a single GA of Mars. We find the results to be unpromising in that for both cases, the total ΔV offers no particular improvement over the direct case with no appreciable reduction in flight time. For Venus a possible launch might be on January 2025 with a ΔV = 15.4 km/s, and for Mars it would be December 2028, with a ΔV=14.7 km/s. These results indicate that further GAs are required for both cases, one alone is not sufficient.

Let us address Venus first, as this opens up further opportunities for GAs of two inner planets, ie Earth or Mars, or indeed a return to Venus, for an additional GA there. We can exclude Mercury because the task of getting there is laden with ΔV difficulties, owing to its closeness to the sun. When an E-V-E-J scenario is entered into OITS, the results again are unpromising, with no missions in the launch interval 2022-2029 which offer advantage over the direct case.

However when we switch to a return to Venus, ie E-V-V-J, things start to fall into place. A note here regarding the V-V segment of the journey. The situation is that the spacecraft departs Venus, reaches an aphelion point where a Deep Space Manoeuvre takes place, and then returns to Venus, conducts a GA of Venus, and finally heads off towards Jupiter. So in fact to be more accurate, this should be abbreviated as E-V-DSM-V-J. The minimum ΔVs for such an arrangement occur when the spacecraft's orbit in the V-DSM-V segment is in a resonance with Venus, so the travel time equals N Venus cycles, where N is a whole number. For OITS we can ensure this by introducing an Intermediate Point, whose distance away from the sun can be user-

