Interstellar News

John I Davies reports on recent developments in interstellar studies

ISOs in the neighbourhood?

Our Centauri Dreams ally Paul Gilster (www.centauri-dreams.org) draws our attention to a recent letter in the Monthly Notices of the Royal Astronomical Society, *Interstellar objects outnumber Solar system objects in the Oort cloud* [1]. Avi Loeb is the indefatigable champion of the thesis that at least some interstellar objects (ISOs) are artificial. Here he and his Harvard colleague, Amir Siraj, aim to show that the detection of Borisov implies that interstellar objects outnumber Solar system objects in the Oort cloud, whereas the reverse is true near the Sun due to the stronger gravitational focusing of bound objects. They suggest that this hypothesis can be tested with stellar occultation surveys of the Oort cloud.

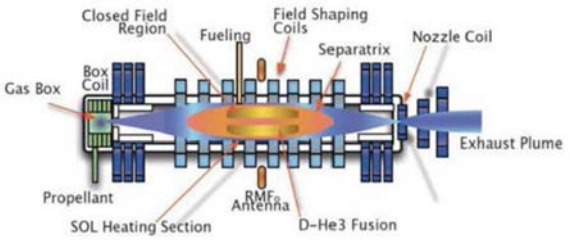
Kezerashvili on a Deuterium-Helium 3 fusion drive

Professor Roman Kezerashvili (City University of New York) is a major contributor to interstellar studies. In his recent paper [2] he advocates a Direct Fusion Drive (DFD) design as a fast way of reaching Solar System objectives such as Mars (around 100 days one way) and Titan (around two years return). This work has been reported in several issues of Principium [3], presented at our FISW workshops in New York 2017 and Gloucestershire UK 2019 - and in JBIS V72 #2 Feb 2019, *Direct Fusion Drive for Interstellar Exploration*, S A Cohen et al - and Acta Astronautica, V178, Jan 2021, *Exploration of trans-Neptunian objects using the Direct Fusion Drive.*

Seligman, Laughlin et al on ISO composition

Darryl Seligman and Gregory Laughlin have been active in interstellar object (ISO) studies since very soon after the discovery of 1I/'Oumuamua by the STARRS telescope. In this latest paper they and colleagues examine the various theories of the appearance and observed properties of the two ISOs found so far [4]. For 2I/Borisov they conclude that it is simply an interstellar comet not significantly different from one of our own long period comets if it strayed into another solar system. For 1I/'Oumuamua (aka "1I") they find all current theories wanting in different respects.

They cite a number of studies which note the relatively low incoming velocity of 1I and deduce that it must have had relatively few gravitational perturbations and thus must be a relatively "young" object. They suggest that the upcoming Vera Rubin Observatory (formerly the Large Synoptic Survey Telescope - LSST), by detecting objects up to three magnitudes dimmer than Pan-STARRS, will detect enough 1I-like objects to deliver a representative population study. We shall see!



Schematic of a DFD with its simple linear configuration and directed exhaust stream. A propellant is added to the gas box. Fusion occurs in the closed-field-line region. Cool plasma flows around the fusion region, absorbs energy from the fusion products, and is then accelerated by a magnetic nozzle. Figure from *Nuclear and Future Flight Propulsion - Modeling the Thrust of the Direct Fusion Drive S J* Thomas, M Paluszek, S Cohen, A Glasser, AIAA 2018-4769 (2018).

Credit (image and caption); Cohen et al - FIG. 1:

[1] *Interstellar objects outnumber Solar system objects in the Oort cloud,* A Siraj, A Loeb - open publication arxiv.org/abs/2011.14900

Monthly Notices of the Royal Astronomical Society: Letters, Volume 507, Issue 1, October 2021, Pages L16–L18, doi.org/10.1093/mnrasl/slab084 Published:23 August 2021

[2] Exploration of the solar system and beyond using a thermonuclear fusion drive, arxiv.org/abs/2108.01689# August 2021

[3] *News Feature: Foundations of Interstellar Studies Workshop 2019*, Principium 26, August 2019,

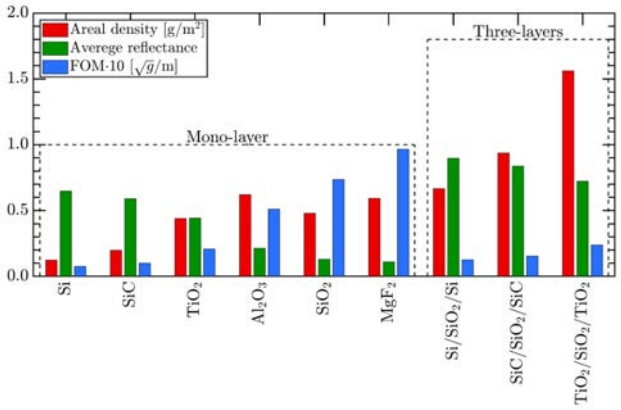
page 9. IAC20 report. *Exploration of trans-Neptunian objects using the Direct Fusion Drive*, Principium 30, August 2020, page 32, and Principium 31, November 2020 page 43. *Direct Fusion Drive for the Gravitational Lens Mission*, Principium 30, August 2020 page 68. *A Titan mission using the Direct Fusion Drive (DFD)*, Principium 31, November 2020, page 22.

