PRINCIPIUM

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SCIENTIA AD SIDERA | KNOWLEDGE TO THE STARS

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EDITORIAL

Welcome to issue 40 of Principium, the quarterly magazine of i4is, the Initiative and Institute for Interstellar Studies. Our lead feature this time is *Searching for Alien Messages to a Nearby Star*; Rob Swinney connects two papers 11 years apart.

The front cover image this time is *Artemis 1 went further*; celebrating our restored capability for our species to venture beyond low Earth orbit. The rear cover image is *Hubble shows Galactic Overlap*; demonstrating that the Hubble telescope can still amaze us in the era of the Webb. More about both covers in *Cover Images* inside the rear cover.

We have 12 pages of Interstellar News and 4 pages of our regular summary of relevant peer-reviewed papers in *The Journal of the British Interplanetary Society* (JBIS) and *Acta Astronautica*.

Another major item is the second report - *IAC 2022: The Interstellar Presentations* - the interstellar themes at the biggest world space conference of the year, which took place in Paris in September.

Other features celebrate ***the 10th anniversary of i4is*** and record more work to realise historic deep space probes in Terry Regan's *The Mariner 2 model*.

As always we have the i4is members' page and our regular call to action, *Become an i4is member*.

Some items held over from this issue include a major i4is project in communications and a new venture from one of the i4is team.

The next issue, in May, will include -

- Current thinking about Faster than light (FTL) travel
- a review of the new book *Astrotopia*: subtitled "The Dangerous Religion of the Corporate Space Race"

- and we hope to announce a new way of finding out what's happening in interstellar studies.

More details in *Next Issue* at the end of this one.

Remember, if you would like to help in any part of ***Working towards the real Final Frontier*** then please take a look at our poster, full-size on page 6. There's lots to do!

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

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

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Please support us through membership of **i4is**. Join the interstellar community and help to reach the stars! Privileges for members and discounts for students, seniors and BIS members. More about this in *Become an i4is member* this issue and at i4is.org/membership.

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Or just print from page 56 of this issue.

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

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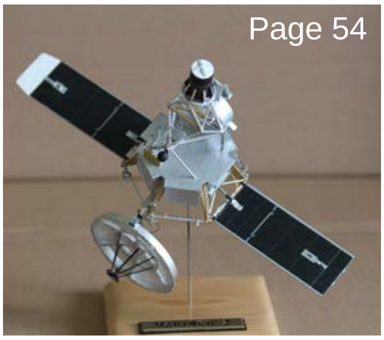

FEATURES

NEWS FEATURES

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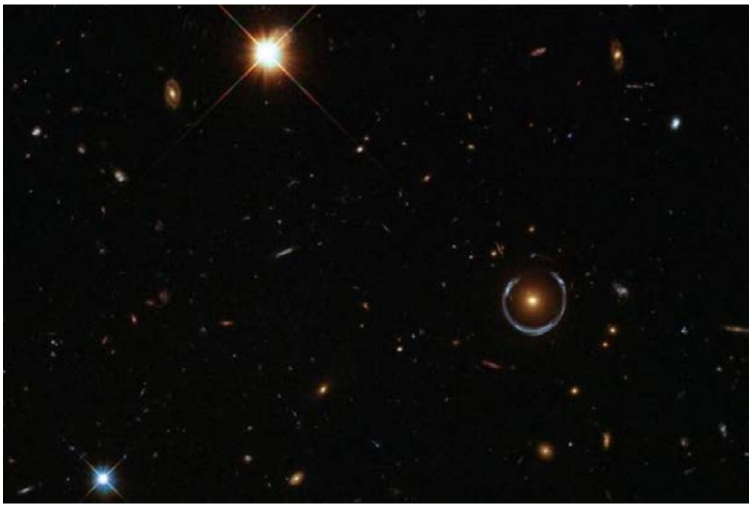
REGULARS

Searching for Alien Messages to a Nearby Star

Rob Swinney

Eavesdropping on putative alien galactic communications network is suggested by a paper in The Astronomical Journal, *Search for an Alien Message to a Nearby Star*. Here Rob Swinney, a co-founder of i4is and our Director of Education, considers how this SETI objective works with efforts to define ways of enhancing our own capability to do this - vital if we are to get data from an interstellar probe.



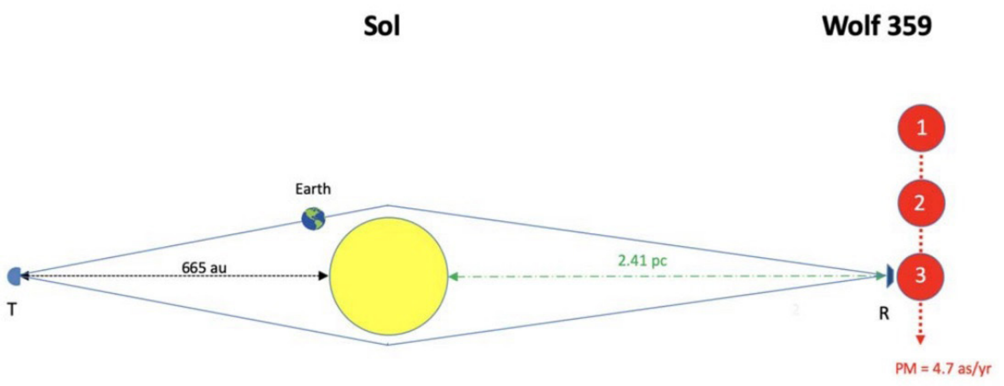
The ring in this picture is created by gravitational lensing due to the red galaxy at its center, which distorts the image of a distant blue galaxy. The magnification from the lens lets us see the blue galaxy, which would otherwise be too faint.
Credit: Image: ESA/Hubble & NASA,
Caption: Harvard Center fpr Astrophysics