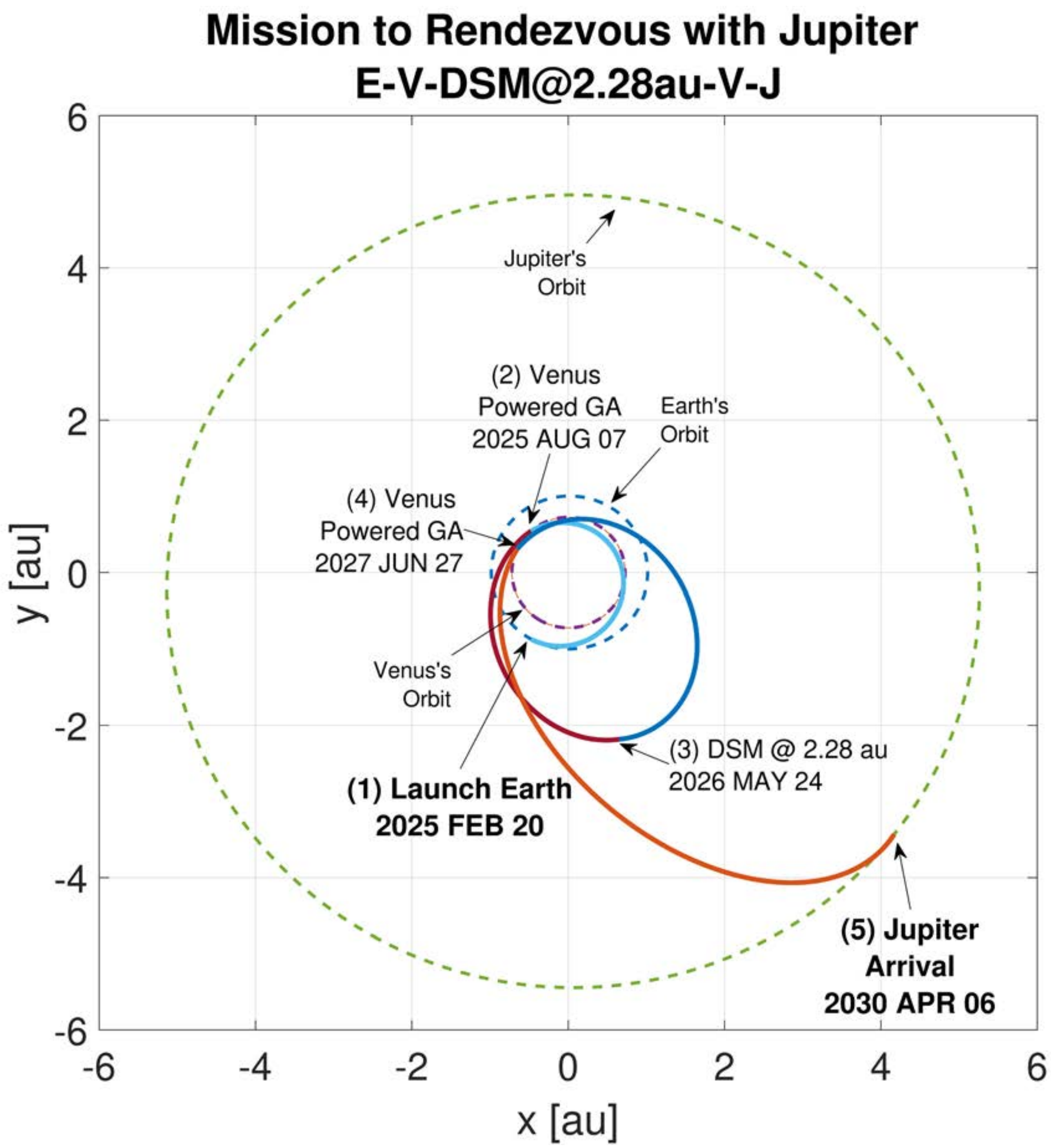

Figure 3

specified to OITS. These resonances and their aphelia distances are illustrated in Figure 2

In the case of the Cassini mission to Saturn, it exploited a Venus resonance of N=2, so we shall attempt N=2 for the E-V-DSM-V-J trajectory, as well as N=3 & N=4. The result? N=3 is the optimal choice with ΔV=12.1 km/s, shown in Figure 3.

But why not try two Venus return segments in the form of E-V-DSM-V-DSM-V-J, with the aphelion of the second encounter greater than the first? I tried this with first N=2 and N=3 and found a launch on 2026 SEP 18 (ΔV=14.3 km/s) arriving 2033. When we try N=2 followed by N=4, OITS calculates a launch date in 2023 MAY 11 (ΔV=11.3 km/s) and arrival in 2030. Thus we have in the latter case a slightly lower ΔV than the trajectory of Figure 3.

