PRINCIPIUM

The Initiative and Institute for Interstellar Studies | Issue 53 | May 2026

SCIENTIA AD SIDERA | KNOWLEDGE TO THE STARS

Lead Feature: Science from the In Situ Exploration of the Proxima Centauri System: a summary

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Mission to an Interstellar Object

Interstellar News

The Journals: JBIS and Acta Astronautica

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EDITORIAL

Welcome to issue 53 of Principium, the quarterly magazine of i4is, the Initiative and Institute for Interstellar Studies.

I'm sad to report that I'm stepping down as Editor because of health issues. I'm also sad to convey this message from the i4is Board of Directors:

"The i4is Board has been considering the future of Principium, given changes in the ways in which people receive and consume information and content. We have decided to pause the publication of Principium with the current issue, number 53, while we undertake a proper review of the future format, content and methods of distribution of the material currently published in Principium. We will announce our conclusions on the i4is website in due course. If you have any ideas and feedback about the future format, or would like to volunteer to help take Principium forwards into the future, please contact us at info@i4is.org. For now, we would like to thank the editorial team, past and present, and all the contributors and readers of Principium for their contributions and their interest."

I understand that this may be a disappointment to some; however Principium (or its successor) will be back in some format as soon as practically possible.

For this final issue before hiatus, we are featuring the paper *Science from the In Situ Exploration of the Proxima Centauri System.* See page 4. We are really proud of this paper, co-authored by many of our own i4is researchers and the resulting publicity is most welcome as it broadens both academic and public engagement with interstellar research.

As we went to press, we were also delighted to hear that the International Astronomical Union (IAU) Executive Committee have approved an interstellar topic as one of the IAU Focus Meetings; see page 18.

We have our usual *Interstellar News* highlights and our regular feature *The Journals* summary contains several interstellar peer-reviewed papers from both The Journal of the British Interplanetary Society (JBIS) and Acta Astronautica.

We will continue our monthly newsletters (they are distributed to members initally and then sent out in arrears to non members). Please see ***Working towards the real Final Frontier*** on page 29 if you want to join us for the journey. It's been an honour to be a small part of that journey and I will remain involved with i4is on a much reduced capacity. With best wishes.

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Members have access to:

- **Networking:** i4is.org/members/networking-opportunities
- **Principium preprints:** i4is.org/members/preprints
- **Videos:** i4is.org/videos

Please print and display our posters - selected poster variants are listed in the Contents and all available at i4is.org/i4is-membership-posters-and-video.

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Contact us on email via info@i4is.org

Back issues of Principium can be found at- i4is.org/publications/principium/

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

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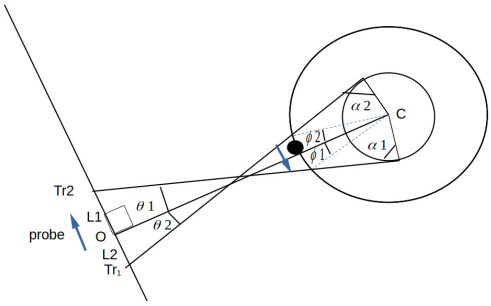

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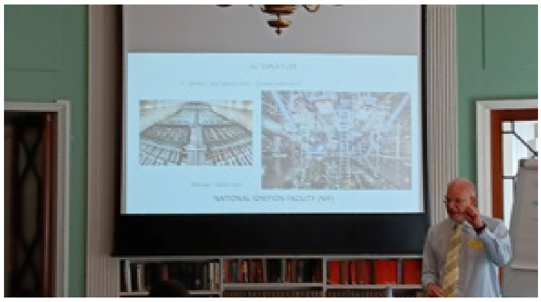

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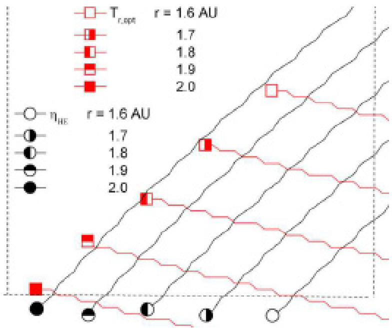

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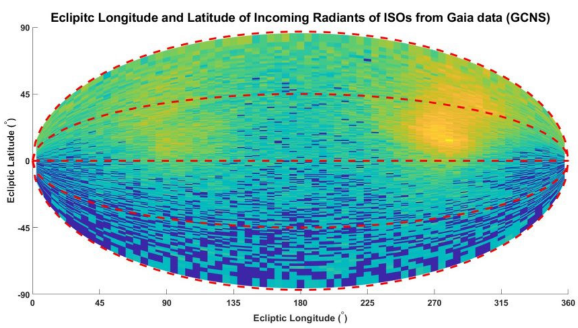


Science from the In Situ Exploration of the Proxima Centauri System: a summary

Gill Norman

This significant paper was submitted to arXiv.org on 22 April 2026. https://arxiv.org/abs/2604.20182 by T Marshall Eubanks (Space Initiatives Inc, USA) et al (including most of our i4is researchers). The paper has received considerable publicity in the scientific community, which is strong and heartening evidence of the surging interest in the subject. We wanted to showcase the content here as well as shine a spotlight on some of the insightful commentary recently posted by sources external to i4is.

Here's the abstract

In the future interstellar exploration at near-relativistic speeds will be possible using beamed energy laser propulsion. With this, spacecraft as small as gm mass picospacecraft become candidates for the exploration of deep-space, with a trade space of velocity and mission duration versus mass. Here, the authors examine the potential science return from interstellar expeditions with Coracle™ laser-sail picospacecraft swarms and show how even with fast flybys at near relativistic velocities, a picospacecraft swarm could deliver gigapixel resolution of the target exoplanets. The mission target is the planet Proxima b in the habitable zone of the red dwarf Proxima Centauri, the tertiary (and nearest) component of the nearest star system, Alpha Centauri. They explore science returns from such an expedition, both en route to Proxima and at the Proxima system, and conclude that initial small spacecraft expeditions would provide a substantial science return, including the ability to detect surface biology or a technological civilization, should either or both be established on the target planet.

Paper acknowledgments

The authors of the paper acknowledge that the work was supported in part by the NASA Innovative Advanced Concepts (NIAC) contract and also in part by a Breakthrough Starshot Foundation award.

Centauri Dreams

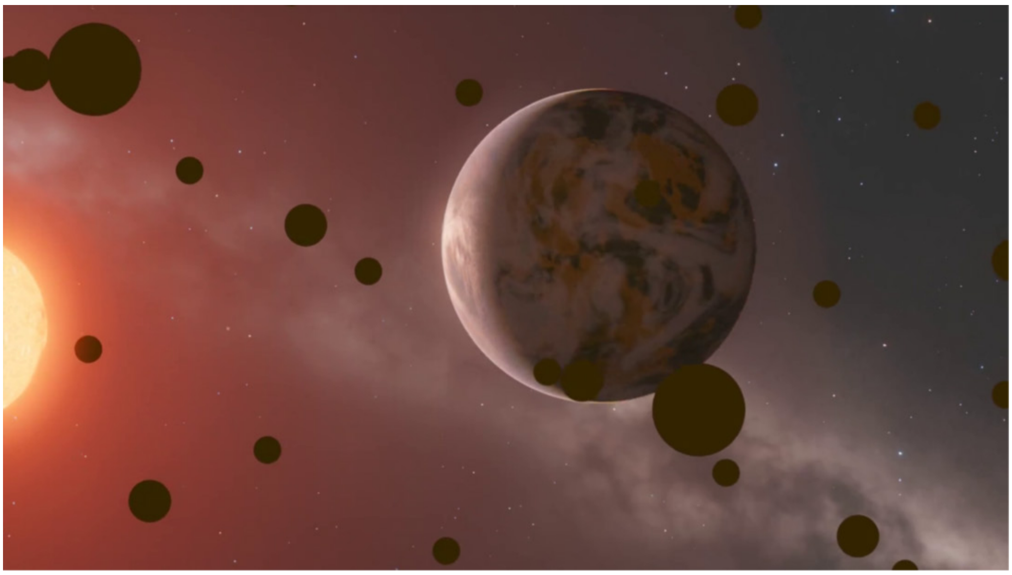
We were happy that our favourite interstellar blogger Paul Gilster penned a comprehensive review of the paper on 9 May 2026 in *A Deeper Dive into the Proxima Centauri Swarm*: https://www.centauri-dreams.org/2026/05/09/a-deeper-dive-into-the-proxima-centauri-swarm/. Discussing the communications problems of transmitting data back to Earth: "The concepts here are ingenious, even startling, and deserve further investigation". He concludes with the following words: "The kind of investigation mounted by this team is how we move the ball forward in interstellar studies. Drawing on recent work including the deep investigations of the Breakthrough Starshot scientists, Eubanks and colleagues have enlarged the speculative space especially in terms of communications and swarm computational options, all making an interstellar crossing in decades rather than centuries possible. This paper should be studied by anyone seriously following our increasingly refined strategies for making such a crossing happen".

Universe Today and Phys.Org

On 29 April 2026, Universe Today posted *Laser-Swarm Science at the Proxima Centauri System*: https://www.universetoday.com/articles/laser-swarm-science-at-the-proxima-centauri-system. Summarising: "Other stars are so far away that it will take bold initiatives to ever reach them. While other advanced propulsion technologies are always being pondered, we never know when they'll come to fruition. That's why the laser sail idea never goes away". Phys.Org also published the same article in their Space Exploration and Astrobiology sections: *Near-relativistic swarm could image Proxima b at 20-meter resolution and scan for biosignatures, paper says;* see https://phys.org/news/2026-04-relativistic-swarm-image-proxima-meter.html.

The art

I adore Dr Mark Garlick's artist's conception so much that I have to include this artwork again.



The Swarm approaches Proxima's planet b.
Image credit:
Dr Mark Garlick,
www.markgarlick.com

Some highlights of the paper

The authors investigate the potential scientific value and feasibility of sending a swam of picospacecraft to Proxima b, an exoplanet orbiting the red dwarf star Proxima Centauri. Proxima b is Earth-mass and orbits within the habitable zone of its star: the primary reasons for the intense scientific curiosity surrounding it. This paper is jam packed with science and my only caveat is that there are dozens of delightful rabbit holes to dive into!

We have previously published a few items on the design of the picospacecraft swarm so I've added those links at the end of this article for ease of reference.

The Coracle™ laser-sail picospacecraft are ultra-lightweight probes that use laser propulsion to achieve sufficiently high velocities that they reach the Proxima Centauri system within a few decades. They will execute a highly co-ordinated high-speed flyby to capture gigapixel-resolution data. The swarm of a thousand probes introduces redundancy to mitigate individual failures and maximise data collection.

Basic parameters of the proposed Coracle™ probe swarm. The aerographene metamaterial that forms the main probe body has a variable density, tailored for the particular mechanical requirements. A denser layer will support the drive-beam dielectric reflector while the middle layer will be very sparse. There would be thicker areas around the sensor/communications telescope array on the front face and around the betavoltaic, capacitor, and electronics layers to support them. There are 169 hexagon spaces for optical aperture, not all of which may be occupied depending on the mission profile and mass budget.
Credit (graphic and caption): Eubanks et al, Table 1

Swarm or Probe Parameter	Value [units]
Individual probe diameter [mm]	4000
Probe rim height [mm]	20
Main disk thickness [mm]	10
Mass budget: total sailcraft mass [mg]	3600
Mass budget: total sail mass [mg]	2600
Mass budget: total payload mass [mg]	1000
Mass budget: payload disk + apertures [mg]	330
Mass budget: betavoltaic battery and ultracapacitor pulsed storage [mg]	330
Mass budget: rim, intra-probe communications, computation and everything else [mg]	340
Overall input electrical power per probe, at flyby [mW]	6
Input electrical power to Swarm-Earth or intra-swarm lasers, at flyby [mW]	4
Optical output power per probe, at flyby [mW]	0.4
Swarm-Earth communications wavelength source / as received red-shifted [nm]	432 / 539
Maximum Number of probe multi-use optical apertures	169
Intra-swarm (rim) communications wavelength [nm]	12,000
Number of rim transceivers per probe	6
Transverse swarm diameter at flyby [km]	100,000
Number of probes at launch	1000
Number of surviving probes at flyby, after the Proxima encounter (assumed)	300
Average probe spacing within main swarm [km]	6100

Operational Considerations

Section 6 details the operational considerations of the mission in great depth, from power to communications and navigation.

Here's some teasers.