[4] *Constraints on the Occurrence of 'Oumuamua-Like Objects*, W Garrett Levine, Samuel H C Cabot, Darryl Seligman, Gregory Laughlin, 25 Aug 2021 arxiv.org/abs/2108.11194

Red-shift of lasers powering a sailcraft

In *Directed Energy Accelerated Lightsails*, Santi et al [1] (a team including Philip Lubin [2]) presents results of a study of the problem of red-shift of the lasers powering a sailcraft as the craft accelerates away from the lasers. They note that "the reflector needs to be broadband enough to allow a modest or perhaps large dynamic range of received wavelengths". This alongside materials and layering, thermal stability of the lightsail, mechanical strength and sail mass per reflecting area will determine the performance of the sailcraft. They conclude that, for a 1,064 nm laser source, TiO_2 as a single layer, or multilayer stack with SiO_2, as a second material looks most attractive. Best propulsion efficiency is achieved by single layer, multilayers offer advantages of thermal control and stiffness. However a longer wavelength laser source could expand the choice of potential materials having the required optical characteristics.

They derive a figure of merit function FOM(ρ_s, R, A) where ρ_s is the area density of the sail, R is its reflectance and A is absorption. See bar graph of various material combinations.



Bar graph of material combinations

Areal density (red bar) and (average) reflectance (green bar) of selected lightsail structures considered, as grouped by the number of layer. For each group, the value of the FOM increases from left to right.

Credit: Santi et al

IRG Eridani Award 2021

Congratulations Dr Albert A Jackson

At the 2021 Symposium of the Interstellar Research Group in Tucson Arizona (see our Lead Feature) the IRG made the IRG Eridani Award 2021 to Dr Albert A Jackson.

Al is a veteran of interstellar studies and has been professionally engaged in space endeavours since his work with the Apollo programme.

We would like to add our congratulations to a friend and colleague of i4is.

[1] *Directed Energy Accelerated Lightsails*

Giovanni Santi et al, Nature journals preprint www.researchsquare.com/article/rs-943018/latest.pdf

[2] Professor Philip Lubin, UCSB, will be familiar to Principium readers. Lead author Giovanni Santi is at Università di Padova, and other team members are at Istituto di Fotonica e Nanotecnologie, Padova, Istituto Italiano Tecnologie, Genova, Istituto di Elettronica, Ingegneria dell'Informazione e delle Telecomunicazioni, Padova and Osservatorio Astronomico di Padova

Microbial Habitability of Rogue Planets

Rogue planets are planets without host stars. They have been known to exist for some time, see *Rogue planet wanders into view* in Principium 7, November/December 2013. In a recent paper, Dirk Schulze-Makuch, Technische Universität Berlin, and Alberto G Fairén, CSIC-INTA, Madrid [1] look at their microbial habitability and suggest they may be vectors for panspermia. They identify two types of rogue planets, sub-brown dwarfs and "rocky" rogue planets, with only the latter capable of hosting or carrying life. They discuss factors such as water (liquid or ice) and energy sources (given no solar energy) including chemical, photosynthesis from hydrothermal light or the occasional passing star, direct hydrothermal energy and temperature gradients - and, more speculatively, osmotic gradients, magnetic fields, or radioactivity.They cite work on the possible conditions on rogue planets and suggest that even planetary collisions are not necessarily fatal to all life and thus could result in panspermia effects.

Searching for Kardashev III civilisations

Supported by a grant from the National Natural Science Foundation of China, Professor Michael Garrett and Zhaoting Chen have been considering a potential identifying factor for Kardashev Type III civilisations (KIII) [2]. Their paper [3] argues that since KIII have, by definition, energy requirements that are likely to generate strong excess waste heat emissions in the mid-infrared (MIR) and low levels of optical radiation then they will differ from a wide range of galaxy types which adhere to the infrared-radio correlation (IRC). This has been found to apply to both star-forming and non-star-forming galaxies over a wide range of orders of magnitude. They conclude that the small number of galaxies which deviate from the IRC may be candidates for investigation both as possible KIII and to determine what natural mechanisms might result in this deviation. They identify three characteristics a galaxy hosting a Type III civilisation might be expected to have: (1) extremely red MIR colours, (2) high values of the IRC parameter q, and (3) unusually low optical/lR luminosity ratios.

Examining the available candidates they remain cautious, there are clearly some slightly "fishy" looking cases but no smoking gun. They suggest that more work along these lines "...can place very strong constraints on the incidence of Type III civilisations in the universe".