In addition, we could introduce Earth returns using

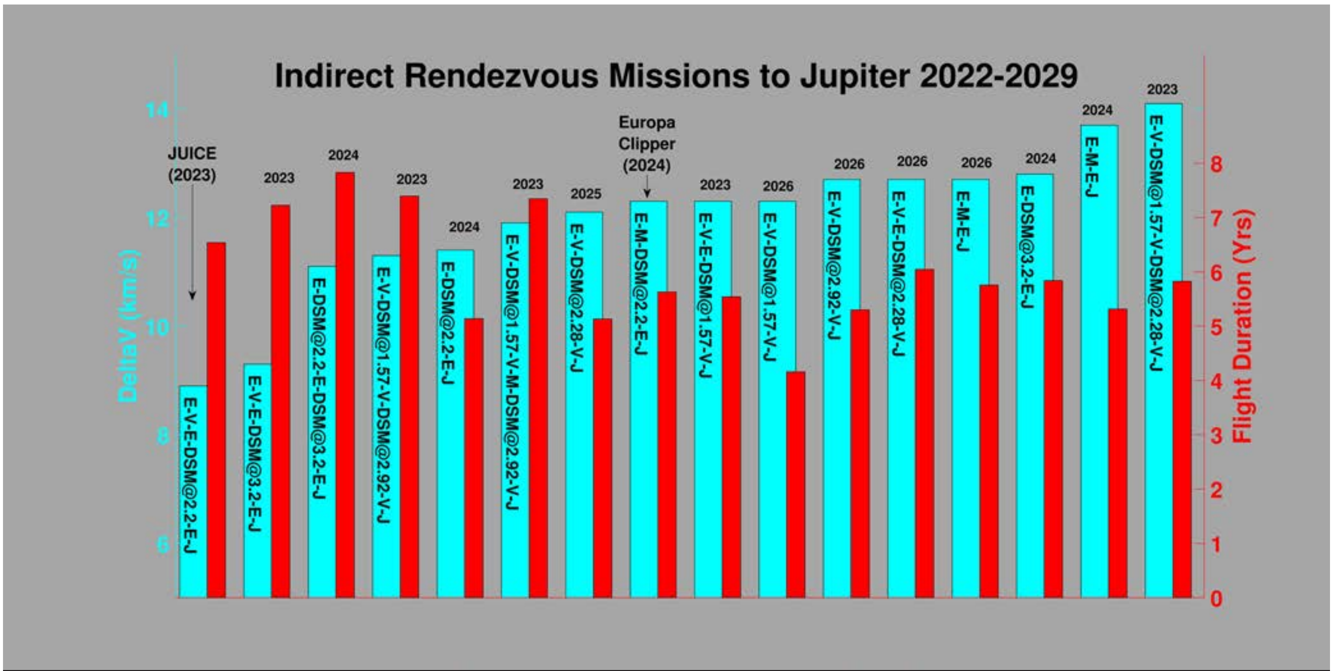

Figure 4

a resonance for the Earth return encounter in a similar vein to that exploited for the Venus return. The results of all these investigations are presented as a bar chart in Figure 4.

The cyan bar for each mission is the 'Total ΔV' (left axis) equal to the sum of the hyperbolic excess required at Earth and all the in-flight ΔV burns, including that required to rendezvous with Jupiter (in other words match velocities with it). The trajectories are ordered from least ΔV at the left, to most ΔV on the right. The red bars are flight duration in years (right axis). Those trajectories worse than the direct solution are not shown. NB I cannot declare this to be an exhaustive list.

The original plan for JUICE was a launch in 2022 with trajectory E-E-V-E-M-E-J. This option is excluded from Figure 4 as it has probably been rejected due to delays in the preparation of the JUICE spacecraft. With an in-flight ΔV of only around 1 km/s, this would have been almost a freeride to Jupiter. If we reject this mission scenario, then we see the JUICE backup mission to be adopted in the eventuality of delays (on the extreme left), is the most efficient with a launch over a year later, in 2023, and an arrival around the same time as the original mission plan. This is similar to the Galileo 'VEEGA' combination. The Galileo 'VEEGA' trajectory was proven to be the theoretically most efficient Jupiter mission scenario available in the timescale of the Galileo launch. A difference is that for JUICE, there is an initial slingshot of Earth's Moon to lower ΔV and so leverage mission payload mass. As OITS cannot model moon encounters, Figure 4 provides the closest OITS can achieve.

What about the Europa Clipper? Here we are presented with a little conundrum in that the trajectory chosen by NASA - refer Figure 5 - is way down and 8th on the list. Let us say that the Clipper's timeline for preparation ruled out any mission earlier than 2024, this would exclude the first two trajectories, but what of trajectory 3? This conundrum is partially yet not fully resolved when we do some further calculations.

Let us assume that the Clipper will have an onboard chemical rocket with the hypergolic combination of propellants hydrazine and nitrogen tetroxide, generating an exhaust velocity of approximately I=3.35 km/s. This system would be able to supply all the in-flight ΔVs, denoted here as ΔVif, for the interplanetary journey. Using the inverse of the Tsiolkovsky equation, we can calculate how much mass would be remaining after the in-flight burns have been executed:

$$M_D = M_0 \, exp\left(-\frac{\Delta V_{if}}{I}\right)$$

Where M0 here is the initial mass of the spacecraft. Figure 6 is a bar chart similar to Figure 4 except the cyan bars represent MD for the Falcon Heavy expendable launcher for each mission