Swarm-to-Earth Communication

"We assume interstellar communications with 2-symbol Pulse Position Modulation (2-PPM), which is widely used in optical communications. 2-PPM uses synchronous time slots, with two adjacent time slots for each bit. A "0" value is sent with a pulse in slot 1 and no pulse in slot 2; and vice versa to send a "1" value. Symbols are transmitted at 1,000 Hz, with pulses nominally 1 ns in duration and the integration slots 10 ns in length. This technique also has the desirable effect of greatly lowering the unwanted background noise, since the integration time is very short...In conclusion, 0.9 kbps data transfers and a data return rate of 3.38 Gbytes/year, comparable to the data return of the New Horizons spacecraft after its Pluto flyby, should be possible with the main picospacecraft swarm at Proxima Centauri, and the two sub-swarms should each be able to return ~188 Mbytes/year back to Earth."

Establishing a Coherent Swarm

"A swarm of probes has a co-ordination problem after it is launched - at first, its members will not on their own know where the other probes are. As described in the Conops (Section 3), we have developed preliminary protocols to develop swarm coherency, defined as a set of probes with intra-swarm communication, positional knowledge, and the ability to position swarm members in a desired configuration. We find that a swarm with a diameter of ~100,000 km can, with assistance from Earth, gain "self-knowledge" and configure itself in deep-space (Eubanks et al 2023b [1]; Ding et al 2023 [2]; Dennison et al 2023 [3]). Establishment of coherence will occur in several distinct phases: Discovery, Probes as Beacons, Convergence."

Damage Reduction by Travelling Edge-On

"The VoT-Attitude Adjustment method could be initially be under control from Earth, but soon (due to communication latency), it has to become fully autonomous, ie, under the control of individual probes and eventually that of the swarm as a whole, which in effect would eventually create a "hive mind." With virtually no mass allowance for shielding, travelling edge-on is the only practical means to minimize the extreme radiation damage and erosion induced by travelling through the ISM at 0.2 c."

[1] *Swarming Proxima Centauri: Optical Communication Over Interstellar Distances* https://arxiv.org/abs/2309.07061
[2] *Distributed Machine Learning for UAV Swarms: Computing, Sensing, and Semantic* https://arxiv.org/abs/2301.00912
[3] *Autonomous Asteroid Characterization Through Nanosatellite Swarming* https://ieeexplore.ieee.org/document/10049738

Sheer volume of data

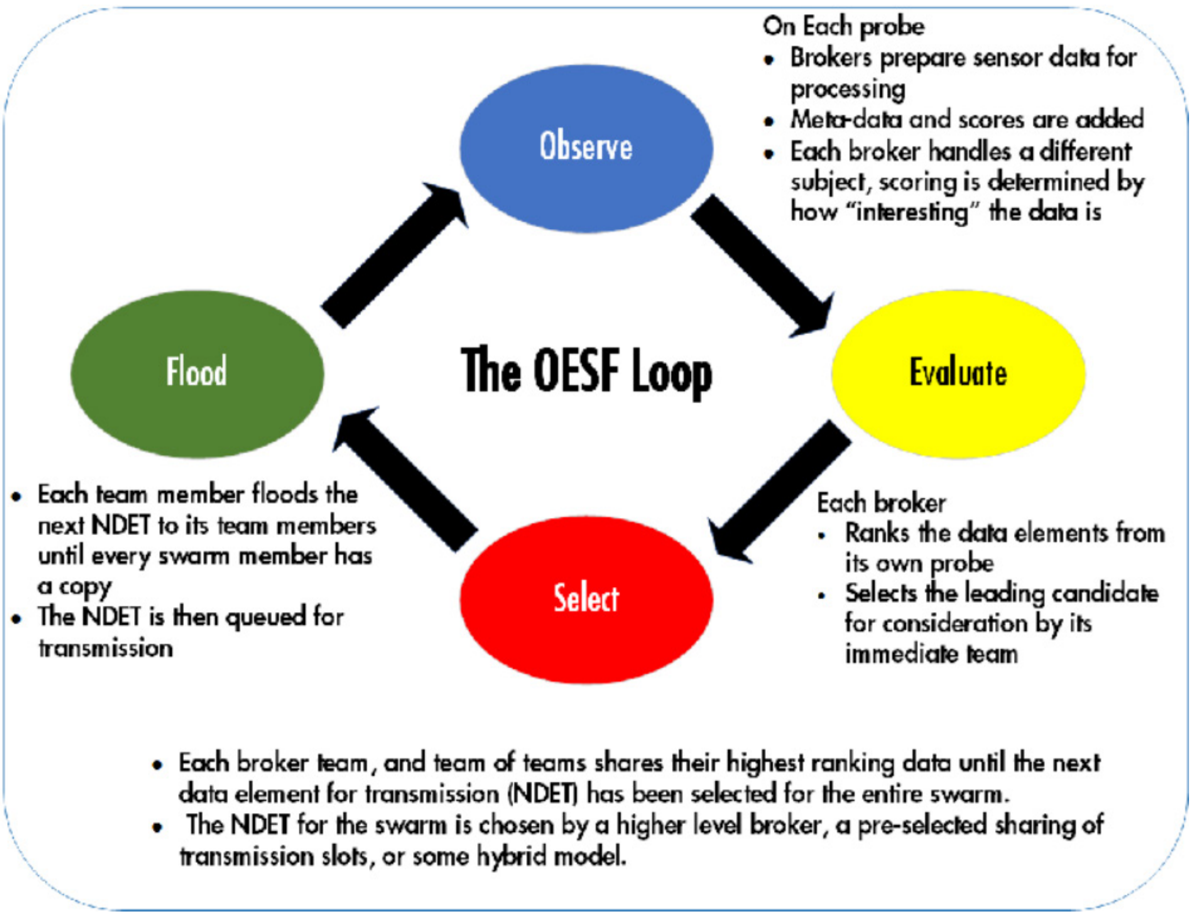
One significant problem is that the volume of data gathered will be simply too vast to send back to Earth in its entirety. Section 7 investigates some solutions.

"With the entire swarm co-ordinating the return of data to Earth, it should be possible to support a data rate of ~0.9 kbps, or ~3.4 gigabytes per year. The data selection process will thus demand new means of filtering and selecting data for return to Earth. Data-broker-agents (or agents) — automated software systems designed to support different scientific goals by sifting, characterizing and prioritizing swarm observations - will be critical tools for managing the floods of data from light-sail swarms."

OESF loops in Swarm data Selection

"There will be a mass of redundant data collected (nearly identical images of the target planet, for example), and having each probe flood all of its data to every other probe is not an efficient use of intra-swarm bandwidth. This can be solved through the use of Observe – Evaluate – Select – Flood (OESF) Loops, and the division of the swarm into nested sets of nearest-neighbour groups."

The basics of the OESF loop. To minimize bandwidth usage, this would be kept to small sets of neighbours, neighbours of neighbours, etc.
Credit (graphic and caption): Eubanks et al, Figure 10



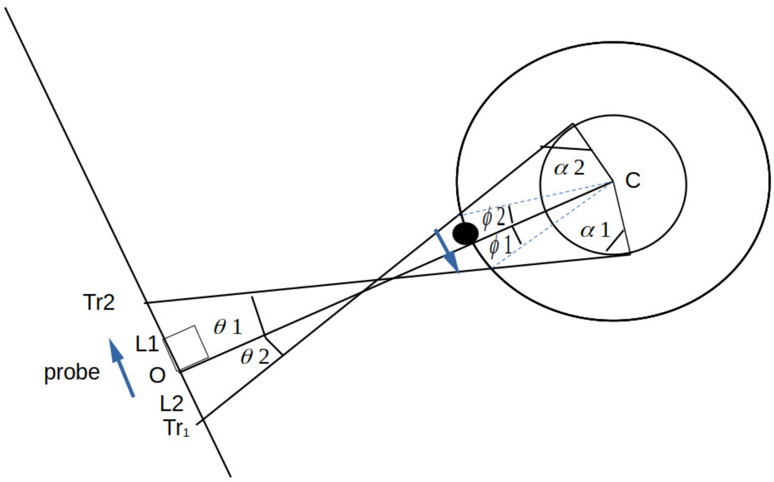
Science. science and more science

There are several scientific goals - both during transit and upon arrival - described in the paper. Some are summarised here.

En route science in section 8

1. Monitoring the Trailing Hemisphere: The orientation of the swarm will enable observation of objects and events in the swarm's trailing hemisphere during the 21-year voyage.
2. Stellar Occultations en route: During its two years voyage through the Solar System's Oort Cloud, the probes will observe stellar occultations by small bodies. Beyond the Oort Cloud, the probes will similarly observe stellar occultations by interstellar asteroids or rogue planets, if any, and then there will be a period when it is exposed to the shadows of bodies in the Oort cloud of the α Centauri system.
3. Detection of Nearby Bodies from Trajectory Deviations: We can investigate how the presence of a single body, with a gravitational mass may, through its gravitational influence, affect the trajectories of some probes as they fly past the object.
4. Exploring the Oort Cloud: The probability that at least one probe passes closer than 0.02 AU from a comet is 50%. Such close approach will allow direct imaging of Oort comets.
5. Astrometry: the probes can observe targets such as the nearby stars from a different perspective to the same stars as seen from the Solar System, possibility improving certain stellar data.
6. Observing Companion Transits en route: statistically, the probes can detect significantly more transits than are possible from Earth or a telescope in orbit.
7. Exploring the Interstellar Medium (ISM): in addition to remote observations, the probe will sample the ISM in situ.
8. Interstellar Dust: Recording the impact rate due to collisions with ISM "dust" (here, any particles bigger than single molecule) or other hazards will both inform this mission's operation and also provide the first high-fidelity map of the dust density all the way between Sol and Proxima.

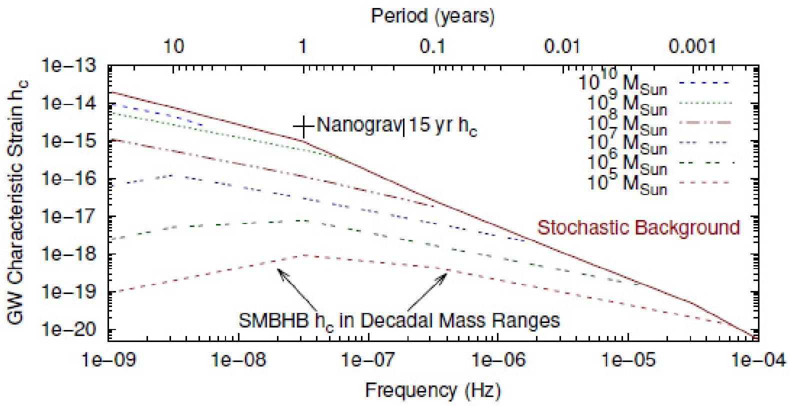
Geometry of the transit seen by the probe in direction antiparallel to the planet trajectory. Credit (graphic and caption): Eubanks et al, Figure 14



Science. science and more science...*continued*

Fundamental Physics in section 9

1. Tests of Gravity: MOND versus Newton. See Banik & Kroupa *Directly testing gravity with Proxima Centauri* [1].
2. Interstellar Gravitational Wave Detection: although unlikely from a single swarm, detection should become possible as multiple swarms are sent through the Proxima system over time.



Predicted gravitational wave characteristic strains based on statistical models of the SMBHB number density (Pesce et al 2022), here broken into decadal mass ranges. At a given mass, the number of sources declines going along the curve to the right (ie, towards higher frequencies); each curve stops at the frequency step where the expected number of sources in that mass decade falls below 1. These models agree reasonably well with the characteristic strain estimate, h_c, from the 15 year Nanograv pulsar timing analysis, shown here scaled to a nominal 1 year period (Agazie et al 2023).
Credit (graphic and caption): Eubanks et al, Figure 15

Arrival Science in section 10

Event	Distance	Time from Encounter	Assumed Abs. Mag. H
Detect Proxima b	∼10,000 au	∼300 days	-4.0
Detect Proxima d	∼6000 au	∼170 days	-1.6
Detect Proxima c	∼1400 au	∼40 days	-7.0
Resolve Proxima disk	∼271 au	7.8 days	-
Detect 100 km Asteroid in Prox. b orbit	∼27 au	18.5 hr	9.0
Resolve Proxima b disk	∼21 au	14.6 hr	-4.0

Imaging possibilities before or after the Proxima encounter. The search for other planets in the system would be possible in the months around encounter, and in the few days around encounter an encounter video could be obtained monitoring atmospheric changes on all 3 planets. (Note that Proxima c, if it exists, is sufficiently far from its star to make it relatively dim, even though it would presumably be considerably larger than Proxima b.)
Credit (graphic and caption): Eubanks et al, Table 7

[1] https://academic.oup.com/mnras/article/487/2/1653/5491320 [2].
[2] Be mindful of rabbit holes mentioned in paragraph 1 on page 6 [3].
[3] Don't say I didn't warn you.