Many theorise that using the sun as a gravitational lens, an effect predicted by Einstein's theory of General Relativity, might be an attractive means of dramatically amplifying the image of a distant object. 'All' that would be required would be to get your detecting craft out to beyond 550 AU from the sun where the effect is thought to occur and in the exact opposite direction to your desired target.

Another possibility of course is that the same effect could be used to amplify communications signals which was an option investigated by Pat Galea as part of Project Icarus, the BIS project to look at the design of an interstellar spacecraft. Some of his work, thinking on communication options, was featured in The Journal of the British Interplanetary Society (JBIS), for example, in 2011, *Project Icarus: Mechanisms for Enhancing the Stability of Gravitationally Lensed Interstellar Communications*: P Galea; R Swinney JBIS v64, 2011, where our very own Rob Swinney (author of this article) helped look at the positioning and pointing requirements for such spacecraft.

This earlier paper was cited in a recent paper *Search for an Alien Message to a Nearby Star*, in The Astronomical Journal [1] where the authors hypothesised that if alien probes had been able to colonise the whole galaxy, they could have formed an efficient galactic-scale communication network by establishing direct gravitationally lensed links between neighbouring systems.

[1] Volume 164, Number 5, 27 October 2022, iopscience.iop.org/article/10.3847/1538-3881/ac9610/pdf

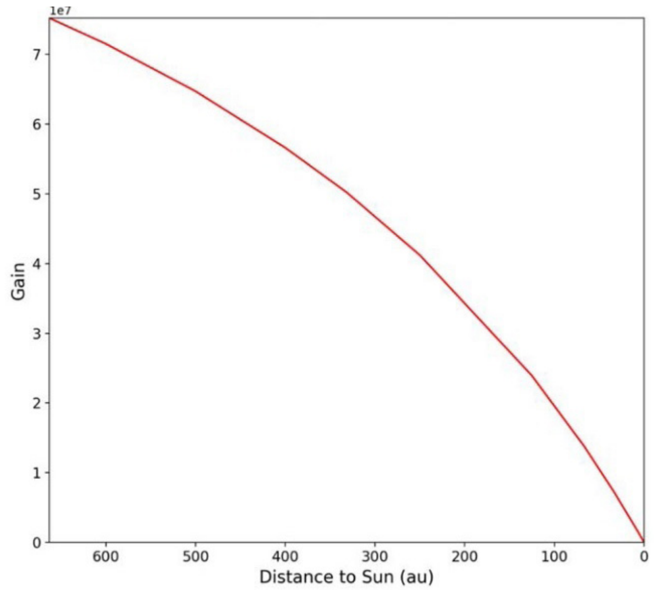


The distances and sizes are not to scale. Wolf 359 is shown at three different positions. Position 1 corresponds to the time of the emission of the photons that we receive from it now. Position 2 corresponds to its current position. Position 3 corresponds to the time at which it will receive the photons emitted now by the transmitter T (R = receptor).
Credit (image and caption) Gillon et al, Figure 2.

Illustration showing the geometry of the hypothesized communication link from the solar system to the Wolf 359 system. Note that PM is "proper motion" the actual movement of a stellar object as apposed to its apparent motion as a result of the movement of the observer's platform, in our case the Earth

Michaël Gillon (University of Liège), Artem Burdanov (Massachusetts Institute of Technology) and Jason T Wright (The Pennsylvania State University) suggest that, if so it could make it possible for us to eavesdrop on the emission of local probes (ie any around our sun) to one of these stars from positions directly opposite nearby ecliptic stars. This they see as a promising artefact-seeking SETI strategy. They further suggest these alien Focal Interstellar Communication Devices (FICDs) could even be discoverable in our solar system.

This paper highlights the first attempt to illustrate the principle using the ~7.8 light year distant star, Wolf 359, based on observations gathered by the TRAPPIST-South and SPECULOOS-South robotic telescopes to detect optical messages sent from our locale to the distant star. Not surprisingly this first search has led to a null result and they list the potential reasons [1].
Nevertheless, alternative strategies are being explored and further observations of more targets are being performed and will be presented in a forthcoming paper.



Communication gain relative to a non-GL emission as a function of distance between the emitter and the Sun (663 au = in-focus), as computed from ray-tracing simulations under the assumptions described in the text.
Credit (image and caption) Gillon et al, Figure 9.