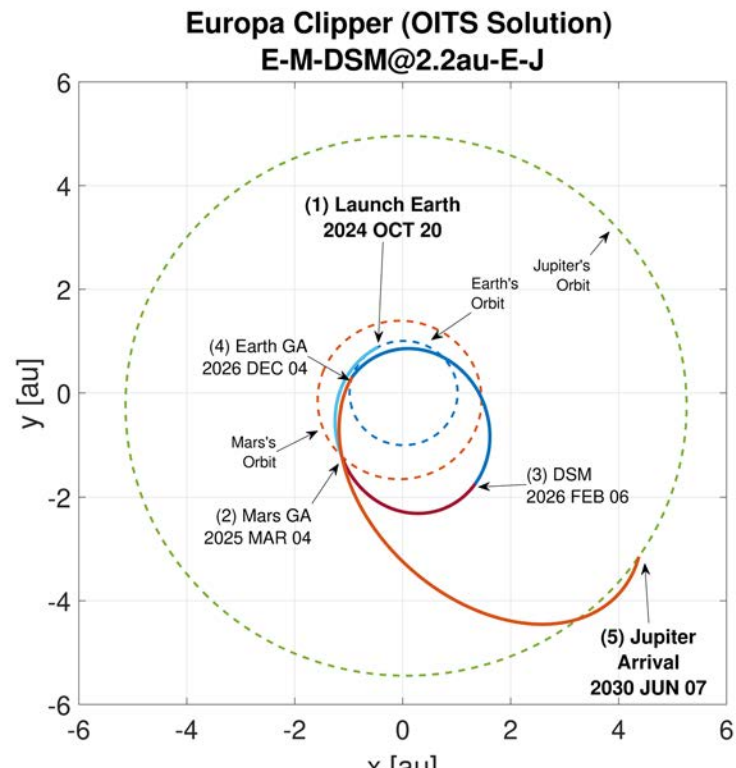

Figure 5

profile.

We see on this basis, the Delta Clipper moves up a couple of places, however mission 3 in Figure 4 remains the superior option. So why did NASA reject mission scenario 3 in favour of 8 from Figure 4? I am currently not in on any decision-making NASA meetings for Delta Clipper, but it could simply be a matter of launch window. Mission 3 has a launch right at the beginning of 2024, in January, whereas mission 8, the route selected by NASA, affords more time for preparing the spacecraft, 9 extra months. Two further points are (a) the spacecraft arrives at

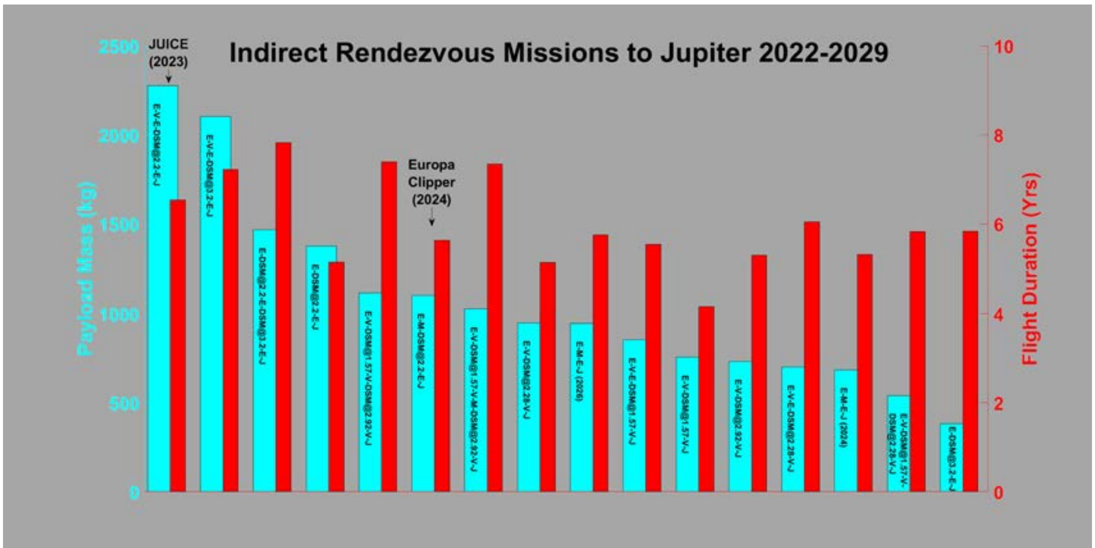

Figure 6

Jupiter before the alternative of mission 3 (though of course with less useful payload mass than mission 3) and (b) mission 8 requires no ΔV application en-route, except that for rendezvous with Jupiter.