Science. science and more science...*continued*

Arrival Science in section 10...*continued*

1. Approach Imaging: Roughly 8 days before the encounter, the primary probe imaging apertures would be able to resolve the Proxima b Hill sphere and begin a search for Proxima b moons.
2. GigaPixel Imaging in the Proxima System: A single 200-mm aperture observing at optical wavelengths has a diffraction limited resolution of order 0.4 arc-seconds, providing a potential for gigapixel imagery in the Proxima system, revolutionizing the study of the Proxima planets.
3. Night-Side Imagery: As Proxima b is likely to be tidally locked - and the night-side could thus remain dark for all future missions - probes, trajectories and mission timing should all be developed to provide the best possible lowlight and IR imagery of the planet's night-side.
4. Bistatic Laser Ranging: The drive laser signal should be pulsed or modulated to allow for bistatic laser ranging (lidar) of objects in the Proxima system.
5. Transmission Spectroscopy: Transmission spectroscopy can be done at Proxima b using natural and artificial sources, and will, through the search for spectral lines of biomarkers and technosignatures, likely provide the best means of establishing the existence of a biology or even a technological society on Proxima b.
6. Proxima Helioscience: Proxima is a frequent flare star and the swarm should be able to provide valuable observations of the details of possibly a few dozen moderate intensity flares.
7. Impact Spectroscopy: it is possible that one or more Coracle™ probes would enter the Proxima b atmosphere, if it exists, or impact the surface, if it does not. The resulting flash would be potentially observable from the visible spectrum into the Gamma Ray bands by nearly the entire fleet and would yield important spectroscopic data about Proxima b's composition.
8. Proxima b geocorona: the Earth's geocorona - the planet's outermost neutral atmosphere - stretches well beyond the lunar orbit (Bertaux et al 1995). Any corresponding geocorona on Proxima b could be detected by probes, either by detecting any atoms in situ or by observing them via Proxima flare light.
9. Biosignatures and Technosignatures: the search for these will be intensive, aiming to image vegetation and detect biologically driven atmospheric lines.
10. Radio Science: Measurements of the intensity and frequency of radio emissions will provide information about the stellar and planetary magnetic fields in the Proxima system complementing direct measurements from magnetometers carried by the swarm.
11. Small Bodies: Beginning approximately 1 day before the Proxima b encounter, imaging of the Proxima system can be used to search for exterior planets, asteroid belts, and planetary moons and ring systems.

Conclusion

The authors conclude that initial, small-scale interstellar expeditions using laser-sail picospacecraft are highly viable and offer immense scientific returns. They serve as a foundational, practical first step for humanity's transition into in-situ interstellar exploration.

Some links to previous articles and milestones

The downlink from swarming micro-probes

Principium Issue 35 November 2021 page 66
https://i4is.org/wp-content/uploads/2021/11/The-downlink-from-swarming-micro-probes-Principium35-print-2111260906-opt-3.pdf

i4is delivers Communications Study to Breakthrough Starshot

Principium Issue 41 November May 2023 page 50
https://i4is.org/wp-content/uploads/2023/05/News-Feature-i4is-delivers-Communications-Study-to-Breakthrough-Starshot-Principium41-23052291003-1.pdf

NASA NIAC funds swarming study

Principium Issue 44 February 2024 page 14
https://i4is.org/wp-content/uploads/2024/02/NASA-NIAC-funds-swarming-study-Principium44-2402201033-comp.pdf

The Interstellar Coracle™ at the NIAC Symposium in Pasadena

Principium Issue 49 May 2025 page 27
https://i4is.org/wp-content/uploads/2025/06/coracle-pasadena-Principium49-2506041431.pdf

In **September 2018**, our Step A proposal #18-NIAC19A-0090 "*Swarming Proxima Centauri: Optical Communication over Interstellar Distances*" was submitted by i4is-US to NIAC.

On **5 December 2018** the Institute for Interstellar Studies submitted a Step B proposal #18-NIAC19A-0090 "*Swarming Proxima Centauri: Optical Communication over Interstellar Distances*".

On **24 April 2023**, after a year of preparation and a year-and-a-half of contracted work, Institute for Interstellar Studies-US delivered its final systems engineering analysis and conceptual design to the Breakthrough Starshot Foundation.

On **12 September 2024,** Marshall Eubanks (Space Initiatives) and the i4is team presented at NASA NIAC 2024 Pasadena on their proposal "*Swarming Proxima Centauri: Coherent Picospacecraft Swarms Over Interstellar Distances*".

The video was officially released by NASA Space Tech on YouTube in September 2025. See https://www.youtube.com/watch?v=XXW_keR5OIM.

Workshops at the Royal Institution April 2026

Our eighth *Skateboards to Starships* workshops were delivered on 7 and 8 April 2026.

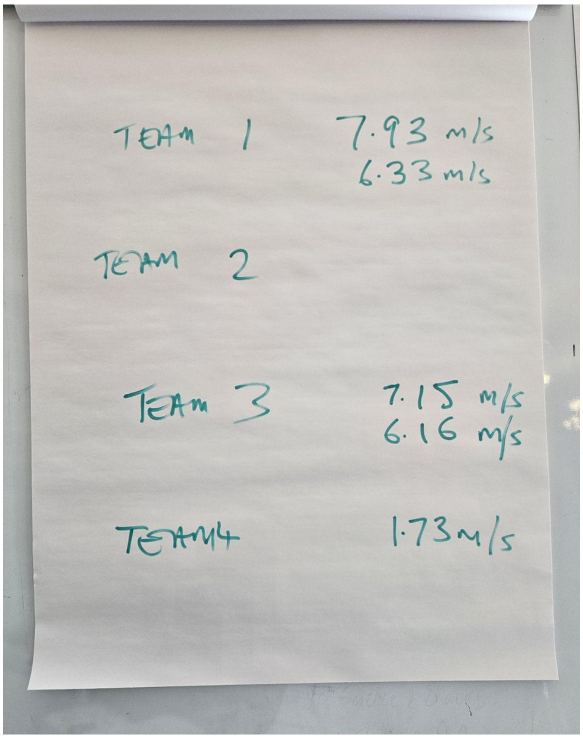
John I Davies

We were back again at the RI to talk to secondary school students (high school to those across the pond). This is just a quick note to record our most recent workshop. Much more in our account of last year in *Workshops at the Royal Institution August 2025* (Principium 51 November 2025 page 27 https://i4is.org/principium-51/).
This year Rob Swinney and John I Davies of i4is were ably assisted by Aditi Singh, KCL Space, a first year physics student at Kings College London. We had a 12-14 year age group on the first day and a 15-18 year age group on the second day.

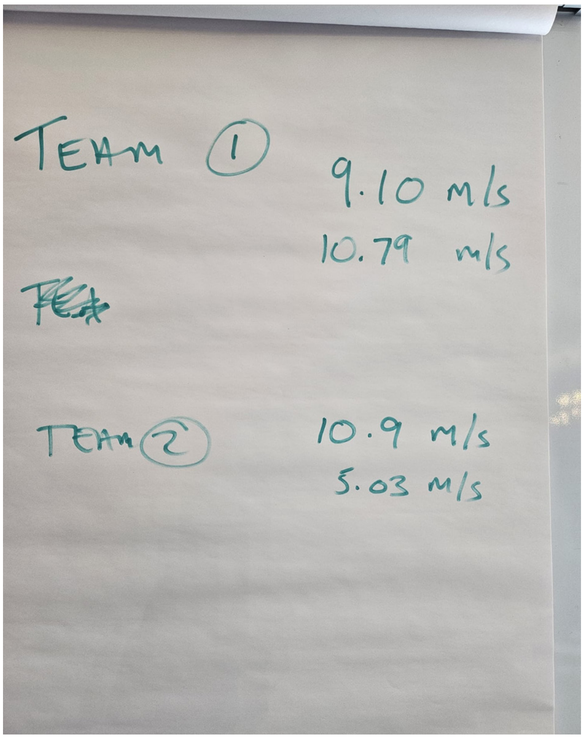
Here's the team on the second day:

Richard Marshall, our Royal Institution organiser, with Aditi Singh, Rob Swinney and John Davies.

Here are the results of our famous "balloon exhaust velocity" experiment for the two days:



We had four teams in the 12-14 years age group and teams 1, 2 and 4 produced results.



We had fewer students in the 15-18 years age group so just two teams. Team 2 had some complications with their second balloon run!

Rob telling the two 15-18 teams about the laser fusion experiment at the US National Ignition Facility. This year we delivered our workshops in the beautiful RI Library.

It was great to be back at the RI again. As always the staff were very helpful. i4is has been delivering workshops for school students *Skateboards to Starships* since 2018. We hope to be invited back for the August Summer Schools this year and for many more years to come!

Mission to an Interstellar Object

Originally published on our blog on 5 May 2026:
https://i4is.org/mission-to-an-interstellar-object/

Adam Hibberd

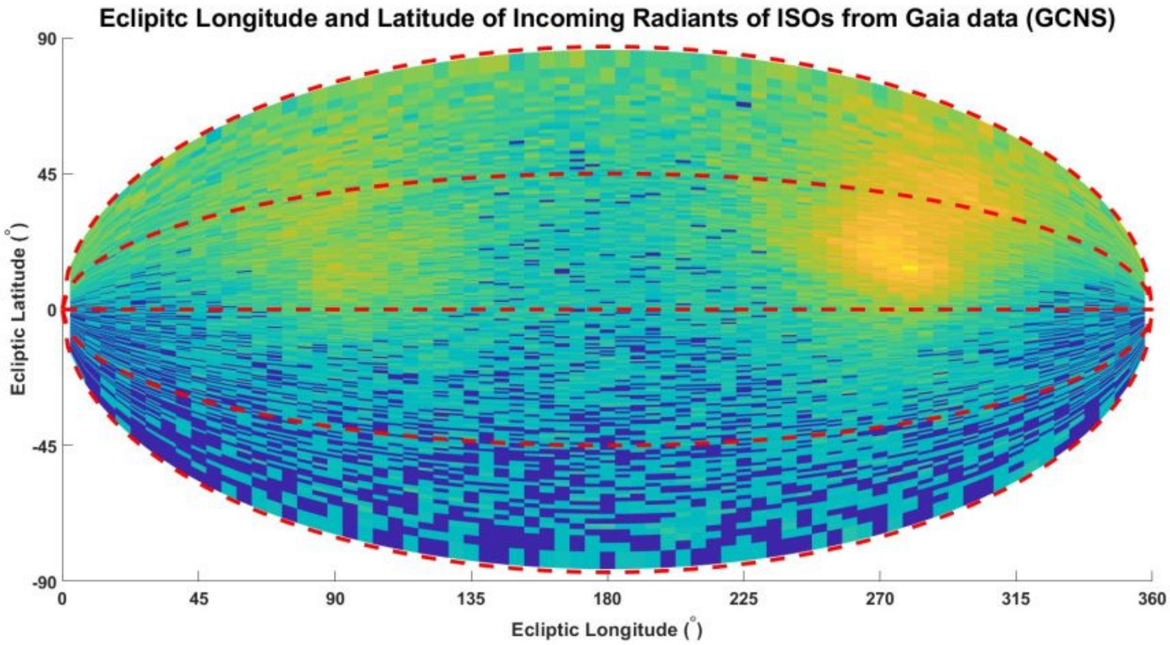
Many readers in-the-know will have heard of the future ESA 'Comet Interceptor' (CI) mission, due to launch in 2029. For those not-in-the-know it is a spacecraft designed to loiter at the famous Sun/Earth Lagrange 2 (S/E L2) point for a few years, waiting for a 'pristine' Oort Cloud comet to come flying in to the inner Solar System and approach close to the Sun. When a suitable target can be identified - probably by the famous Vera C Rubin telescope in Chile and 'suitable' in the sense that it is reachable by the CI (ie, its ΔV requirement is below a threshold for the spacecraft) - then the CI will be dispatched at the proper moment to intercept the comet and study it up close.

All very well and good, but what relevance is this to interstellar travel? Well it seems a secondary target for this spacecraft may be a convenient approaching interstellar object (ISO). But how likely will an interstellar object be reachable by the CI architecture? The answer is quite a reality check and is along the lines of 'not many, if any'! For instance it was discovered that the interstellar object, 3I/ATLAS, would have been infeasible for the CI architecture (at least in its current form and with current ΔV budget which corresponds to 'oomph from the rocket').

Stimulated by a conversation with a US colleague I decided to have a go at finding the chances.
I assumed that the spacecraft would be loitering somewhere along the Earth's heliocentric orbit around the Sun at 1 AU from it. This is clearly different from the S/E L2 point which is about 1.5 million km further out from the Sun than the Earth. The reason for this change of orbit was simply that our own proposed mission architecture under investigation demanded it.