[1] *Evaluating the Microbial Habitability of Rogue Planets and Proposing Speculative Scenarios on How They Might Act as Vectors for Panspermia,* Dirk Schulze-Makuch, Technische Universität Berlin, Alberto G Fairén, Centro de Astrobiología (CSIC-INTA), Madrid, in the journal *Life*, 2021, 11(8) www.mdpi.com/2075-1729/11/8/833/htm

[2] See Robert Kennedy's *Guest Introduction: A Modest Proposal for Photometric SETI* in Principium 11 for more about the Kardashev scale of civilisations. Also articles by Dmitry Novoseltsev in P18, P23, P27, P29 and David Gahan in P32. Earlier related work by Mike Garrett was reported in P23 (*SETI radio surveys of the distant Universe*), There is a useful Wikipedia entry at en.wikipedia.org/wiki/Kardashev_scale

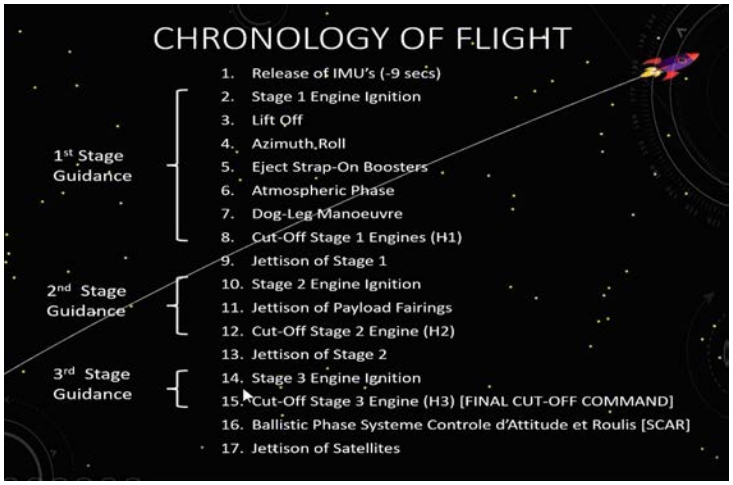
[3] *Searching for Kardashev Type III civilisations from High q-Value Sources in the LoTSS-DR* (MNRAS Preprint 14 August), H. Chen (National Astronomical Observatories, Chinese Academy of Sciences, Beijing,) and M A Garrett (Jodrell Bank Centre for Astrophysics, University of Manchester) arxiv.org/abs/2108.06597

Adam Hibberd at BIS West Midlands

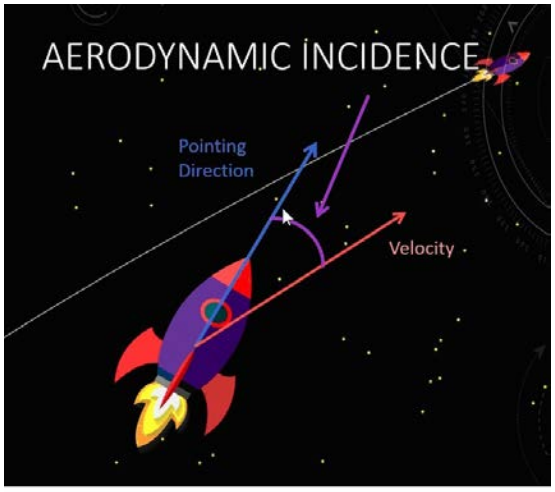
The West Midlands group of the British Interplanetary Society is one of its most active. Our i4is colleague Adam Hibberd recently took members through the basic dynamics of some of his earlier professional work, long preceding his vital contribution to i4is Project Lyra. This was the Ariane 4 rocket, the immediate predecessor of the current Ariane 5 heavyweight - due to launch the JWST next month. We can't show his brilliant animations in our magazine but here are a couple of snapshots.

Amongst the BIS members present were a number of rocket engineers with decades of experience, notably at the UK Westcott establishment - these days a test site for the Reaction Engines air-breathing rocket, Sabre. Their enthusiasm for Adam's presentation was readily apparent!

An earlier version of Adam's presentation was given to i4is members as part of our talk series on 8 June 2021 and is available in the members' area of our website.



Snapshots from animation by Adam Hibberd



"Hycean worlds" better hab-zone candidates than Earth?

Researchers from the Institute of Astronomy, University of Cambridge, have investigated a new class of habitable planets, "Hycean worlds" [1] composed of water-rich interiors with massive oceans underlying H_2-rich atmospheres which they suggest can be candidates for habitability and may be abundant in the exoplanet population. They may exist in a wider habitable zone than Earth-like planets and easily detectable by the James Webb Space Telescope (JWST).

Avoiding the "Great Filter"

The "Great Filter" is a class of explanations for the absence of detectable extraterrestrial intelligences, the Fermi Paradox. It is speculated that, at some point before detectability, intelligence or simply life is extinguished. If the probability of this is high enough then the Fermi Paradox is resolved.