I trust this has been an instructive insight into the design of interplanetary trajectories using OITS and you have come away with some appetite for more.

Are we alone in this Universe? Is Earth an oasis in an otherwise barren desert? Well if we were to find biosignatures - and then perhaps even life - on one of Jupiter's moons, or indeed Enceladus, then surely the prospect of the universe supporting an abundance of life would increase immeasurably. When Galileo observed the moons of Jupiter, was he unwittingly the first human to observe an inhabited alien world? The only way to answer these questions is to go there and I am proud that OITS can assist in this noble quest.

If you wish to view trajectory videos for these missions, as calculated by OITS go to:

GALILEO:
www.youtube.com/watch?v=Xa2iYAcsv34
JUICE #1:
www.youtube.com/watch?v=1K_fefX8yZo
JUICE #2:
www.youtube.com/watch?v=FjPH8zrUwF4
EUROPA CLIPPER:
www.youtube.com/watch?v=s0hRZG6_s_U
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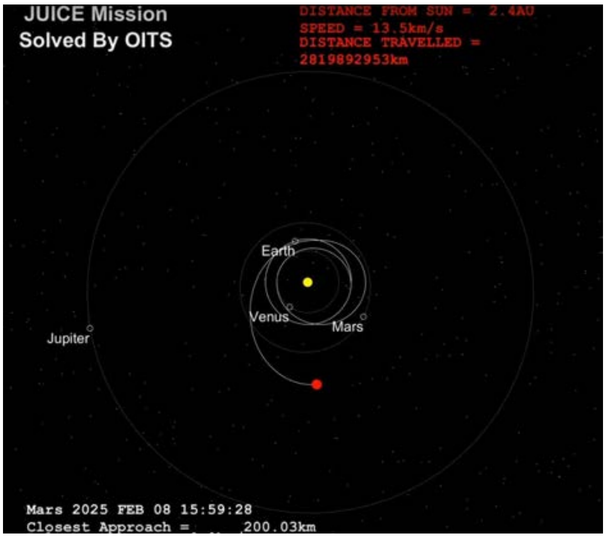
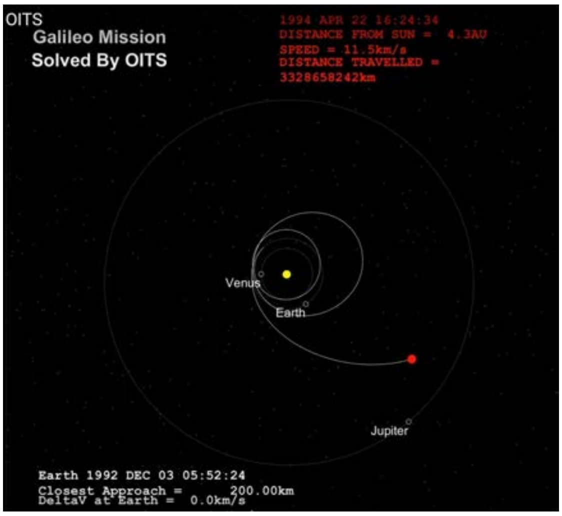
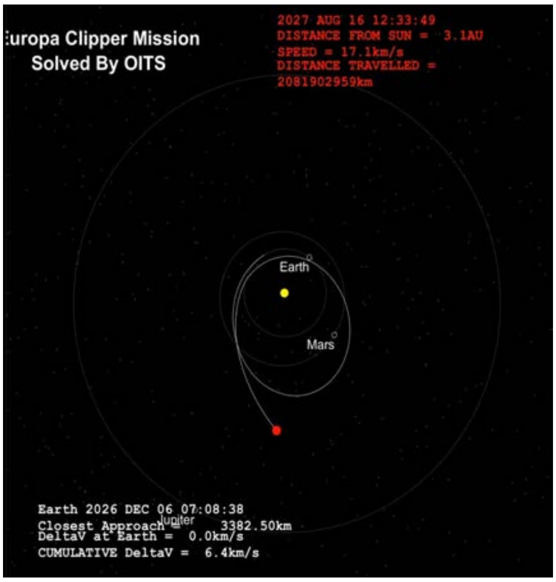
trajectory videos for three missions, as calculated by OITS