The first problem was to model the incoming ISOs which I did with the '*Gaia Catalogue of Nearby Stars*' [1], a huge database of stars in the vicinity of the Sun, specifically using their velocities relative to the Sun in Galactocentric co-ordinates. With this data I could derive the distribution of the so-called 'incoming radiants' of ISOs, and this is shown in the plot on the next page.

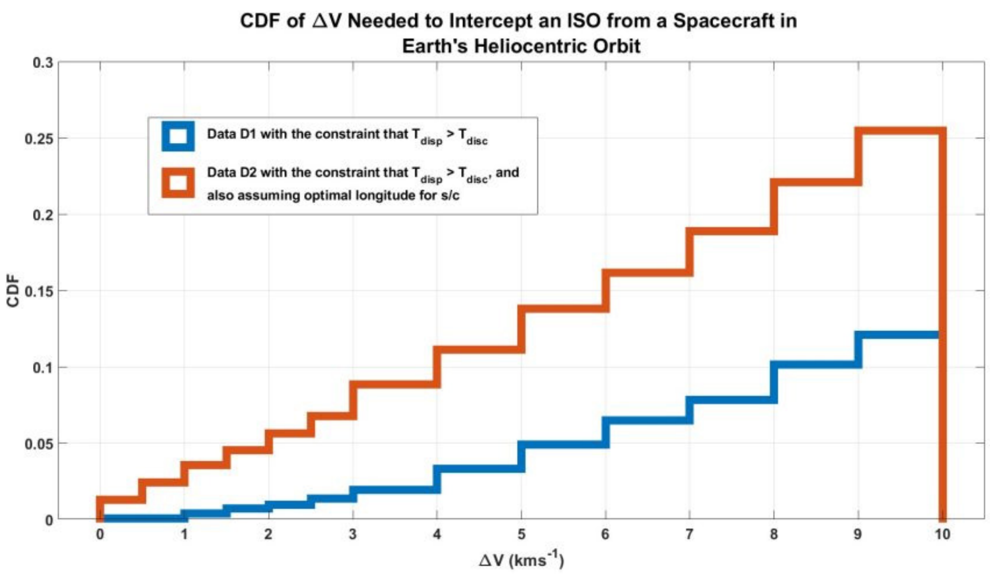
[1] https://www.gaia.ac.uk/science/observation/gaia-catalogue-of-nearby-stars/

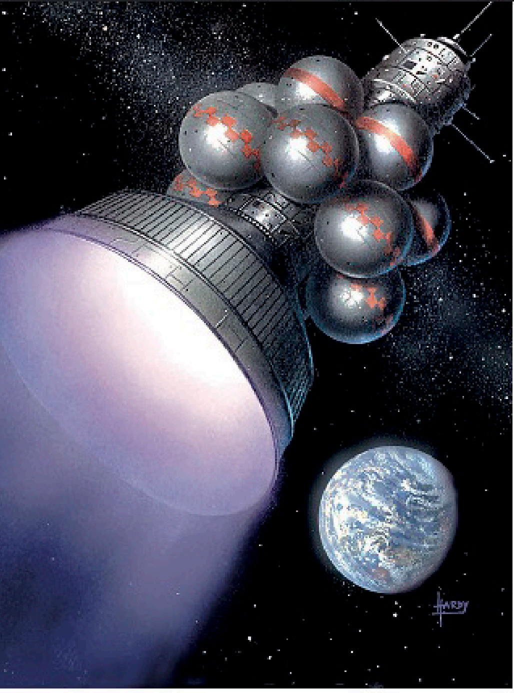


Having computed this distribution, I could then model the orbits of incoming ISOs as required. My software generated 10,000 ISOs and generated Data D1 and Data D2:

- Data D1: The spacecraft is randomly and uniformly distributed in longitude around Earth's heliocentric orbit, what is the probability that the ISOs can be intercepted (blue data in graph below).
- Data D2: The ISOs are hurled at the inner Solar System as in D1, but the spacecraft are positioned longitudinally precisely on the optimal longitude to allow the spacecraft to intercept the ISO with minimum ΔV (red data below).

These two datasets are shown in histogram form in the plot below, and perhaps unsurprisingly, the optimally placed probe would be able to reach far more ISOs (the red data), than the randomly placed probes (blue data). The results don't look great for the CI architecture but the potential for this plan is very good, since if optimally placed with an allowable ΔV budget of < 1 km/s, the probability of interception is ~ 2.5 % compared to ~ 0 % for CI. The idea then is that if we had sufficient probes orbiting the Sun at 1 AU, we could increase the success probability quite significantly.





John I Davies & Gill Norman report on recent developments in interstellar studies

IAU Focus Meetings at the 2027 IAU General Assembly

Many congratulations to T Marshall Eubanks and W Paul Blase (Space Initiatives Inc, USA) who proposed '*Interstellar Objects in the Time of the Rubin LSST*' [1] to the International Astronomical Union (IAU) [2]. The IAU Executive Committee has approved this as one of twelve IAU Focus Meetings to be held during the 2027 IAU General Assembly in Rome, Italy [3]. IAU Symposia and Focus Meetings are "at the very core of the IAU's scientific activities" and they have described the proposal "excellent and exciting". See the list of Scientific Meetings here: https://www.iau.org/Iau/News/Ann2026/IAU-Scientific-Meetings-2027.aspx.

Propulsion Options for the Solar Gravitational Lens Mission

A recent post by Paul Gilster caught our eye and can be viewed here on his excellent Centauri Dreams site:
https://www.centauri-dreams.org/2026/02/17/propulsion-options-for-the-solar-gravitational-lens-mission/.
"A mission to the Sun's gravity focus – or more precisely, the focal 'line' we might begin to use at around 650 AU – is never far from my mind. Any interstellar mission we might launch within the next thirty years or so (think Breakthrough Starshot, about which more next week) will essentially be shooting blind. We have little idea what to expect at Proxima Centauri b, if that is our (logical) target. But a mission to the solar gravity focus (SGL) would give us a chance to examine any prospective target at close hand. Indeed, so powerful are the effects if we can exploit this opportunity that we should be able to see continents, weather patterns, oceans and more if we can disentangle the Einstein Ring that the planet's image forms as shaped by general relativity. We've discussed the phenomenon many a time: the Sun's gravitational well so shapes the image of what is directly behind it as seen from the SGL so as to produce stupendous magnification, the image served up as a 'ring' around the Sun in the same way that astronomers now see some distant galaxies as rings around closer galaxies."

[1] The Rubin LSST: The Vera C Rubin Observatory's Legacy Survey of Space and Time, https://rubinobservatory.org/news/visitors-from-distant-stars

[2] https://www.iau.org/

[3] https://iaurome2027.org/

Broadband SETI: a New Strategy To Find Nearby Alien Civilizations

Ben Zuckerman (University of California, USA) has published "*Broadband Searches for Extraterrestrial Technological Intelligence: a New Strategy To Find Nearby Alien Civilizations*" (see https://arxiv.org/abs/2603.07333). One of the most interesting questions that astronomy can hope to answer is: are we alone in our Milky Way galaxy? A detection of an electromagnetic (EM) signal generated by an extraterrestrial technological intelligence (ETI), or the presence in our Solar System of an alien probe, would answer this question in the negative. Purposeful interstellar communication is a 2-way street - the transmitting and receiving technological intelligence (TI) both need to do its part. As the receiving TI, our EM search programmes should incorporate a model of what a transmitting TI is likely to be doing. Published searches for extraterrestrial technological intelligence (SETI) have generally not done so and, thus, have often been sub-optimally designed. They propose an improved search technique that more closely corresponds to astronomical surveys that have been undertaken for reasons that have nothing to do with SETI. Published non-SETI radio and optical surveys are sufficiently extensive that they already supply meaningful constraints on the prevalence of nearby purposely communicative alien civilizations. Purposeful communication can also include the sending of spaceships (probes). The absence of evidence for alien probes in the Solar System suggests that no alien civilization has passed within 100 light-years of Earth during the past few billion years.

2nd European Interstellar Symposium: Call for Papers

The Interstellar Research Group (https://irg.space/) have announced that the Call for Papers is now open for the 2nd European Interstellar Symposium, taking place in December 2026, in Venice, Italy. Hosted by the Venetian Institute of Sciences, Letters and Arts in association with the Interstellar Research Group and the International Academy of Astronautics, [1] this symposium will bring together an interdisciplinary community focused on the future of interstellar exploration.

Abstract Submission Deadline: 31 July 2026
Notification of Abstract Acceptance: 15 September 2026
Symposium Dates: 2 to 4 December 2026

To learn more, please visit the symposium page:
https://irg.space/second-european-interstellar-symposium/
Abstracts should be submitted to Registrar@irg.space.

[1] https://iaaspace.org/

What Is Space Bioethics?

Maurizio Balistreri (University of Tuscia, Italy) has published this paper: https://onlinelibrary.wiley.com/doi/10.1111/bioe.70082. Classical bioethics examines moral issues in terrestrial medicine and the life sciences. According to Konrad Szocik [1], space bioethics merely relocates those questions to harsher environments. They argue that this view is incomplete: space bioethics is a genuinely original domain. Unprecedented conditions – chronic radiation exposure, partial gravity, closed ecologies, long communication delays, and severe resource constraints – reconfigure risk and responsibility. Survival-oriented interventions – human bio-enhancement, human-machine integration, germline editing for adaptation and off-world reproduction (potentially via ectogenesis) – pose dilemmas with no close terrestrial analogue. Moreover, some technologies may be developed and adopted in space before diffusion to Earth, generating ethical challenges in advance. These scenarios strain the portability of standard moral norms and cannot be addressed by simply importing frameworks from military or extreme-environment medicine.

Toward extraterrestrial librarianship: Designing knowledge systems for human settlements in space

Dattatraya Kalbande has published a paper in the Journal of Space Safety Engineering. As humanity moves closer to establishing settlements beyond Earth, libraries must be reconceptualized as autonomous, adaptive, and ethically grounded systems that support human survival, learning, and cultural continuity in extraterrestrial environments. This paper presents a conceptual framework for "extraterrestrial librarianship," integrating insights from space science, digital preservation, human-computer interaction, and Library and Information Science (LIS). The proposed three-layered model - Sensing, Processing, and Interaction - guides the design of space libraries capable of functioning under extreme conditions such as microgravity, radiation, communication latency, and social isolation. Comparative and functional analysis tables distinguish traditional Earth-based libraries from their space counterparts and map practical use-cases ranging from mental health support to conflict mediation. The paper expands the librarian's role into that of a knowledge architect, ethical curator, cultural diplomat, and emotional support agent. Through speculative yet grounded scenarios - including Martian knowledge pods, bio-encoded interstellar archives, and zero-gravity VR story lounges - the study demonstrates the transformative potential of libraries in future space civilizations. It affirms that wherever humans venture, libraries will remain critical infrastructure for preserving memory, fostering identity, and sustaining civilization beyond planetary boundaries. The full paper is behind a paywall, however extracts from the paper can be read here: https://www.sciencedirect.com/science/article/abs/pii/S246889672600039X.

[1] Konrad Szocik, University of Information Technology and Management, Poland
https://www.researchgate.net/profile/Konrad-Szocik

The Jevons Filter: Why Civilizations May Fail Before Reaching Type I Status

Giray Fidan (Ankara HBV University, Turkey) presents this interesting proposition: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=6090866.
Humanity's accelerating energy use poses profound questions about the long-term viability of technological civilization. This paper introduces the "Jevons Filter" hypothesis: a self-reinforcing feedback loop between efficiency improvements and rising aggregate consumption, rooted in the classical Jevons Paradox that systematically drives civilizations toward resource depletion and environmental thresholds. Drawing on economic history, thermodynamic modelling, and astrobiology, they argue that this feedback constitutes a critical developmental barrier, hindering sustainable progression toward Kardashev Type I [1] energy mastery. By amplifying the risks of overshoot, the Jevons Filter may form part of the Great Filter proposed to account for the Fermi Paradox. They develop a simplified thermodynamic model linking energy efficiency, economic expansion, and civilizational dynamics, and critically engage with counterarguments regarding absolute decoupling and transformative technological innovations. Their analysis suggests that, without fundamental structural transformations to break the growth consumption cycle, civilizations are likely to face collapse or stagnation before reaching stable, planetary-scale energy management. Grasping this embedded dynamic is essential for futures thinking: overcoming the Jevons Filter may represent an exceptionally rare and difficult pathway, requiring sweeping reorientations in socioeconomic priorities, governance frameworks, and cultural values. This paper emphasizes the implications for sustainability transitions and reframes planetary stewardship as a central determinant of civilizational longevity.