[1] Gillon et al make the following assumptions about sensitivity (see also gain/distance graph above)
"To estimate it, we assumed the following parameters for the communication link from the solar system to Wolf 359:
1. The use of the Sun only as a GL.
2. A mean emission wavelength of 500 nm (600 THz)...so as to minimize the divergent impact of the Sun's corona. [and] for practicality purposes, as it lies in the optical range and the emission could then be detected by a ground-based telescope.
3. A mass and radius of 0.11 Me [ie relative to the mass of the Sun] and 0.14 Re, respectively, for Wolf 359.
4. An impact parameter b of 1.1 for the light rays grazing the Sun. For this impact parameter, our ray-tracing computations lead to a distance to the Sun of 663 au for the alien transmitter.
5. For the receptor around Wolf 359, a circular receptor with a radius Rrec = 100 m.
6. For each laser, a waist (radius of the beam at its emission) of 1 m corresponding thus to a space telescope with a 2 m diameter."

The Initiative & Institute for Interstellar Studies

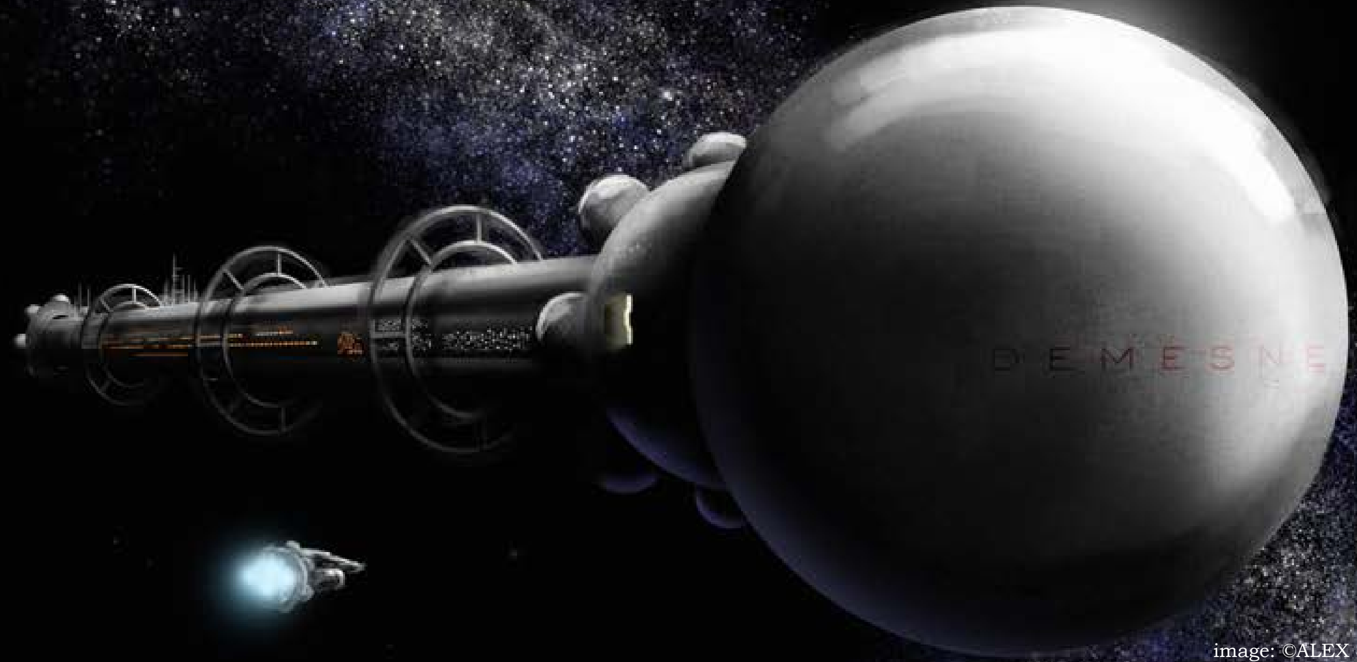


image: ©ALEX STORER

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Working towards the real Final Frontier

Help us to realise our mission to reach the stars - we need your help - physics to software engineering, graphic design to project management - and rocket engineering of course! ...and much more....
Some of us have PhDs, some masters and first degrees and others simply have talents! What we all share is enthusiasm for the interstellar future of humanity. We have about 20 active team members, led by -

- **Dr Andreas Hein: Executive Director/Technical Director -** andreas.hein@i4is.org
- **Robert G Kennedy III: President i4is USA -** robert.kennedy@i4is.org
- **Rob Swinney: Education Director -** rob.swinney@i4is.org
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- **Tam O'Neill: Manager Membership/Website team -** tam.oneill@i4is.org

Join the team if you can help - become a member if you simply want to support our work.