Adam Hibberd is the lead astrodynamicist for i4is. He has been an author of 16 papers in this and related topics in the past three 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.

The Initiative for Interstellar Studies

image: ©ALEX STORER

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

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THE i4iS MEMBERS' PAGE

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

i4is talks

We are currently planning the next phase of the i4is Talks Series. If you would like us to cover a particular topic, please email Rob.Swinney@i4is.org or John.Davies@i4is.org with your ideas. Members can access videos and presentations from previous talks at www.i4is.org/what-we-do/education/talkseries.

Members' newsletter, preprints and web pages

Members receive an exclusive newsletter, early preprints of articles before they appear in Principium, and access to the members-only section of the i4is website. Recent preprints include reports from IAC 2021 and the 7th Interstellar Symposium. Items in the last newsletter included 'Limitless Space Institute: Human Exploration of the Far Solar System and on to the Stars' and 'Talk Series – Series 3 Videos'. We currently need some extra help in putting the newsletter together. If you think you might be able to assist, please contact the newsletter editor, Conor MacBride, at Conor.MacBride@i4is.org.

Getting more actively involved

If being an i4is member isn't enough, and you'd like to 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. If you think you could volunteer some time, please get in touch at info@i4is.org, and one of the team will get back to you quickly.

Project Lyra

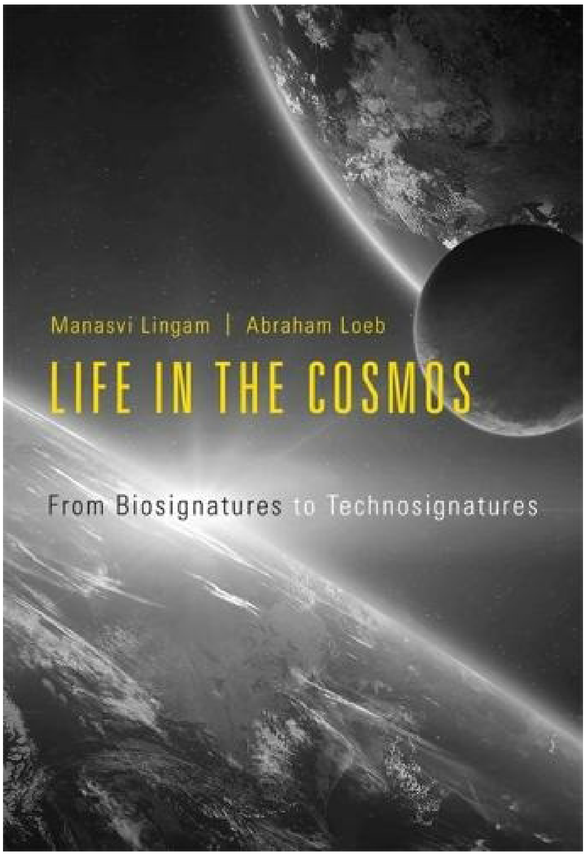
The latest paper in our series on the Project Lyra mission, which aims to explore interstellar objects such as 1I/'Oumuamua, was published on the academic preprint website arXiv on 11 January 2022. In this paper, a team from i4is, with the assistance of our friend T Marshall Eubanks, has established that it would be possible for a spacecraft to reach 'Oumuamua within 26 years of launch, without the necessity to use a technically challenging Solar Oberth Manoeuvre. This work received media coverage from varied outlets, including Universe Today, Newsweek – and even the Sun newspaper! If you want to read the preprint, it's at arxiv.org/pdf/2201.04240.pdf.