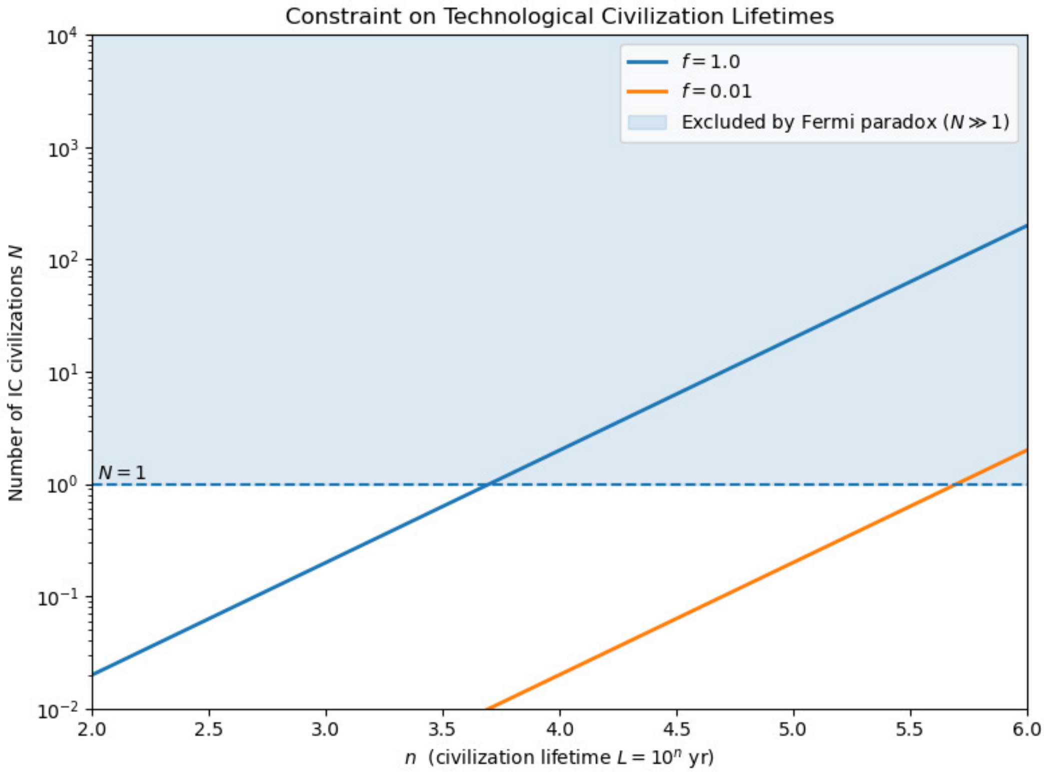
Dami Lee on Project Hyperion

We were really happy to see that our Project Hyperion competition captured the imagination of the architect and Youtuber Dami Lee, who posted a detailed and thoughtful video commentary 'Can Humans REALLY Leave Earth?' Over one million views! Check it out: https://m.youtube.com/watch?v=BBb2gC0lByk&pp=0gcJCVACo7VqN5tD.
(You may want to skip the ads that are part of the video from 13.00 to 14:30).

[1] Kardashev Type I civilisation, see, eg, https://en.wikipedia.org/wiki/Kardashev_scale

Constraining the Lifespan of Intelligent Technological Civilization in the Galaxy

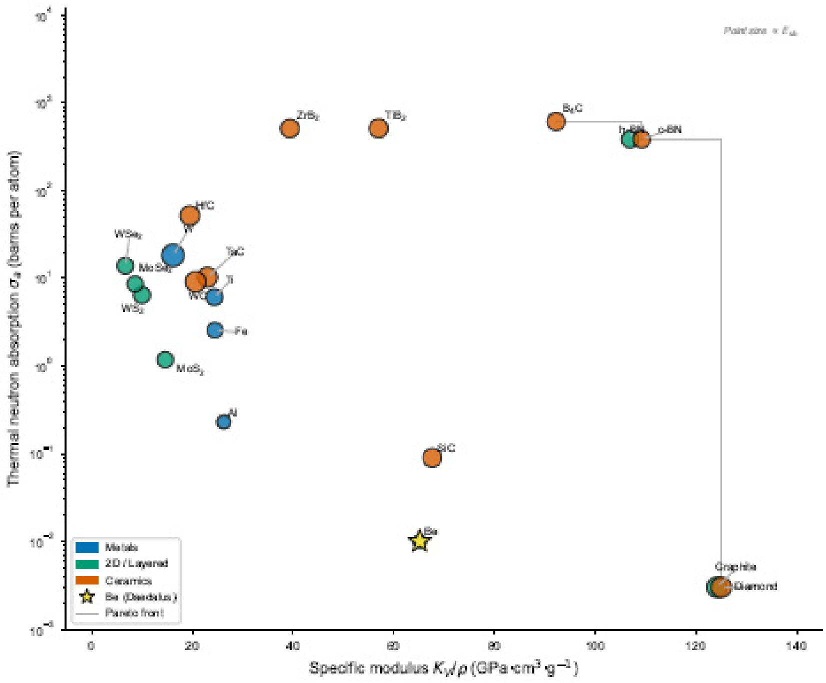
Sohrab Rahvar and Shahin Rouhani (Sharif University of Technology, Iran) have released this paper exploring constraints on the emergence and longevity of technologically intelligent civilizations in our Galaxy, considering the Fermi paradox: https://arxiv.org/abs/2602.22252 (also published in the Monthly Notices of the Royal Astronomical Society). They argue that under optimistic assumptions about the probability of life and intelligence emerging on Earth-like planets, the absence of contact with extraterrestrial civilizations imposes limits on their lifespan. Their analysis suggests that if intelligent life is common, technological civilizations must be relatively short-lived, with lifetimes constrained to years under their most optimistic scenario. Considering electromagnetic communication, they note that our current light cone encompasses the entire Galactic history over the past years, making the lack of detected signals particularly puzzling for long-lived civilizations. They emphasize that these results should be interpreted as upper bounds derived from the Fermi paradox, not as predictions of actual lifespans.



Constraint on the lifetime $L = 10^n$ of intelligent technological civilizations derived from the Fermi paradox. The expected number of co-existing civilizations N is shown as a function of the civilization lifetime for different assumptions about the probability f that a habitable planet produces a technological civilization. The shaded region corresponds to values for which $N \gg 1$, which are observationally excluded by the absence of detected extraterrestrial civilizations. The dashed line indicates the boundary $N = 1$ and is shown for reference.
Credit (graphic and caption): S Rahvar and S Rouhani, Figure 1

Beyond Beryllium: AI-Accelerated Materials Discovery for Interstellar Spacecraft Shielding

Yue Li (Nanyang Interstellar University, Singapore) et al have published this paper on materials for interstellar spacecraft shielding. Project Daedalus (1973–1978), the most detailed interstellar probe design study ever conducted, specified a 9 mm beryllium erosion shield to protect the spacecraft payload during its 5.9 light-year cruise to Barnard's Star at 12% of the speed of light. This design, however, predated both the isolation of two-dimensional materials and the development of graph neural network (GNN) property predictors. The authors systematically screen 20 candidate materials—spanning conventional aerospace metals, transition metal dichalcogenides, and ultra-high-temperature ceramics—using density functional theory (DFT) data from the JARVIS database (76,000 materials) with independent validation by the Atomistic Line Graph Neural Network (ALIGNN). They evaluate candidates across four criteria: specific mechanical stiffness (K_V / ρ), sputtering resistance, thermal neutron absorption cross-section, and thermodynamic stability. Their screening identifies hexagonal boron nitride (h-BN) and boron carbide (B_4C) as dual-function materials offering simultaneous mechanical protection and neutron radiation shielding, and they propose a graphene/h-BN/polymer layered heterostructure shield design that achieves an estimated 47% mass reduction relative to the original beryllium specification. These findings will become immediately actionable upon the successful development of fusion pulse propulsion; they note that this remains an outstanding engineering challenge. See the paper here
https://arxiv.org/abs/2604.00571.



Multi-objective screening: specific modulus versus thermal neutron absorption cross-section. Point size is proportional to surface binding energy. Staircase line indicates the Pareto front. The gold star marks beryllium (Daedalus baseline). Credit (graphic and caption): Li et al, Figure 4

Civilization Supply Theory (CST): Supply Chain Constraints on Interplanetary and Interstellar Expansion

Michelle Cannon (independent researcher) introduces Civilization Supply Theory (CST), a framework for understanding the constraints governing the expansion and long-term survivability of technological civilizations. CST models civilization as a distributed supply network rather than a collection of independent nodes, emphasizing the necessity of supply chain closure for sustained operation. The theory proposes that only systems achieving full internal supply chain closure (Level 1 nodes) can maintain technological continuity without regression. Partial or prebuilt systems, including autonomous or AI-driven colonies, may extend operational lifetimes but remain subject to eventual degradation due to incomplete supply chains and cumulative failure. The model further demonstrates that over sufficiently long timescales, including cosmological scales, any system lacking full closure will experience regression with probability approaching one. This provides a potential explanation for the absence of persistent, large-scale, autonomous technological systems in observed space (Fermi paradox context). CST is substrate-independent and applies equally to biological and autonomous systems, suggesting that expansion is constrained not by energy alone, but by the ability to establish and maintain distributed, self-sustaining supply networks.
View the paper here: https://zenodo.org/records/19422196.

Colony Success/Failure Index (fs) Trajectories Over Time — three outcome paths under varying supply chain conditions. Credit (graphic and caption): Cannon, Figure 2

The Dyson Minds 2025 Workshop: SETI Around Black Holes

Olivia Curtis (The Pennsylvania State University, USA) et al have authored a paper in the Publications of the Astronomical Society of the Pacific. See https://iopscience.iop.org/article/10.1088/1538-3873/ae5a02.

The Dyson Minds 2025 Workshop, held at the Center for Brains, Minds & Machines at Massachusetts Institute of Technology (MIT) and organized by Penn State, MIT, and The Ultraintelligence Foundation, brought together researchers in astrophysics, engineering, artificial intelligence, computer science, and philosophy to examine "Dyson Minds"—large-scale post-biological intelligences powered by energy harvested from supermassive black holes (SMBHs). Building on the ideas of Dyson [1] and Good [2], participants explored the physical, engineering, behavioural, and observational consequences of civilizations embodied as machinery operating near the universe's most powerful energy sources. The workshop aimed to develop new observational strategies capable of detecting signatures of such systems. Despite the highly cross-disciplinary scope, discussions centred on how a Dyson Mind might be constructed, how it might behave, and how those factors would shape strategies for the search for extraterrestrial intelligence. Key themes included the thermodynamic, mechanical, and stability limits of Dyson swarms; the trade-offs between power availability and communication latency in distributed minds; and how observability changes depending on whether Dyson Minds act as coherent entities or as loosely co-ordinated collectives. Across these topics, the consensus was that details of architecture and behaviour strongly influence observational signatures. A major recommendation was to apply anomaly-detection methods to archival datasets, including those from Wide-field Infrared Space Explorer, JWST, and the Event Horizon Telescope, to identify unusual sources potentially overlooked by standard reduction pipelines. By integrating insights from multiple disciplines, the meeting advanced concrete, observation-focused strategies for future technosignature searches around SMBHs.

Thermal adaptability and low-power survival-operation strategies for lithium batteries in deep-space cryogenic environments

As deep-space exploration transitions from short-term flybys to long-term residency, spacecrafts energy systems face severe challenges from extreme cryogenic environments typical of lunar nights. High-specific-energy lithium batteries are critical enablers, yet their adaptability is constrained by low-temperature limitations. This paper reviews thermo-electrochemical failure mechanisms and survival-operation synergistic strategies for lithium batteries in these environments.

[1] Physicist Freeman Dyson https://en.wikipedia.org/wiki/Freeman_Dyson.

[2] Mathematician Isadore Jacob Good https://en.wikipedia.org/wiki/I._J._Good.

First, critical failure modes are elucidated, including hindered mass transfer during electrolyte phase transitions, kinetic polarization, anode plating risks, and multiscale thermal stress. Subsequently, temperature maintenance technologies for the operation state are evaluated, focusing on the heat transfer limits of passive thermal protection systems like multi-layer insulation, aerogels, and phase-change materials. Furthermore, the review emphasizes low-power hibernation for the survival state, validating the energetic advantages of freeze-thaw cycles. It addresses electrolyte freezing safety in confined pores and rapid revival mechanisms based on internal Joule heating. Finally, a mission-cycle-based survival-operation thermal management model is proposed, and key scientific challenges regarding confined phase transition thermodynamics and non-equilibrium revival damage are identified. The full paper is behind a paywall, however extracts from the paper can be read here:
https://www.sciencedirect.com/science/article/abs/pii/S2405829726002424.