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INTERSTELLAR NEWS

John I Davies reports on recent developments in interstellar studies

Artificial Gravity for Human Habitation

If humans as presently constructed are to live "off planet" for extended periods, for example in artificial habitats or, ultimately, in world ships to take us to other stars then we must provide a way to avoid the adverse effects of microgravity on the human body. A new paper, *A Review of Challenges & Opportunities: Variable and Partial Gravity for Human Habitats in LEO* [1] by Dr Ronke Olabisi, UC Irvine, and Dr Mae Jemison, 100yss.org, reviews the requirements, human biology, and possible solutions - spacecraft engineering, to achieve this goal. Sponsored by Orbital Assembly (orbitalassembly.com) the report outlines the current situation and discusses in detail -

- Impact of Microgravity on Physiological Systems
- Impact of Microgravity on Human Activities
- Impact of Microgravity on Habitat Systems
- Reviews of Artificial Gravity Literature
- Benefits and Challenges of Variable and Partial G Habitats
- Opportunities and Considerations for Designing a Rotating Artificial Gravity Habitat

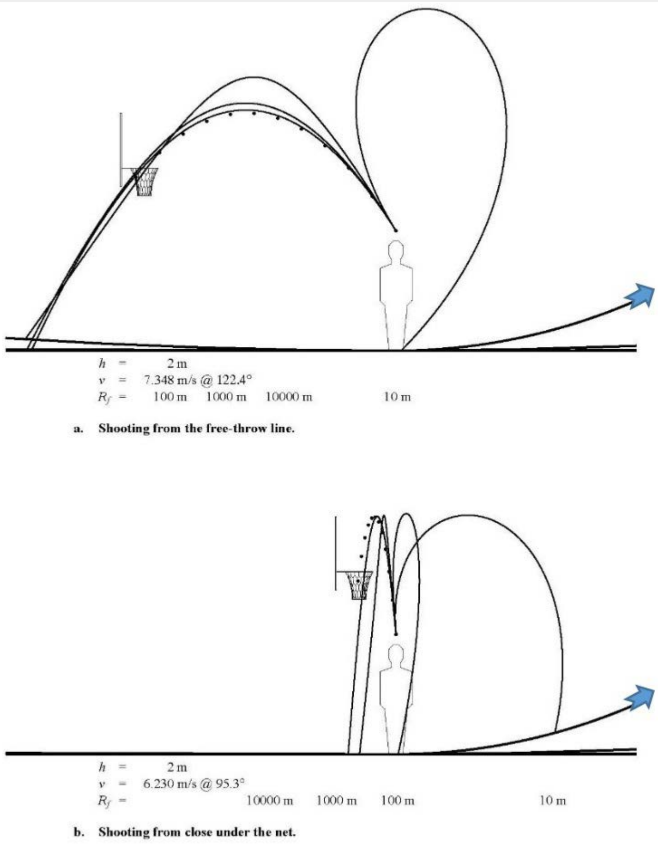
The report concentrates on the human aspects of the problem but does not neglect the engineering issues.

One particularly illuminating section covers the effects of Coriolis forces under rotational artificial gravity. These have often been discussed and, at low rotational radii, produce significant physiological effects. But here the authors also include a striking graphical illustration effects on a less obvious but essential part of normal human society, sport. The example given, basketball, allows for a particularly powerful illustration.

The effect on hand-eye coordination for more mundane but vital tasks can be imagined - and the authors cite the example of surgery.

The effects at low rotational radii look bizarre but even at quite large radii would require players to adjust their reflexes (and the basketball example here is simply a shot parallel to the direction of rotation, imagine the shot at 45 degrees, 90 degrees and 180 degrees). The same would apply to football in all its varieties and just about all physical sports and, beyond Coriolis, imagine the 100m record for races run with and against the direction of rotation!

Other points raised in the practical provision of rotational artificial gravity include use of visual clues to mitigate Coriolis effects, curving wide floors (and I guess large tables?) and the direction of apparently vertical surfaces to match the essentially cylindrical orientation of the gravity field, the possibility that 0.3 to 0.5 g would be sufficient (might the upcoming Moon expeditions help?) and the necessity for a transdisciplinary approach extending beyond space medics and engineers to behaviourists, artists, athletes, wider health professionals, architects, investors, chemists and ecologists.



Basketball in artificial gravity. The dots represent a successful shot in Earth gravity. The curves represent identical shots in 1-G rotating environments with radii of 10 m, 100 m, 1,000 m, and 10,000 m. The blue arrows indicate the direction of rotation. Credit (image and caption): Olabisi and Jemison, Figure 40

[1] orbitalassembly.com/gravity and https://news.orbitalassembly.com/2022/artificial-gravity-may-offer-a-myriad-of-benefits-to-humans/

Finding your interstellar way - and finding dark matter

In *Autonomous Navigation of Relativistic Spacecraft: Theory and Applications* (ecommons.cornell.edu/handle/1813/112098), PhD student Doga Yücalan introduces some thinking about autonomous spacecraft navigation methods and how relativistic effects on a spacecraft could identify dark matter. He observes that "A spacecraft designed to detect acceleration could sense the gravitational effects of nearby dark matter." And that "a space exploration mission aiming to detect dark matter needs to employ spacecraft located far enough away from ordinary matter's gravitational interactions within the solar system." -and, of course, the Sun and the planets are the most powerful effects, To achieve results within a lifetime would require missions accelerating to significant fraction of the speed of light such as the proposed Breakthrough Starshot probes.

Doga observes that current means of autonomous navigation for spacecraft include NASA's AutoNav, which tracks nearby objects using optical sensors to navigate, and its XNAV algorithm, using X-ray emissions from pulsars. Doga also cites several other autonomous navigation algorithms based on Newtonian mechanics which are in development. But none of these navigation technologies are adequate for a future interstellar mission, including the uncertain nature of the interstellar medium (ISM). For the very high speed required, relativistic effects also become significant.