Front cover of P20 February 2018 featuring *Project Lyra : mission to 'Oumuamua*

NEXT ISSUE

• **Human Exploration of the Far Solar System and on to the Stars:** A report on our summer 2021 course*s*, delivered by i4is for the Limitless Systems Institute (LSI) - reporter: Patrick Mahon

• **Life in the Cosmos - From Biosignatures to Technosignatures:** Review of a new book, by Manasvi Lingam (Florida Tech) & Avi Loeb (Harvard) - reviewer: Andreas Hein



COVER IMAGES

Our cover images for this issue interpret reality and imagination to look forward to intelligent life in space, alien and human.

FRONT COVER

Bubble Nebula - NGC 7635

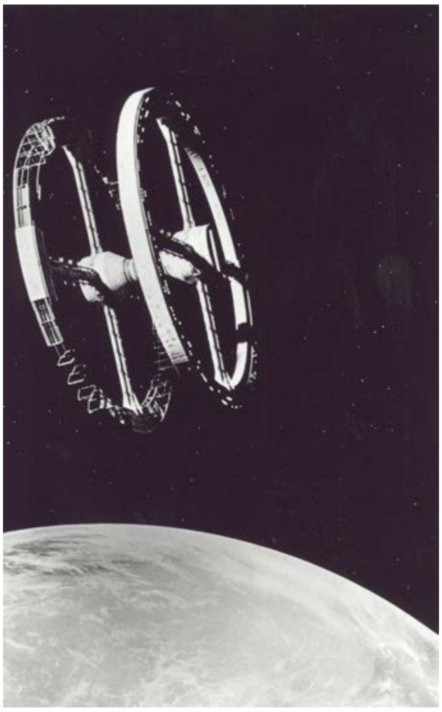
This image is a zoom into the Hubble Space Telescope photograph of an enormous, balloon-like bubble being blown into space by a super-hot, massive star, the Bubble Nebula, NGC 7635.

It featured in the 2018 NASA story *NASA Is Taking a New Look at Searching for Life Beyond Earth* (www.nasa.gov/feature/nasa-is-taking-a-new-look-at-searching-for-life-beyond-earth).

The story announced the 2018 NASA Technosignatures Workshop in Houston.

Credits: NASA, ESA, and the Hubble Heritage Team (STScI/AURA), F Summers, G Bacon, Z Levay, and L Frattare (Viz 3D Team, STScI).

BACK COVER



Space station from *2001: a space odyssey*

This image and its close cousins have their ancestry in the work done by Wernher Von Braun and other pioneers including Willy Ley - most widely seen in "Man Will Conquer Space Soon!", a series in Collier's magazine in the early 50s.

Your editor was too young and on the wrong side of the Atlantic at the time but he acquired a copy of pop science book *Rockets, Jets, Guided Missiles and Space Ships*, Jack Coggins and Fletcher Pratt, published in 1951 with an introduction by Willy Ley. He was an avid reader of the adventures of Dan Dare, Pilot of the Future, in the new comic, the Eagle, and great enthusiast for the nearby Jodrell Bank radio telescope when it was built in the mid fifties. By the time Kubrick and Clarke's masterpiece was released in 1968 he was working in the space business and its message, ambiguous as it was, came through loud and clear, to a sort of "hippy with a slide rule". One day we must build it!

The image here is from *Space station from 2001: A Space Odyssey* (www.esa.int/ESA_Multimedia/Images/2012/01/Space_station_from_2001_A_) by ESA in 2014, crediting NASA.

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

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

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

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Front cover: Hubble Space Telescope photograph of the Bubble Nebula NGC 7635
Credit: NASA, ESA, and the Hubble Heritage Team
Back cover: Space station from *2001: a space odyssey*
Credit: NASA/ESA

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