How to evaluate Breakthrough Starshot?

Paul Gilster and his Centauri Dreams blog has published a two-part analysis of the consequences of the Breakthrough Starshot initiative, penned by James Benford. Whilst some of the press coverage has discounted the project, these articles highlight the achievements and accomplishments.

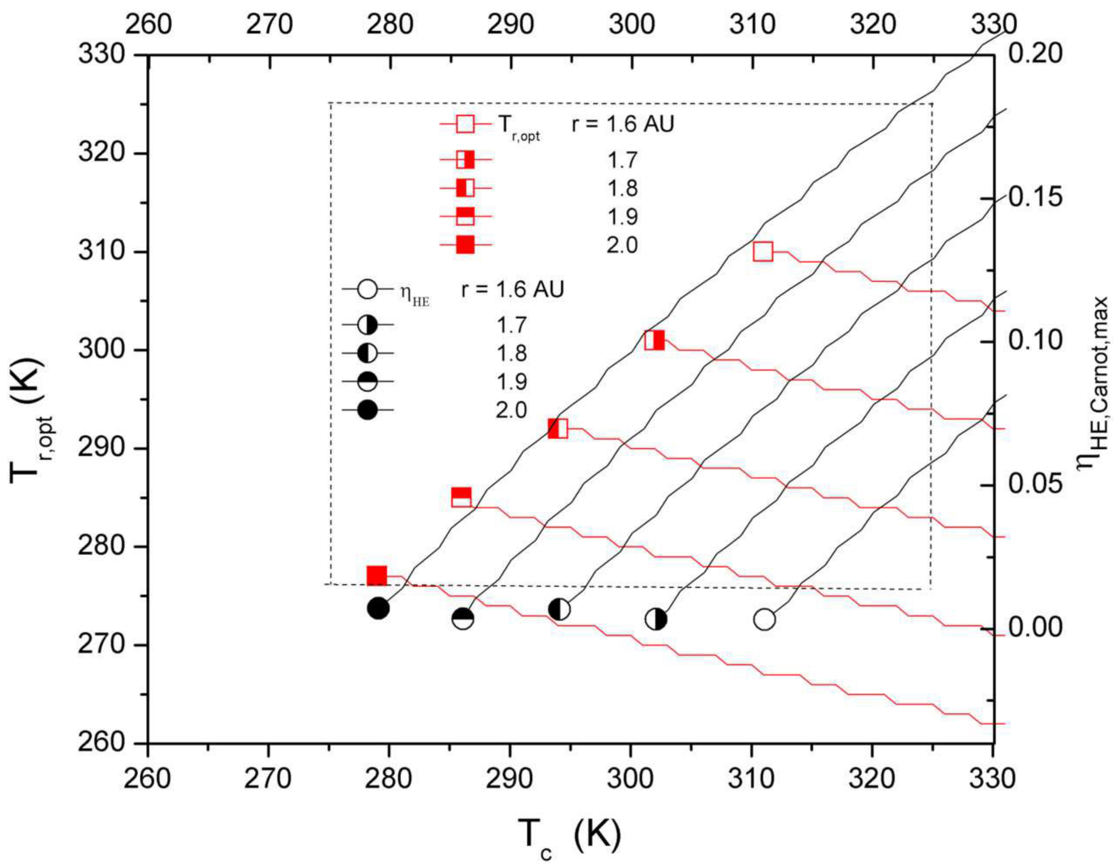
"The fortunes of Breakthrough Starshot have been the subject of so much discussion not only in comments in these pages but in backchannel emails that it is with relief that I turn to Jim Benford's analysis of a project that has done significant work on interstellar travel and is still very much alive. Jim led the sail team for several of his eight years with Breakthrough Starshot and was with the project from the beginning. In this article and a second that will run in a few days, he explains how and why press coverage of the effort has been erroneous, and not always through the fault of writers working the story. Let's now take a look at what Starshot has accomplished during its intensive Phase I."
https://www.centauri-dreams.org/2026/03/03/starshot-is-a-success-part-i/.

"The second part of Jim Benford's examination of Breakthrough Starshot concludes our look at the numerous issues advanced by Phase I of the project. Largely discounted in recent press coverage, the Starshot effort in fact completed a successful Phase I and left behind numerous papers that illuminate the path forward for interstellar flight. This is solid work on everything from laser arrays to metamaterials and the engineering of data return at light-year distances. Read on."
https://www.centauri-dreams.org/2026/03/10/starshot-is-a-success-part-ii/.

Feasibility constraints and detectability of habitable class B stellar engines at maximum performance

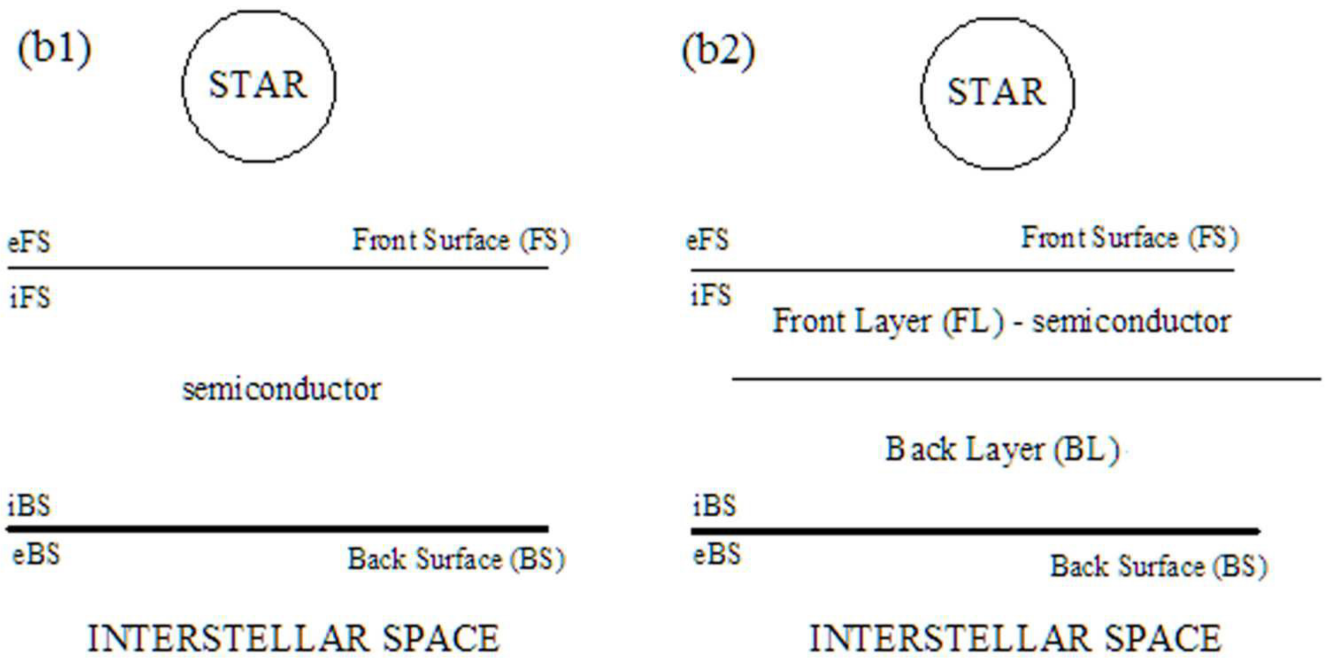
IOP Publishing has released a paper by Viorel Badescu (University Politehnica of Bucharest, Romania); see https://iopscience.iop.org/article/10.1088/1402-4896/ae4a5c.

Class B stellar engines (SEs) are hypothetical megastructures designed to collect the entirety of the radiation emitted by a star and transform its energy into mechanical, electrical or chemical work. This paper has two different objectives. First, a theory is proposed regarding the feasibility of building a class B SE. Second, based on the hypothesis that such class B SEs already exist in our galaxy, information is provided about their detectability. Numerical applications refer to the case of the Solar System and humanity for which the habitable temperature is restricted to an interval between 275 K and 325 K. It is shown that different mechanisms of work generation are involved for SEs based on metals and semiconductors (specifically silicon), respectively. The efficiency of mechanical work generation increases with the radius of a metal-based SE radius but the temperature remains habitable only for radii ranging between 1.6 AU and 2.0 AU, for which the radiation energy conversion efficiency is lower than 10%.



Dependence of the radiator temperature $T_{r,opt}$ and Carnot heat engine efficiency $\eta_{HE,Carnot,\,max}$ on the collector temperature T_c for several values of the class B stellar engine radius r. Values of T_c in the range of habitable temperatures $T_{habitable}$ are considered. The dashed area corresponds to habitable temperatures for both collector and radiator. The case of the solar system is considered (T_s = 5772 K, R_s = 696340 km) and T_0 = 3 K.
Credit (graphic and caption): Badescu, Figure 2

Conversely, very high quality silicon-based SEs can generate electrical work. In this case, the conversion efficiency decreases as the temperature and radius of the SE increase. When lower quality silicon cells are used, another layer of metallic material should be added as a broadband radiation emitter toward the interstellar space. In this configuration the SE is habitable for radii ranging between 1.0 AU and 2.2 AU. For a given radius, a maximum conversion efficiency exists, which is associated with the minimum cell temperature required for SE operation. The maximum efficiency value increases slightly with the SE radius. The search for class B SEs should focus on a 10 µm IR thermal signature. Continuous non-thermal signals peaked around the band gap energy of common semiconductors should be also sought. A class B SE engine composed of a large swarm of satellites or O'Neill cylinders may possess a distinct spectral and temporal signature, consisting of non-continuous and irregular thermal and non-thermal contributions received from the star and from the inner and outer surfaces of the SE.



Two configurations of a class B stellar engine generating electrical power; (b1) a semiconductor layer acts as star radiation collector, electrical work extractor and radiation emitter; (b2) a semiconductor front layer (FL) acts as star radiation collector and electrical work extractor, while a back layer (BL) of material serves as a broadband radiation absorber and emitter. Prefixes i and e denote 'internal' and 'external' , respectively.
Credit (graphic and caption): Badescu, Figure 4

The Initiative & Institute for Interstellar Studies

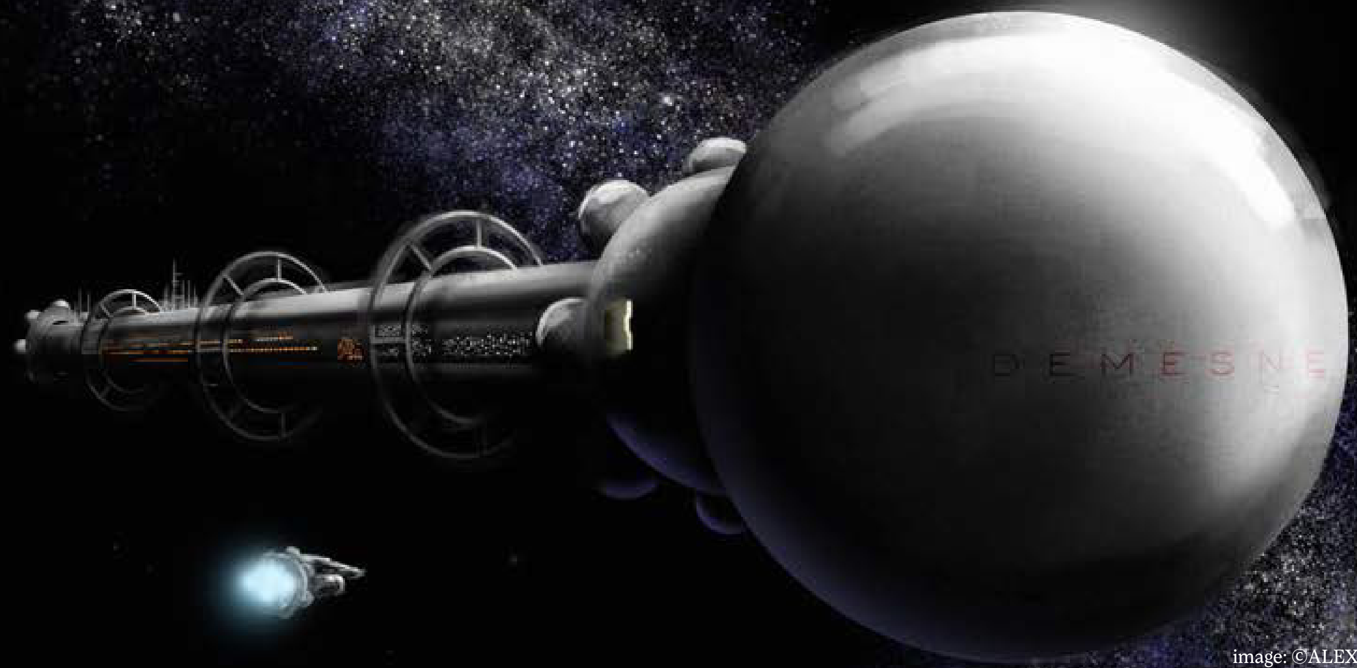


image: ©ALEX STORER

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The Journals

John I Davies

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

JBIS

Five issues of JBIS have appeared online since our last issue, P52. They are – volume 79 issues #1 (January 2026) to #5 (May 2026). Of these issues, one was an Interstellar issue.