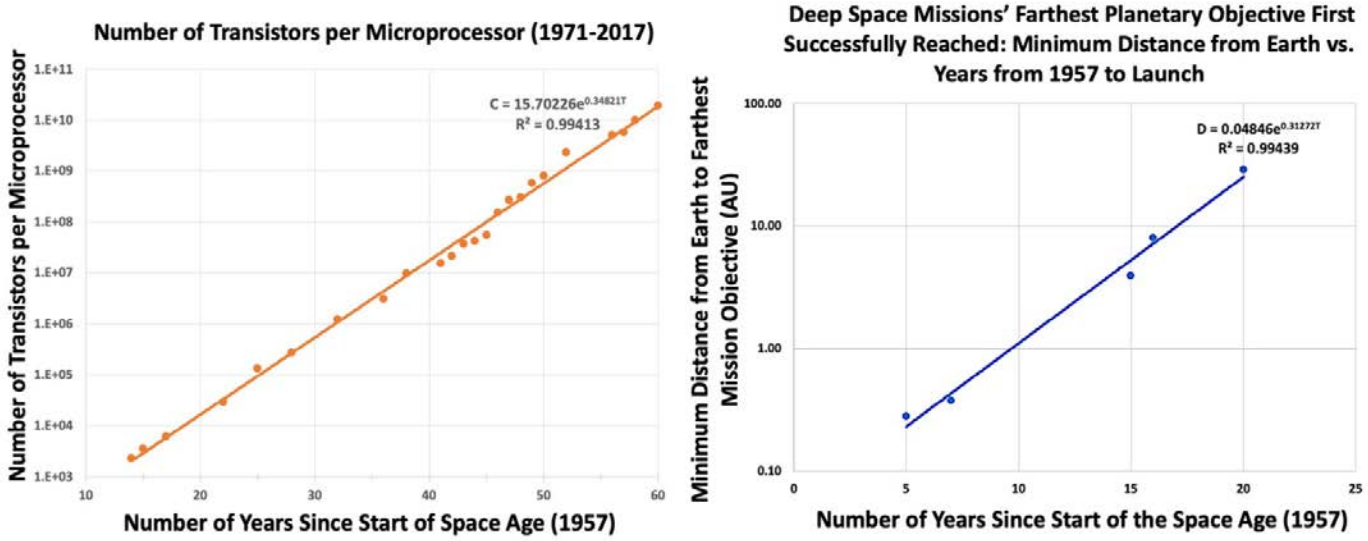
A team at JPL has been looking at how our own species might avoid this. In their paper *Avoiding the "Great Filter": A Projected Timeframe for Human Expansion Off-World* [2], they use the history of space exploration to extrapolate to the earliest possible launch dates to Solar System and interstellar destinations. They suggest the first human-crewed missions to Mars, Asteroid Belt objects and moons of Jupiter and Saturn before the end of the 21st century and launches of human-crewed interstellar missions within 40 light-years being possible during the 23rd century, with intragalactic missions by the end of the 24th century.

They suggest that computational power will be the limiting factor and use a transistor-neuron/synapse

[1] *Habitability and Biosignatures of Hycean Worlds*, Madhusudhan et al, The Astrophysical Journal, Volume 918, Number 1, August 2021 open publication:arxiv.org/abs/2108.10888 "Hycean" is a contraction of 'hydrogen' and 'ocean'.

[2] *Avoiding the "Great Filter": A Projected Timeframe for Human Expansion Off-World*, arxiv.org/abs/2108.01730, Jonathan H Jiang and Kristen A Fahy (Jet Propulsion Laboratory, Caltech), Philip E Rosen (Energy Industry Engineer - Retired, USA)

analogy to drive the required extrapolation. They set this against distances achieved by probes to date and in future. They are sceptical about the application of Moore's law given the physical limits to packing circuitry on semiconductor chips but nevertheless assume that human ingenuity will achieve a roughly exponential growth of computing power.



Left: Computational power - number of transistors per microprocessor - log scale
Right: Probe distance - first robotic flybys by objective minimum distance from Earth - log scale
Both versus years since start of the Space Age (1957) - linear scale
Image credit: Jiang et al

On this basis they present log-linear graphs setting probe distance and computational power against years since the start of the space age in 1957. They do not imply that "correlation implies causation" but the parallel is striking. They make similar comparisons between robotic and crewed missions but the data points for the latter are, of course, much more sparse.

Having derived empirical equations from the above they suggest a method of bringing these together and, taking a date of 2038 for the first crewed Mars landing, they derive a table of destinations and dates.

Tables for LookUp Data on Pre-Chosen Destinations and Projections for Earliest Possible Mission Launch Dates

Destination	Moon	Mars	Asteroid Belt	Jovian System	Saturn System	Proxima Centauri	Tau Ceti	Trappist System	4 kpc from CoMW
Dist. from Earth (AU)	0.0026	0.3763	1.5587	3.9501	8.0412	265,486	752,526	2,562,570	882,424,035
1st Flyby	1959	1964	1972	1972	1973	Not Yet Launched	Not Yet Launched	Not Yet Launched	Not Yet Launched
1st Robotic Lander	1966	1975	Not Yet Launched	Not Yet Launched	1997	Not Yet Launched	Not Yet Launched	Not Yet Launched	Not Yet Launched
1st Human Landing	1969	2038	Not Yet Launched	Not Yet Launched	Not Yet Launched	Not Yet Launched	Not Yet Launched	Not Yet Launched	Not Yet Launched
Actual and Calculated Projections for Calendar Year of Launch from Earth of First Successful Mission Type and Destination and Corresponding Computational Power Requirement									
Launch Year of 1st Successful Flyby Mission	1959	1964	1972	1972	1973	2007	2010	2014	2032
Year Computational Power First Achieved	1948	1964	1968	1971	1973				
Launch Year of 1st Successful Robotic Landing	1959	1975	1979	1982	1984	2018	2021	2025	2043
Year Computational Power First Achieved	1959	1975	1979	1982	1984	2018	2021	2025	2043
Launch Year of 1st Successful Human Landing	1969	2038	2064	2076	2086	2254	2270	2290	2383
Year Computational Power First Achieved	1969	2038	2064	2076	2086	2253	2269	2289	2381