The paper aims to suggest both improved methods for acquiring navigational inputs (with a recursive algorithm to continuously update the onboard star catalogue) and an Interstellar Dark Matter Explorer Mission using known technologies to detect deviations in the dark matter distribution near the heliopause with mission duration around 25 years. This would not be a cheap mission. The paper assumes a SpaceX Starship launch into a 500 km orbit delivering a 150 ton vehicle with mass ratio of about 150/8 (18.75) for an initial velocity to Jupiter of 12,494 m/s [1] at a total cost of about $1.6 bn.

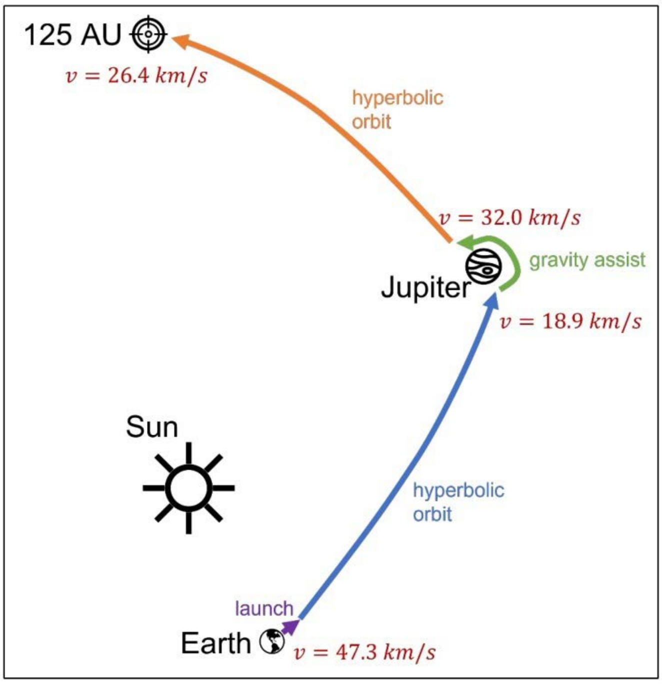


Illustration of the dark matter explorer spacecraft's proposed trajectory from Earth to 125 AU (not to scale). Included speeds denote spacecraft's speed relative to the Sun at points of interest.

Credit (image and caption): Doga Yücalan

Practicalities of Antimatter

Antimatter is a favourite of writers of "hard" science fiction (sf-encyclopedia.com/entry/antimatter) but is it a serious possibility as a very powerful store of energy?

Antimatter and Its Application-Collecting Antimatter and Storage It as Energy Source [2] is a survey of the prediction and discovery of antimatter, its properties as store of energy, how to collect and store it, its most useful form (suggesting antiprotons) and its application to propulsion. The writer is Ruichen Zhang, TianJin University, China.

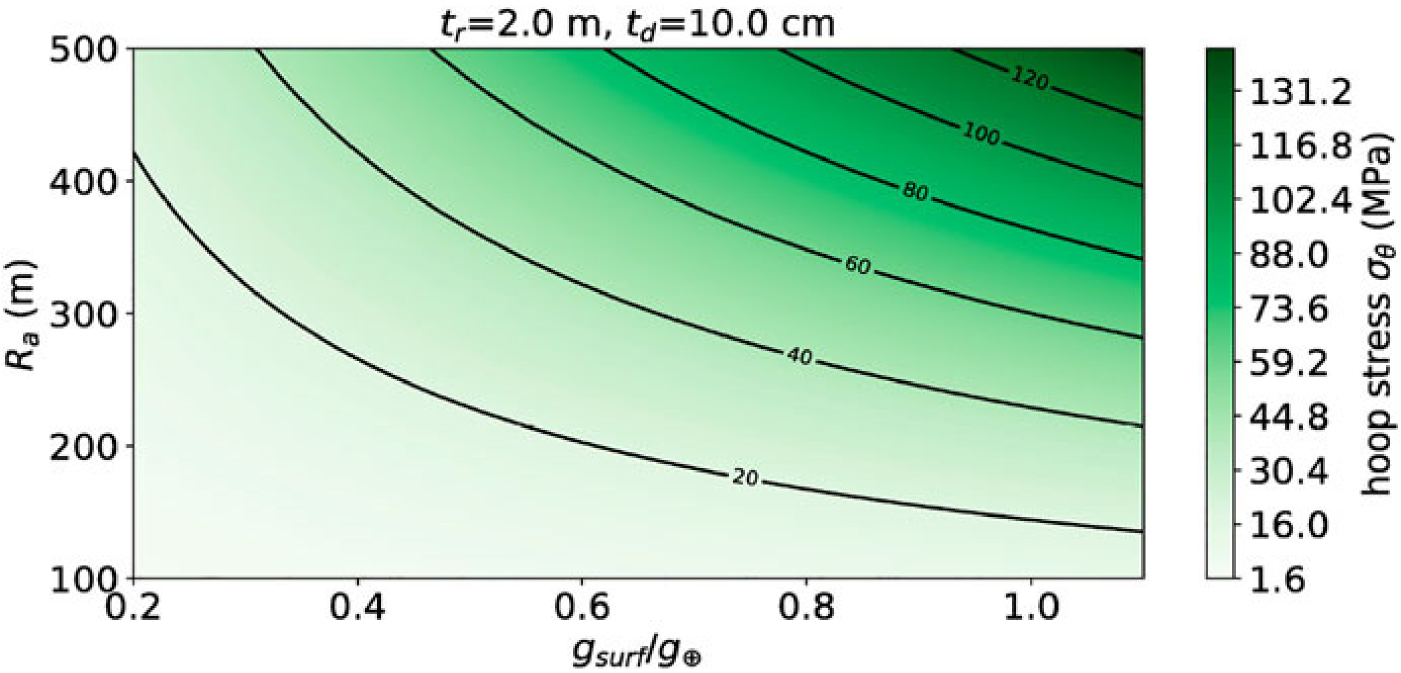
[1] The required exhaust velocity can be calculated applying a transposed Tsiolkovsky equation Ve=deltaV/ln MassRatio. This yields 12,494/ln 18.75 = 12,494/2.93 = 4,264 m/s.
[2] iopscience.iop.org/article/10.1088/1742-6596/2386/1/012074