Volume 79 #2 February 2026 Interstellar

Ultra-Long Wave Civilization Filter: a Selective Approach to Interstellar Communication	Victor Zames	-

For decades, SETI projects have searched for extraterrestrial signals primarily in the centimetre and decimetre wave ranges. These searches implicitly assume that technologically advanced civilizations would broadcast in easily detectable bands. This paper proposes an alternative: the use of ultra-long waves (ULW), with wavelengths from hundreds of thousands to millions of kilometres, as a civilization filter — a deliberate physical and socio-technological barrier ensuring that only unified, interplanetary civilizations can detect and decode the signal. Such a model not only introduces a technological threshold but also an ethical safeguard, reducing the risk of premature or destabilizing contact. The ULW approach offers a potential explanation for the absence of detected signals despite decades of observation, suggesting that our current SETI strategies may systematically overlook a possible primary contact channel.

Laser-ZPE Interstellar Propulsion Revisited	Gregory L Matloff	USA

Obtaining useful energy from universal vacuum fluctuations is a very controversial topic. Recently, Casimir Space, a US startup, has announced the development of a chip that seems to produce a small amount of continuous, net Zero Point Energy (ZPE). This may be the first time that ZPE has been quantified. Although replication of this feat by other laboratories has not yet been reported, a useful exercise is to investigate the potential application of ZPE to interstellar travel. Here, ZPE is assumed to pump a large laser or laser array as the propulsion system of an interstellar generation ship. Apparently, such an approach as the primary propulsion system yields performance equivalent to that of fusion rockets or Sun-diving photon sails on voyages to the nearest extra-solar stars. But the ZPE laser, if it is feasible, can serve as a second acceleration stage and, if used continuously, can shorten voyage duration to more distant stars. This technology may allow the ultimate development of space habitats within the Oort Cloud, far from any source of radiant stellar energy.

Toward a Physics of the Ceiling: Structural Limits on the Evolution of Advanced Civilizations and the Emergence of Compact Final Forms	H Lapczynski	-

The classical Kardashev scale assumes that energy harvesting and spatial expansion can increase indefinitely. This assumption is incompatible with several universal physical constraints. In this work, we show that three minimal ingredients – (H1) finite propagation speed, (H2) attractive gravity with a compactness threshold, and (H3) the existence of a cosmic horizon-combined with information-theoretic and gravitational bounds (the Bekenstein limit and the gravitational radius) impose a finite admissible radius window $[R_{min,}, R_H]$ for any advanced civilization. Within this window, information, gravity, causality, and thermodynamics jointly impose a structural ceiling that prevents unbounded extensive expansion and drives sufficiently advanced civilizations toward compact, optimized hollow configurations. Building on this structural framework, we introduce a simple parametric model in a ΛCDM (Lambda Cold Dark Matter) universe that incorporates (i) construction logistics through an effective expansion velocity v_{eff}, (ii) finite cosmological lifetime through a remaining time T_{tot}, (iii) energy availability through an effective density ρ_{eff}, and (iv) the requirement of energetic autarky. Maximizing the total number of logical operations achievable over T_{tot} yields a distinct internal optimum radius $R_{opt} < R_{ceil} < R_H$, strictly below both causal and structural bounds. Taken together, the structural ceiling and the internal computational optimum provide a unified, physics-based reinterpretation of long-term civilizational evolution. The framework predicts that the most advanced civilizations should be faint, cold, compact, radiatively closed, and detectable primarily through negative observational signatures.

Optimal Energy and Resource Distribution in Kardashev Type III Civilizations	Erotokritos Skordilis	USA

In 1964, Nikolai Kardashev introduced a method for quantifying advanced extraterrestrial civilizations based on their energy production into three levels, namely planetary (Type I), stellar (Type II), and galactic (Type III). Since then, multiple studies have proposed megastructures for producing the amounts of energy required to reach Type II and III levels. This empirical study presents a decision-making framework that optimizes the resource utilization required to elevate an interstellar civilization to a Type III status, focusing on maximization of energy production and computation. Numerical simulations were based on a synthetic galactic environment, where a multidimensional action space incorporating a variety of megastructure construction decisions was considered. The results suggest that a Milky Way-sized galaxy can be fully converted into such an environment within ~1.3 Gyrs.

Mapping the Galactic Biosphere: A Fokker-Planck Approach to the Stochastic Distribution of Life	Elio Quiroga Rodriguez	Spain

This paper presents a stochastic model to estimate the probability of finding life in our galaxy using partial differential equations. The proposed stochastic equation, based on the Fokker-Planck equation, models the probability density function of the existence of planets with life in different star systems over time, modelling the variability and uncertainty in the emergence of life in three-dimensional space. The approach combines concepts from thermodynamics, statistical mechanics and astrobiology to address the complex question of the search for extraterrestrial life.

Consciousness Bandwidth and Frequency Orthogonality: An Energy-flux resolution to the Fermi Paradox	Bo Zhang	China

The "Great Silence" of the Fermi Paradox is conventionally attributed to the scarcity of extraterrestrial intelligence (ETI) or the insurmountable barriers of spatial distance. This paper challenges these sociological and spatial assumptions by proposing a physical framework based on non-equilibrium thermodynamics and signal processing theory. It is posited that human perception is confined by "Scale Geocentrism," a bias presupposing that intelligence manifests exclusively within mesoscale timeframes and chemical energy levels. By establishing a positive correlation between environmental energy flux (ΦE) and the coupling frequency (fc) of biological consciousness, a spectrum of life is constructed, spanning from high-frequency entities dominated by nuclear forces to ultra-low-frequency structures dominated by gravitation. Applying the Shannon-Nyquist sampling theorem, it is demonstrated that signals from these "ultrafast" or "ultraslow" civilizations are mathematically orthogonal to the human perception bandwidth (1,100 Hz). Consequently, these signals manifest as thermal noise or static physical background respectively. The paper concludes that the universe is not silent; rather, the detection bandwidth of current SETI methodologies is insufficiently tuned to demodulate the multi-scale cosmic symphony.

Volume 79 #3 March 2026 General issue

Orbit to Interstellar: A Kevlar Tether Deployment System	Douglas DeCandia	-

This paper presents a design for multi-target, unguided probe deployment from Low Earth Oribt (LEO) using commercially available materials. The model consists of multiple, 1 kg payloads mounted at the tip of 1,000 metre (1 km) rotating arms constructed from commercially available Kevlar. At 75.5 RPM, the tip velocity reaches 7.91 km^{-s}, more than sufficient for Earth escape velocity at LEO. We analyze stress distribution, axial load, and material constraints, confirming that Kevlar remains within tensile limits under optimized conditions for escape velocities once in LEO. The design offers a scalable, reusable companion to chemical propulsion, with implications for orbital logistics and interplanetary missions. The analysis shows that high-performance deployment systems can be constructed using conventional, low-cost, available materials and technologies, opening new pathways for high-efficiency space payload deployment and scientific research.

Giant Planet Lagrange Points L2 as Locations for Photon Sail Manufacturing Facilities	Gregory L Matloff	USA

Interstellar exploration or colonization ventures by humans will be major undertakings that will likely require utilization of solar system resources. If photon sailing by Sunlight using Sun-diving manoeuvers or propulsion by beamed lasers/masers is the preferred method of interstellar travel, it may be necessary to manufacture the required huge and hyper-thin sails in space. An ideal site for a sail manufacturing facility would be permanently shaded from the Sun. This paper investigates planet-Sun Lagrange 2 (L2) points as possible locations for such facilities. Using a simple geometric construction, it is demonstrated that Sun-Venus and Sun-Earth L2 are located in the shadow's penumbra and are therefore not suitable for this application. But giant planet Lagrange 2 points are all within the shadow umbra and are totally shaded from solar irradiation. The estimated diameters of the shaded regions at Sun-Jupiter and Sun-Saturn L2 are both greater than 50,000 km in diameter.

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In Consideration of Artificial Nanoprobes Jet Ejection from the Interstellar Object 3I/ATLAS	Kelvin F Long	UK

The interstellar object 3I/ATLAS achieved perihelion, and then images indicated the presence of large jets in the direction of the Sun of order ~106 km in size. We consider the speculative hypothetical that within these jets may have contained ~5 billion tons of nanograin dust particles, where ~1033-1035 objects are distributed throughout the Solar System that had the function of artificial probes for the purpose of solar system surveillance. To examine this, we look at the likely mass required for such probes, which we consider to be either coupled to the solar magnetic field, <1 nm, ~10^{-23} kg, or drifting ballistic, 10s nm, ~10^{-21} kg. Although this is speculation, if there were nanoprobe ejections, due to the presence of nickel thermal emission and the suggestion of grain heating at large distance, any such probes would likely be nanoscale in size and guided by the solar magnetic field and solar wind outflow once released, fully departing the Solar System on a timescale of order 1 year. This paper is not intended to advocate for an artificial function behind the object 3I/ATLAS but instead should be seen as an exploration for scenario modelling, useful for future speculations with other visiting interstellar objects.

Catching 3I/ATLAS Using a Solar Oberth [1]	Adam Hibberd, Marshall Eubanks, Andreas M Hein	UK USA Luxembourg

The third interstellar object to be discovered, 3I/ATLAS, has a unique and continually unfolding story to tell of its nature and origin as it is monitored by telescopes on Earth and in space. Previous research into missions using chemical propulsion have addressed the direct case, where the opportunity to launch already expired before 3I/ATLAS's discovery. In contrast, investigations herein exploit 'Optimum Interplanetary Trajectory Software' to simulate an indirect option for chemical propulsion, namely the Solar Oberth Manoeuvre (SOM). Thus, a low perihelion burn provides maximum benefit from the Oberth Effect, accelerating the spacecraft rapidly towards the receding 3I/ATLAS. Though in principle feasible, results indicate this presents significant challenges. For launch years between 2031 and 2037 inclusive, a 2035 launch permits the most efficient transfer to 3I/ATLAS. The reference mission requires a SOM at 3.2 Solar Radii from the Sun's centre, with an intercept after 35-50 years. We find the SOM can leverage spacecraft masses up to ~500 kg. Two or three solid boosters could deliver the required SOM ΔV, whilst a refuelled Starship Block 3 in LEO has sufficient performance for such a mission. Also with a SOM, some of the payload mass would be needed for a heat shield to protect against the high solar flux at low perihelion.

[1] The pre-print of this paper was included in our lead feature *Interstellar Visitors to our Solar System,* Principium Issue 52 February 2026 page 6
https://i4is.org/wp-content/uploads/2026/03/Principium-52-Lead-Feature-0203261114.pdf

Acta Astronautica

Acta Astronautica papers are announced online before print. The relevant papers below have appeared since our last issue, Principium P52, which reported announced papers up to the in-progress Volume 238 January 2026, Part B. This issue reports announced papers up to Volume 246 September 2026.

Enrichment of the driving metanarratives shared between SETI and space sustainability through a multispecies lens	Volume 239 Feb 2026	George Profitiliotis

The fields of SETI and Space Sustainability appear to have significant conceptual common ground. This article argues that this cross-fertilization of ideas is the effect of socially-shared nonfictional narratives at work in each of the two fields, which are tacitly driven by the same cross-cutting metanarrative foundations. The article suggests that the scientific communities of SETI and SS utilize such narratives to enable sense-making, decision-making, and action-generation at the collective level, under conditions of radical uncertainty. It then posits that the distinct narratives at work in each of these two fields are implicitly framed and driven by a finite set of four shared metanarratives, whose assumptions are organized on the basis of the following combinations of descriptive and normative (non-)anthropocentrism:
a) descriptive anthropocentrism & normative anthropocentrism;
b) descriptive anthropocentrism & normative non-anthropocentrism;
c) descriptive non-anthropocentrism & normative anthropocentrism; and
d) descriptive non-anthropocentrism & normative non-anthropocentrism.
Despite being less intuitive than the first three, the nascent fourth one is argued to be accessible through a multispecies lens borrowed from adjacent academic bodies of work and is highlighted as very promising for stimulating fruitful dialogue between the two fields and for enriching the existing pool of competing narratives in each of them.