Actual and projected timing of first successful robotic and human missions for selected destinations within the Solar System and interstellar space. Credit (image and caption): Jiang et al

The objective of the researchers is "...to provide a timeframe for humanity to become a multi-world species through off-world colonization that would logically follow on the heels of earlier human landings" and thus avoid a future "Great Filter".

Laser Communication using the Solar Gravitational Lens

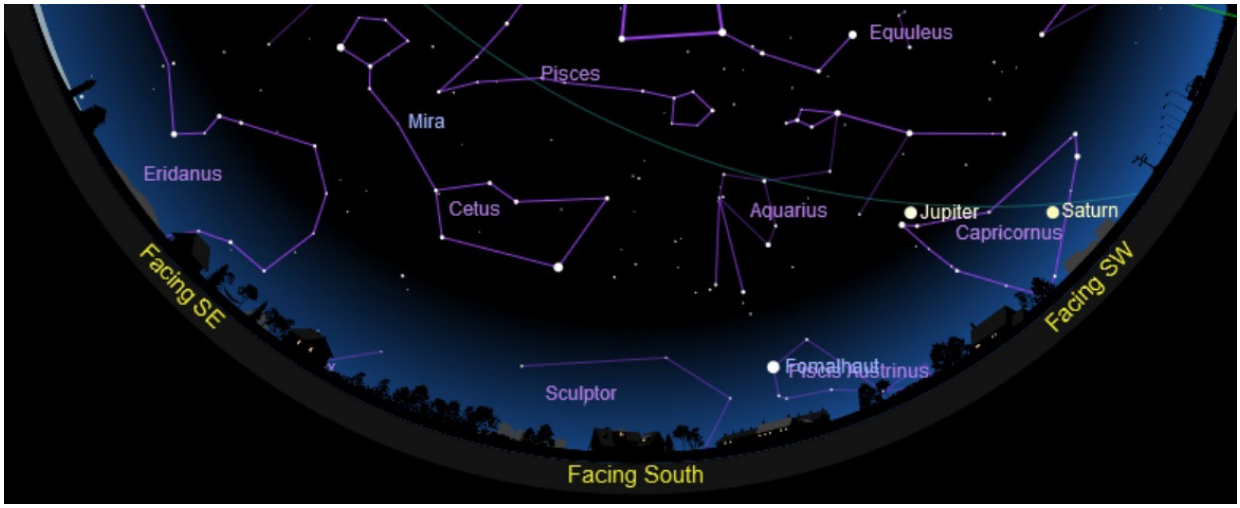
If we are to send probes to the nearest stars the greatest challenge may not be the speed required to reach them in a reasonable time but to communicate, if only one-way, with our probes.

Principium has reported on this in several issues, most recently in this issue in the feature, *The downlink from swarming micro-probes*. We have also reported on the potential use of the solar gravitational lensing point at 542 AU or greater distance, about 1% of a light year away, as an extremely powerful telescope.

In the paper, *Laser Communication with Proxima and Alpha Centauri using the Solar Gravitational Lens* [1], researchers tested the possibility that transmissions are already being made from focus points on the Earth-Sun radius and thus would be detectable at Earth. In the case of four nearby stars, Tau Ceti, Proxima Centauri, and Alpha Centauri AB, the beam would miss Earth because the directions to them do not lie in the plane of the ecliptic but any sub-optimal focusing of the beam might still generate a detectable signal. The researchers modified a Schmidt telescope of aperture 0.28 m (11 inch) using a custom-designed prism.

This very detailed work presents a new means of doing SETI but it also provides foundation information for future potential use of gravitational lensing for communications from our own interstellar probes and, longer term, communications to more capable probes we may send later.

It's worth noting that if you look along the ecliptic plane by taking a line between any two planets you can eavesdrop on signals from probes to stars on that line if you have a good enough telescope!



Where might we find signals intended for ETIs using our own Solar Gravitational Lens?

Look between Jupiter and Saturn. You may just be able to intercept signals to stars on that line.

Image credit: Sky and Telescope.