Avoiding the Great Filter - via fundamental physics

In *Avoiding the "Great Filter": Extraterrestrial Life and Humanity's Future in the Universe* [1], Federico Re of Universita di Milano Bicocca, suggests that if and when a "Theory of Everything" [2] is found this can act as a "Great Filter". After a useful tour of possible explanations for the Fermi Paradox Re suggests that "The myth of an unlimited scientific progress comes from the principle (in philosophy of science) that all scientific theories are falsifiable." This appears to derive from his idea that any overarching "fundamental Law of Nature" is itself not falsifiable but "we must suppose that the Law exists". He suggests that this leads to an examination of the Fermi Paradox which is independent of human culture (ie the idea that we, and all similar civilisations, will make mistakes which will lead to our extinction).

Build your house from rubble

That's if you want to be a pioneer on "The High Frontier", Gerard K O'Neill's book *The High Frontier* (1976) suggested we build vast habitats to populate the space between the planets. But how do you build the first human habitats in space? Researchers from the University of Rochester (Rochester, New York) suggest that so-called rubble pile asteroids might make a good start. O'Neill envisaged processing raw materials into construction elements and others have advocated hollowing out asteroids as a faster route avoiding the need for the processes of in-situ resource utilisation (ISRU) but Peter M Miklavcic et al [3] point out that the spin rate required to give the artificial gravity to suit human biology would cause known asteroids to fly apart under centrifugal forces. They therefore advocate starting with asteroids which are only loosely bound by gravity, rubble piles, and binding them with high tensile strength materials before spinning them to the required rates of rotation.



Hoop stress for an asteroid spun up to form a cylindrical shell of thickness 2 m and contained in a scaffold of thickness 10 cm. The asteroid is assumed to have a uniform density of 1 g/cm^3. The vertical axis is the radius Ra of the asteroid, in meters. The horizontal axis is the surface gravity of the asteroid in units of Earth surface gravity.

Credit (image and caption): Peter M Miklavcic et al

[1] www.researchgate.net/publication/365374857_Can_the_Theory_of_Everything_be_the_Great_Filter
[2] A hypothetical union of general relativity and quantum theory. They describe the universe and its smallest constituents respectively and have been at odds since they were first discovered and codified about 100 years ago. More in en.wikipedia.org/wiki/Theory_of_everything and *The Great Filter - Are We Almost Past It?* mason.gmu.edu/~rhanson/greatfilter.html
[3] *Habitat Bennu: Design Concepts for Spinning Habitats Constructed From Rubble Pile Near-Earth Asteroids* in Frontiers in Astronomy and Space Sciences www.frontiersin.org/articles/10.3389/fspas.2021.645363/full

Canopus Awards and NEXUS™ NAIROBI

100 Year Starship (100YSS), the advocacy and campaigning organisation led by former astronaut Dr Mae Jemison, has published its annual Canopus awards (canopusawards.org). They recognise recent fiction and non-fiction. Categories are Published Long-Form Fiction, Published Short-Form Fiction, Published Long-Form Nonfiction, Published Short-Form Nonfiction, Published Digital Presentation, Original Short-Form Fiction and Original Local Short-form Fiction.

In the category Published Long-Form Nonfiction we noted *A Traveler's Guide to the Stars* by Les Johnson and *Extraterrestrial* by Avi Loeb. In the category Published Short-Form Nonfiction we noted *Artificial Intelligence for Interstellar Travel* by Andreas M Hein and Stephen Baxter (JBIS 2018). Stephen is a long-established friend of i4is and Andreas is the i4is Executive and Technical Director. All awards are listed at canopusawards.org/?page_id=166.

We'll be looking at the award winners in later issues of Principium. Awards were presented at Nexus Nairobi January 31 – February 4, 2023. (nexusnairobi.org). Winners at locusmag.com/2023/02/2023-canopus-awards-winners.