Exploring Fermi's Paradox using an intragalactic colonization model	Volume 240 Mar 2026	Gregory Roudenko, Yurrian Pierre-Boyer

We explore Fermi's Paradox via a system of differential equations and using simulations of dispersal and interactions between competing interplanetary civilizations. To quantify the resources and potentials of these worlds, three different state variables representing population, environment, and technology, are used. When encounters occur between two different civilizations, the deterministic Lanchester Battle Model is used to determine the outcome of the conflict. We use the Unity Game Engine to simulate the possible outcomes of colonization by different types of civilizations to further investigate Fermi's question. When growth rates of population, technology and nature are out of balance, planetary civilizations can collapse. If the balance is adequate, then some civilizations can develop into dominating ones; nevertheless, they leave large spatial gaps in the distribution of their colonies. The unexpected result is that small civilizations can be left in existence by dominating civilizations in a galaxy due to those large gaps. Our results provide some insights into the plausibility of various solutions to Fermi's Paradox.

Propellantless space exploration	Volume 242 May 2026	Roman Ya Kezerashvili

Propellantless propulsion refers to methods of space travel that do not require onboard propellant, instead relying on natural forces or external energy sources. In this paper, I review different approaches that have been explored and discuss Pros and Cons for each approach for interstellar space exploration.

Gravitational assist uses planetary gravity to change a spacecraft's speed and direction without fuel. It is effective but limited to specific alignments. Solar sails harness radiation pressure from sunlight for continuous, fuel-free acceleration. While effective over time, they require large, reflective materials that degrade in space. Speed can be enhanced by thermal desorption triggered by solar radiation. Magnetic sails generate thrust by interacting with the solar wind through superconducting loops that produce a magnetic field. They provide lower acceleration compared to solar sails, and their performance depends on the available power and the variability of solar wind conditions. Electric sails utilize charged tethers to repel solar wind protons, producing gradual acceleration. Their effectiveness depends on the successful deployment of very long, lightweight conductive wires. They can achieve higher acceleration than solar sails, and their performance is influenced by available power and solar wind conditions. Lastly, quantum effects, such as the Casimir force, offer a speculative but intriguing route to propellantless propulsion based on the vacuum energy of space.

Redshifted civilizations, galactic empires, and the Fermi paradox	Volume 246 Sep 2026	Chris Reiss, Justin C Feng

Given the vast distances between stars in the Milky Way and the long timescales required for interstellar travel, we consider how a civilization might overcome the constraints arising from finite lifespans and the speed of light without invoking exotic or novel physics. We consider several scenarios in which a civilization can migrate to a time-dilated frame within the scope of classical general relativity and without incurring a biologically intolerable level of acceleration. Remarkably, the power requirements are lower than one might expect; biologically tolerable orbits near the photon radius of Sgr A* can be maintained by a civilization well below the Type II threshold, and a single Type II civilization can establish a galaxy-spanning civilization with a time dilation factor of 104, enabling trips spanning the diameter of the Milky Way within a human lifetime in the civilizational reference frame. We also find that isotropic, monochromatic signals from orbits near the photon radius of a black hole exhibit a downward frequency drift. The vulnerability of ultrarelativistic vessels to destruction, combined with the relatively short timescales on which adversarial civilizations can arise, provides a strong motivating element for the "dark forest" hypothesis.

"It is not easy to see how the more extreme forms of nationalism can long survive when men have seen the Earth in its true perspective as a single small globe against the stars..."

Arthur C Clarke, The Exploration of Space (1951)

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John I Davies

If you're fascinated by what you read in Principium, and want to help us turn science fiction into science fact, it's time to become an i4is member!

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THE i4iS MEMBERS' PAGE

John I Davies and Gill Norman

The i4is membership scheme exists for anyone who wants to help us achieve an interstellar future. By being a member of i4is, you help to fund our technical research and educational outreach projects. Members can access the members-only area of the website including our video talks, members' newsletter and Principium preprints.

Recent member newsletters

There have been three member newsletters since P52 our last issue. All member newsletters are emailed to members and also available from the members-only area on the website - i4is.org/members. They include access to preprints of Principium articles as well as interstellar news and announcements from i4is. It is envisaged that these newsletters will contine, although the future format may change, as the i4is Board reviews options.

Membership

The best way to support the mission of i4is is to become a subscribing member.
https://i4is.org/membership
Subscription costs £50 per year. If you are over 65, you can avail of the concessionary rate of just £10 per year. Students in full-time education can become members of i4is for just £5 per year. Please use your institutional email account if you have one. You can also subscribe monthly. Monthly payments are £5 per month (equivalent to £60 per year). If you have any specific questions, please see our membership FAQ or email the membership manager at membership@i4is.org.

Volunteering for i4is

All our team are unpaid. Some are professionals in fields like astronomy and space technology but many are enthusiasts inspired by that Outward Urge which has carried sailing canoes across the Pacific and Asian peoples to populate the Americas. There is lots to do from gathering news for our newsletters and future publications to maintaining our website and membership scheme - and of course contributing to our technical R&D for those with suitable skills and qualifications. We are actively looking for volunteers to help manage our social media.

And a special mention for the i4is Educational team which is currently recruiting! If any of our members are interested, and especially if you are in striking distance of London or Lincoln, both in the UK, we would welcome support at our outreach events mentioned below, such as:

- Our "Skateboards to Starships" at the Royal Institution, London, UK
- Lincoln University, UK, 15 & 16 July 2026, continuing our involvement with schools outreach at the university.
- We also talk to schools, mainly across the USA, via the "Skype a Scientist" programme. Email john.davies@i4is.org if you want to volunteer or need a bit more information!

Writing for future publications

If you have a particular topic which interests you then please propose an article to the Commissioning Editor for future consideration. During our hiatus, email info@i4is.org or kajol.mistry@i4is.org with a brief summary of your idea and a little about yourself.

COVER IMAGES

Cover images for this Issue 53

Our cover images for this issue feature remarkable views of our two main interstellar neighbours, Alpha Centauri A and B, courtesy of the Hubble Space Telescope and the James Webb Space Telescope. Humanity's initial interstellar venture may be to Proxima Centauri; although that remains a small point of light in our best telescopes for now.

FRONT COVER

Alpha Centauri A and B from the Hubble Telescope

The NASA/ESA Hubble Space Telescope has this stunning view of the bright Alpha Centauri A (on the top) and Alpha Centauri B (on the bottom). The image was captured by the Wide Field and Planetary Camera 2.

Image credit: ESA/Hubble & NASA
https://esahubble.org/images/potw1635a/

BACK COVER

Alpha Centauri A and B from the James Webb Space Telescope (JWST)

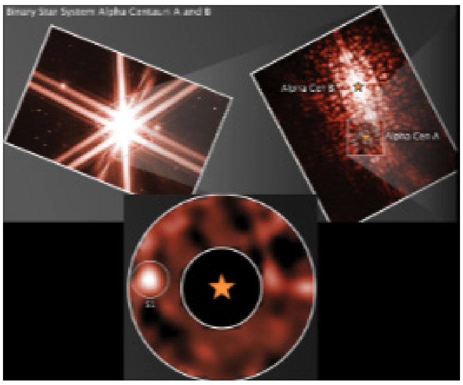


Image top left shows Alpha Centauri A and Alpha Centauri B. Image top right shows the system with a coronagraphic mask placed over Alpha Centauri A to block its bright glare. However, the way the light bends around the edges of the coronagraph creates ripples of light in the surrounding space. The telescope's optics cause some light to interfere with itself, producing circular and spoke-like patterns. These complex light patterns, along with light from the nearby Alpha Centauri B, make it incredibly difficult to spot faint planets. In the bottom image, astronomers have subtracted the known patterns (using reference images and algorithms) to clean up the image and reveal faint sources like the candidate planet.

Credit Image and caption: NASA, ESA, CSA, STScI, A Sanghi (Caltech), C Beichman (JPL), D Mawet (Caltech), J DePasquale (STScI)
https://esawebb.org/images/weic2515c/

The Initiative for Interstellar Studies is a pending institute, established in the UK in 2012 and incorporated in 2014 as a not-for-profit company limited by guarantee.

The Institute for Interstellar Studies was incorporated in 2014 as a nonprofit corporation in the State of Tennessee, USA.

Mission

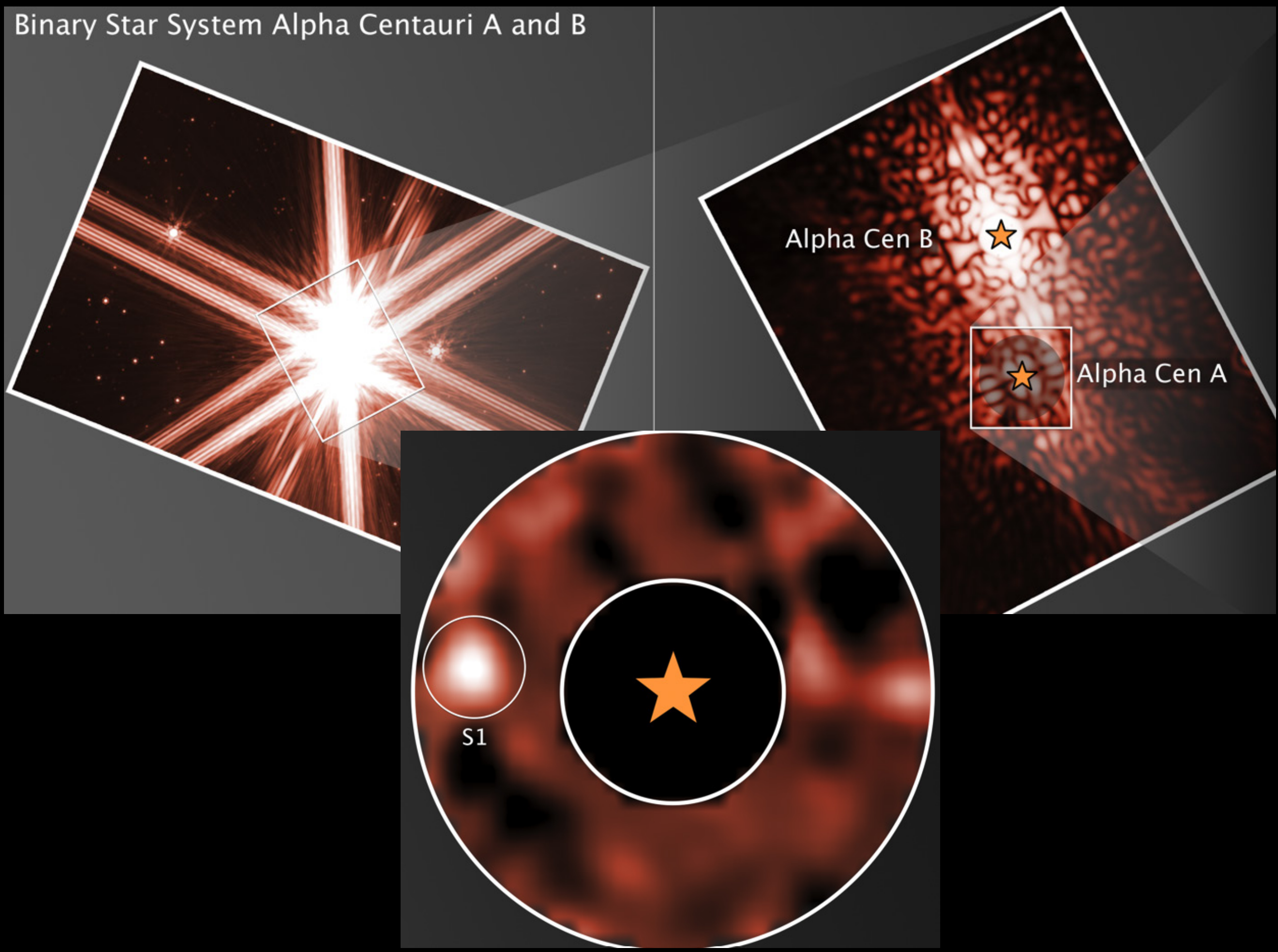
The mission of the Initiative & Institute for Interstellar Studies is to foster and promote education, knowledge and technical capabilities which lead to designs, technologies or enterprise that will enable the construction and launch of interstellar spacecraft.

Front cover: Alpha Centauri A and B
Credit: ESA/Hubble & NASA
Back cover: Alpha Centauri exoplanet search
Credit: NASA/ESA/CSA James Webb Space Telescope

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.

SCIENTIA AD SIDERA
KNOWLEDGE TO THE STARS



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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