Sending a spacecraft to 2I/Borisov

Another i4is Project Lyra paper, *Sending a spacecraft to interstellar comet 2I/Borisov,* will appear in the December issue of Acta Astronautica [2]. This was first announced in Principium 33, May 2021. For a launch in 2027 a 765 kg mission could reach 2I in 2052 (using the NASA Space Launch System and Parker probe heat shield technology). Alternatively SpaceX Falcon Heavy could deliver 202 kg. Challenges include Borisov's high hyperbolic excess speed (around 32 km/s) and high orbital inclination with respect to the ecliptic (44°). It's notable that 1I/'Oumuamua is not travelling so fast but its trajectory has been much closer to Earth - see our front cover visualisation of its closest approach to the Earth in Principium 20, February 2018.

[1] *Laser Communication with Proxima and Alpha Centauri using the Solar Gravitational Lens,*

Geoffrey W Marcy (Center for Space Laser Awareness, USA), Nathaniel K Tellis (RocketCDL), Edward H Wishnow (Space Science Laboratory, University of California, Berkeley) arxiv.org/abs/2110.10247. Accepted for publication in the Monthly Notices of the Royal Astronomical Society October 2021

[2] *Sending a spacecraft to interstellar comet 2I/Borisov*, Adam Hibberd(i4is), Nikolaos Perakis (Technical University of Munich and i4is) Andreas M Hein(i4is), Acta Astronautica V189, December 2021. Open publication: www.researchgate.net/profile/Adam-Hibberd/publication/354593769_Sending_a_spacecraft_to_interstellar_comet_2IBorisov/links/61448f19a3df59440b922ef3/Sending-a-spacecraft-to-interstellar-comet-2I-Borisov.pdf

A chronology of Principium

Principium is now in its 10th year so maybe it's time to put our issue creation dates on public record.

#	Date	Year	pages
1	Tue Dec 4	2012	13
2	Thu Jan 17	2013	14
3	Sat Feb 23	2013	14
4	Mon Apr 22	2013	16
5	Mon Jul 22	2013	20
6	Wed Aug 7	2013	26
7	Wed Dec 18	2013	17
8	Wed Jul 30	2014	18
9	Sat May 9	2015	34
10	Fri Aug 7	2015	26
11	Sat Nov 7	2015	26
12	Wed Feb 10	2016	23
13-	Thu Jun 2	2016	28
14	Sat Aug 20	2016	32
15	Tue Nov 29	2016	36
16	Sun Feb 26	2017	36
17	Wed May 17	2017	40
18	Tue Aug 29	2017	44
19	Sat Dec 16	2017	44
20	Tue Feb 27	2018	40
21	Tue May 29	2018	40
22	Thu Aug 23	2018	48
23	Tue Dec 4	2018	44
24	Mon Feb 18	2019	40
25	Mon May 27	2019	56
26	Fri Aug 30	2019	56
27	Thu Nov 28	2019	44
28	Sat Feb 29	2020	52
29	Wed May 27	2020	60
30	Mon Aug 31	2020	96
31	Sun Nov 29	2020	92
32	Mon Feb 22	2021	88
33	Fri May 28	2021	76
34	Wed Aug 25	2021	56

- and here are our total pages per year- 2012 13 pages, 2013 107 pages, 2014 18 pages, 2015 86 pages, 2016 119 pages, 2017 164 pages, 2018 172 pages, 2019 196 pages, 2020 300 pages.

Will Interstellar Astronauts Be Human?

A recent paper asserts that the first, at least, will not [1]. The paper explores the biological and technological challenges of interstellar space biology, focusing on radiation-tolerant micro-organisms capable of cryptobiosis (a state of extreme inactivity in response to adverse environmental conditions), planetary protection and other ethical considerations of sending life to the stars.

They ask "Why should we develop the technology to send spacecraft into interstellar space?" and answer "the human drive to understand and explore" and that "the same technology we use to enable relativistic flight also enables a transformative range of possibilities for space exploration". The paper cites the NASA Starlight program for laser sailcraft as the leading initiative and examines the challenges of any future human interstellar flight. The robustness of some microorganisms such as tardigrades and C. elegans makes them attractive interstellar voyagers but modifying mammals to have similar characteristics is by no means a trivial undertaking! Experimental interstellar craft could carry a range of species as laboratory subjects.

The suggested motivations here seem to be rather modest. As a species we have always migrated and the settlement of the Pacific islands in just a few hundred years by what lofty Europeans and Americans once called "primitive peoples" is a powerful instance of this (see next page).

A real, albeit humble, warp bubble?

Sonny White (Limitless Space Institute) has published, with colleagues, more thinking which just may give us the access to the warp drive technology suggested by Miguel Alcubierre [2]. The setup consists of a standard parallel plate Casimir cavity and subsequently a toy model consisting of a 1 micrometer diameter sphere centrally located in a 4 micrometre diameter cylinder as a three dimensional demonstration. They find qualitative correlation suggesting that chip-scale experiments might attempt to measure tiny signatures illustrative of the presence of the conjectured phenomenon "a real, albeit humble, warp bubble".

[1] *The First Interstellar Astronauts Will Not Be Human*, Stephen Lantin et al, arxiv.org/abs/2110.13080. Lantin is at Department of Agricultural and Biological Engineering, University of Florida. Other authors are with a range of deparments at UCSB (including Prof Philip Lubin), UCLA Health Center and Ruhr-Universitat Bochum.