Chasing Nomadic Worlds

In Chasing Nomadic Worlds: A New Class of Deep Space Missions [1], Manasvi Lingam (Florida Institute of Technology and University of Texas at Austin), Andreas M Hein (University of Luxembourg and i4is.org) and T Marshall Eubanks (Space Initiatives Inc) discuss missions to nomadic worlds, objects not bound to any star, given their great interest to planetary science and astrobiology. They evaluate the prevalence of nomadic worlds with radii, R, of 100 km to 10,000 km, which might permit habitable conditions. The cumulative number density n, for radii above R appears to follow a heuristic power law given by n > proportional to R^3. Therefore, smaller objects should be much more numerous than the largest rocky nomadic planets, and thus statistically more likely to have members relatively close to the inner Solar system. Their results suggest that tens to hundreds of planet-sized nomadic worlds may populate the spherical volume centred on Earth and circumscribed by Proxima Centauri, and thus may comprise closer interstellar targets than any stellar planetary system. They analyse the feasibility of exploring these unbounded celestial bodies via deep space missions and investigate what near-future propulsion systems could theoretically enable us to reach nomadic worlds (of radius > R) on a 50-year timescale. Objects of radii approximately 100 km are accessible using multiple propulsion methods such as electric sails, laser electric propulsion, and solar sails, but nomadic worlds with R > 1,000 km are accessible only by laser sails (or perhaps fusion propulsion). Their result is summarised -

Approximate radius of nomadic worlds reachable by propulsion systems in 50 years

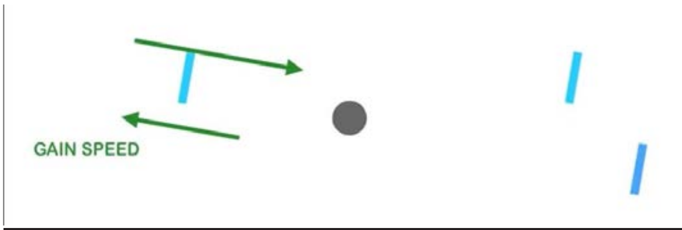
c	Terminal speed (in AU/yr)	Radius (in km)
Solar sails	~ 20	~ 75
Laser sails	$\lesssim 63$ to $\gtrsim 6.3 \times 10^3$	$\lesssim 230$ to $\gtrsim 2.3 \times 10^4$
Magnetic sails	~ 20	~ 75
Electric sails	~ 25	~ 93
Magneto-plasmadynamic thrusters	$\lesssim 63$	$\lesssim 230$
Laser electric propulsion	~ 40	~ 150
Nuclear fusion	~ 63 to ~ 6.3×10^3	~ 230 to ~ 2.3×10^4
Chemical propulsion	~ 9	~ 34

Additional notes: More precisely, nomadic worlds of radius > R (third column) can be reached by a given propulsion system in 50 years. The last column is estimated by invoking [heuristic equation $v_t \sim 0.27$ AU/yr (R/1 km) / (Δt/50 yr)], setting $\Delta t = 50$ yr, and substituting the terminal speed (second column) to solve for R. All values should be viewed as strictly heuristic.
Credit (table and Additional notes): Lingam, Hein, Eubanks - Table 1.

[1] www.researchgate.net/publication/365298186_Chasing_Nomadic_Worlds_A_New_Class_of_Deep_Space_Missions

Faster than the (Solar) Wind

In *Dynamic Soaring as a Means to Exceed the Solar Wind Speed* [1] a team from McGill University and Tau Zero Foundation suggest a way to achieve very high speeds which, at first sight, looks like "pulling yourself up by your own bootstraps" - something our parents (and our physics teachers) always warned us would not work - except metaphorically - where it was, of course, universally recommended. The paper suggests that using a plasma magnet technique rather than a magnetic or electric sail will better exploit the charged particles which comprise the solar wind. And they tell us that "Several structures in the solar system offer wind gradients large enough for dynamic soaring maneuvers to extract energy." They report that "dynamic soaring can deliver payloads to 2% of c, essentially "for free" (meaning, without expenditure of propellant or significant power) and that "this technique is ideally suited to deliver reaction mass that can be used for additional stages of propulsion capable of even greater speeds." A variant of this technique, the wind-riding plasma magnet, could, for example, allow a mission to the solar gravitational lens (SGL) distance (> 550 AU) in 7 years from launch.
Just to get around the "by your bootstraps" worry, here's a video DYNAMIC SOARING EXPLAINED (www.youtube.com/watch?v=SVN-oF6tPLc).



The blue plates at the top are part of an endless succession moving to the right. The single plate at the bottom is fixed. If all collisions are perfectly elastic then the ball goes a little faster each time it hits one of the moving plates. Credit: see video.

Videos
USAF www.youtube.com/watch?v=xIPI0AOj5MI
Animation (commentary in German) www.youtube.com/watch?v=hcrJXVg0zS4
Bouncing ball animation:www.youtube.com/watch?v=SVN-oF6tPLc
Explanation www.youtube.com/watch?v=nv7-YM4wno8

Radio controlled gliders can now approach supersonic speeds using this technique (www.youtube.com/watch?v=nv7-YM4wno8) and the US Air Force has had a go (www.youtube.com/watch?v=xIPI0AOj5MI) but not quite that fast yet. But albatrosses worked this one out a few million years ago. It's still hard for us humans to do better than evolution - but then we haven't been around that long!