[2] *Worldline numerics applied to custom Casimir geometry generates unanticipated intersection with Alcubierre warp metric.* Harold White et al, European Physical Journal V81, #677 2021 epjc.epj.org/articles/epjc/abs/2021/07/10052_2021_Article_9484/10052_2021_Article_9484.html

SETI on fire

In *Strategies and Advice for the Search for Extraterrestrial Intelligence* [1], Jason T Wright has produced a how-to guide and potential roadmap. As he says, SETI is currently experiencing a resurgence and he surveys methods and potential types of evidence. And he notes the distinction between deliberate investigation versus the use of the vast amount of astronomical data accumulated for other purposes where SETI can be a "byproduct" (note that a chemical engineer will tell you that byproducts often rise in value to equal or surpass that of the original intended product).

Communicative signals he call "dispositive" since any signal that is sufficiently compressed in time or frequency must be artificial. Technosignatures would be unambiguous but their absence need not necessarily imply absence of an ETI.

He draws a useful distinction between targeted searching, imaging a signal or signature that an ETI might be expected to produce, versus simply searching for anomalies (the "that's funny" reaction that resulted, for example, in the discovery of pulsars).

He wraps up with some guidelines and a model plan for SETI research.

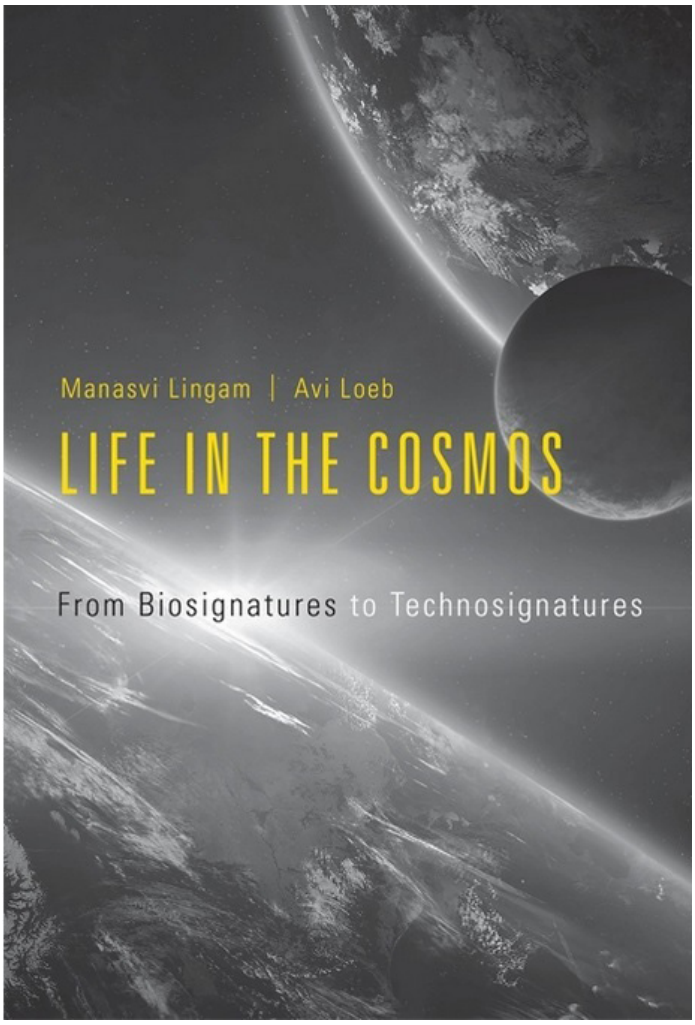
Jason is a professor of astronomy and astrophysics at Penn State, a member of the Center for Exoplanets and Habitable Worlds, and director of the Penn State Extraterrestrial Intelligence Center.

Jason has also produced *SETI in 2020* [2], which he characterises as a brief and subjective review of developments in SETI in 2020. He mainly reviews 75 papers and books published or made public in 2020. He identifies six broad categories: results from actual searches, new search methods and instrumentation, target and frequency selection, the development of technosignatures, theory of ETIs, and social aspects of SETI.

Life in the Cosmos: From Biosignatures to Technosignatures

Our interstellar colleague, Manasvi Lingam (Assistant Professor of Astrobiology, Florida Institute of Technology) has now published his book, written with Professor Avi Loeb, *Life in the Cosmos: From Biosignatures to Technosignatures* [3]. It is a very substantial (1088 pages) review of possible ETIs.

We look forward to reviewing it in a future issue.



[1] *Strategies and Advice for the Search for Extraterrestrial Intelligence*, Jason T Wright, Pennsylvania State University, July 2021, arxiv.org/abs/2107.07283

[2] *SETI in 2020*, Jason T Wright, August 2021 arxiv.org/abs/2107.07512

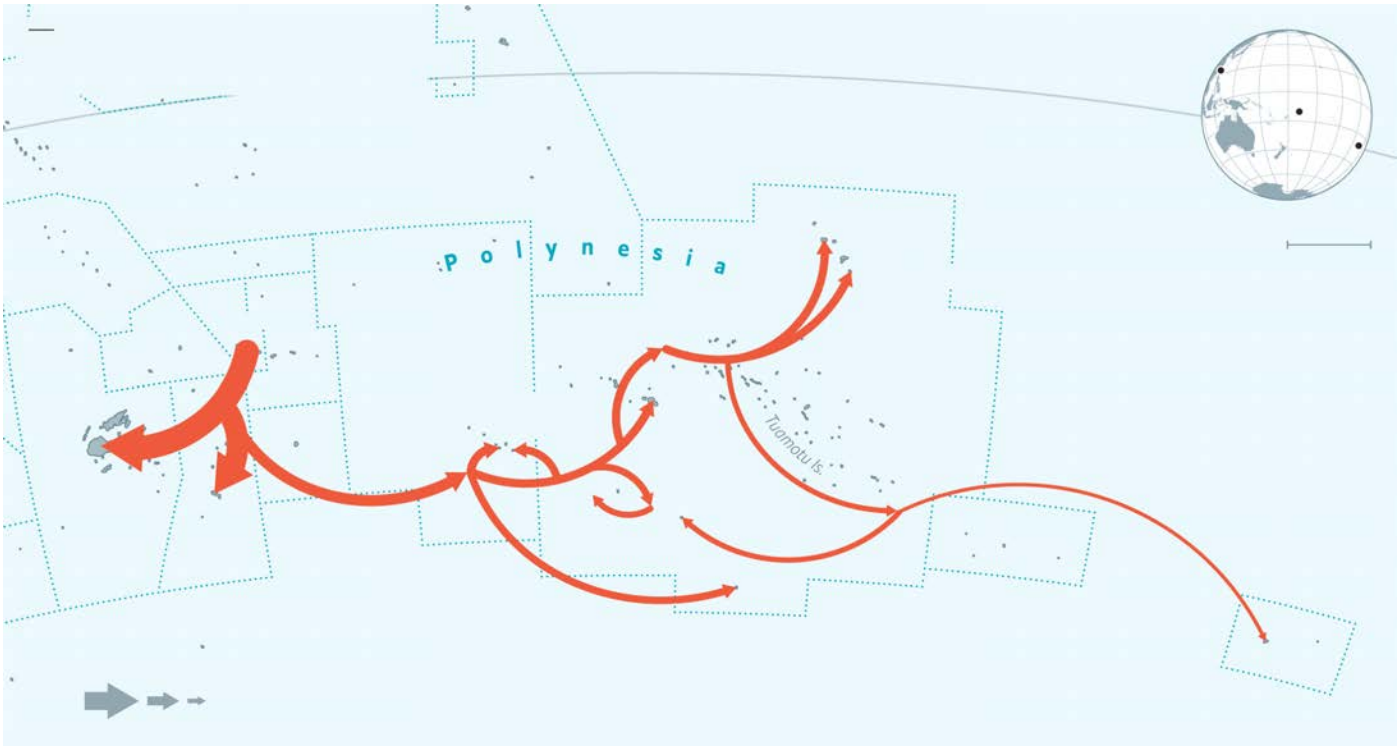
[3] *Life in the Cosmos: From Biosignatures to Technosignatures*, Manasvi Lingam & Avi Loeb, Harvard University Press, www.hup.harvard.edu/catalog.php?isbn=9780674987579

"Canoeing" to the stars

The Economist newspaper and Nature recently published *Settling the Pacific by canoe in a few hundred years - Paths and timings of the peopling of Polynesia inferred from genomic networks* [1], reporting recent research by a team stretching from Oxford and Stanford to the Mata Ki Te Rangi Foundation, Hanga Roa, Easter Island. They used genetic evidence to show that the Pacific was settled by canoe in the space of a few hundred years. It shows how the Pacific, one third of the area of our planet, was settled by humans using canoes propelled by wind and muscle between AD 830 and AD 1200, about 370 years. The straight line distance between Rarotonga and Easter Island is about 5,000 kilometres. If we double this for indirect travel then this might be approximated to 10,000 kilometres.

If our ingenious ancestors achieved this using vehicles capable of only a few tens of kilometres per day, settling many times along the way, then cannot our outward urge take us, at a few percent of the speed of light, to the stars in similarly feasible times?

More than 70 years ago Thor Heyerdahl respected the maritime capabilities of our ancestors enough to journey from South America to Polynesia on the raft, Kon Tiki, to support a theory of such staggering achievement. He seems to have got the direction reversed but his faith in the capacity of our species should hearten us. What was called impossible just after the Second World War was achieved by 1948 and modern genetics now shows that Heyerdahl's suggested migration, in the reverse direction, was achieved by humans in canoes over less than four centuries - and long before westerners even knew the Pacific existed.



The settlement of Polynesia Reconstructed from the genes of modern inhabitants.
Credit: The Economist / Nature

[1] *Genes reveal how and when humans reached remote corners of Pacific - The islands settled most recently have the least genetic diversity* www.economist.com/graphic-detail/2021/09/25/genes-reveal-how-and-when-humans-reached-remote-corners-of-pacific.