Finding ET in Gravitational Waves

In *Searching for Intelligent Life in Gravitational Wave Signals Part I: Present Capabilities and Future Horizons* [2], researchers from The Advanced Propulsion Laboratory at Applied Physics (New York), UCLA, Israel Institute of Technology, Lund University (Sweden) and Carnegie Mellon University state that the instrument which first detected naturally occurring gravitational waves may also detect signs of very high speed propulsion, via the gravitational waves resulting from their acceleration. The Laser Interferometer Gravitational Wave Observatory (LIGO) can detect gravitational waves (GWs) from accelerating astrophysical sources, such as binary black holes, and the authors suggest it provides the potential to detect extra-terrestrial mega-technology, such as Rapid And/or Massive Accelerating spacecraft (RAMAcraft) and that LIGO is sensitive to RAMAcraft of one Jupiter mass accelerating to a fraction of the speed of light (eg 10%) up to about 100 kpc (100*3,262 light years - so beyond our home galaxy). They observe that existing SETI searches probe on the order of thousands to tens of thousands of stars for human-scale technology such as radio signals, whereas LIGO can probe all 10^{11} stars in our galaxy for RAMAcraft and that planned space-based instruments could look even further. However they caution that a candidate detection of a RAMAcraft signal should be treated with scepticism since other phenomena could produce similar burst signals though matched-filtering (MF) detection will be more conclusive but still vulnerable to false positives. Once the shape of the signal can be analysed sufficiently it should become possible to reverse-engineer propulsion methods.

[1] *Dynamic Soaring as a Means to Exceed the Solar Wind Speed*, arxiv.org/abs/2211.14643, Mathias N Larrouturou and Andrew J Higgins of McGill University, Montréal, and Jeffrey K Greason, Tau Zero Foundation
[2] *Searching for Intelligent Life in Gravitational Wave Signals Part I: Present Capabilities and Future Horizons*, Sellers et al, December 2022, arxiv.org/abs/2212.02065

Hive or Brain? Hoyle's Black Cloud and Telepathy

A posting by the perennially interesting Paul Gilster, Life from Elsewhere (www.centauri-dreams.org/2022/12/13/life-from-elsewhere/), reported below, is mainly focused on panspermia but, in passing, he remarks "Hoyle was interested not just in the nature of consciousness but likewise the matrix in which it can be embedded". In Fred Hoyle's novel, *The Black Cloud*, the scientists who first establish that the cloud contains intelligence speculate about the distribution of that intelligence within the enormity of the cloud and whether it was, in fact, a community or a "hive mind". They conclude that since the entities forming the intelligence communicated by electromagnetic means (light, radio or other frequencies) that the bandwidth of communication would make it inevitable that the entity would be a single intelligence. To steal from Arthur C Clarke we might conclude that "Any sufficient telepathic bandwidth between minds is indistinguishable from a single mind". However, even the simplest computer system can deal with multiple simultaneous tasks and this is more than just the the ability to "walk and chew gum at the same time" [1] since this capability allows any number of levels of priority between tasks and is possible within a single processor system by allocating slices of time between tasks.

Replacing Greenwich

In *Establishing A Landmark in Space - Spacetime Zero* [2], Gregory A Harrison, proposes establishing Spacetime Zero as a benchmark based on the concept of Universal Spacetime. He suggests that current timekeeping methods are too Earth-centric and that we require an interstellar coordinate system. He suggests that "At zero-time, the locations and orientations of everything in the universe is considered to be known and established". This reporter is not qualified to comment on the plausibility of this but Dr Harrison has a long career in aerospace and this appears to be related to his subsequent enterprise, "Gravitronics". No doubt citations in future will test the plausibility versus current understanding of spacetime, light cones and the shape of the universe.

The Ethics of Directed Panspermia

The idea of using technology to spread life deliberately is far out on the horizons of our technology and we take great care to clean anything biological from all planetary landers. But what if the answer to Arthur C Clarke's two possibilities for ETI is that there is nobody else, at least in our galaxy? Should we seed the galaxy with life if and when we can? Paul Gilster [3] draws on *Interstellar Objects in Our Solar System*, a recent collection of papers and specifically *Directed Panspermia Using Interstellar Comets* [4], Christopher P McKay (NASA), Paul C W Davies (Arizona State University), and Simon P Worden (Breakthrough Initiatives). The paper observes that the detection of interstellar objects in our solar system provides evidence of a possible mechanism for the spread of life including, possibly, that on our own planet. But should this process be initiated deliberately rather than as a random natural event? The authors cite numerous earlier works analysing mechanisms, probability and ethics, though not, curiously, the work of Prof Dr Claudius Gros - cited in a number of Principium articles over the past four years notably *Long duration Genesis-type missions to exosolar planets* in the IAC18 (Bremen) report in issue 23 and *Why planetary and exoplanetary protection differ: The case of long duration Genesis missions to habitable but sterile M-dwarf oxygen planets* (arxiv.org/abs/1901.02286) reported in issue 25.

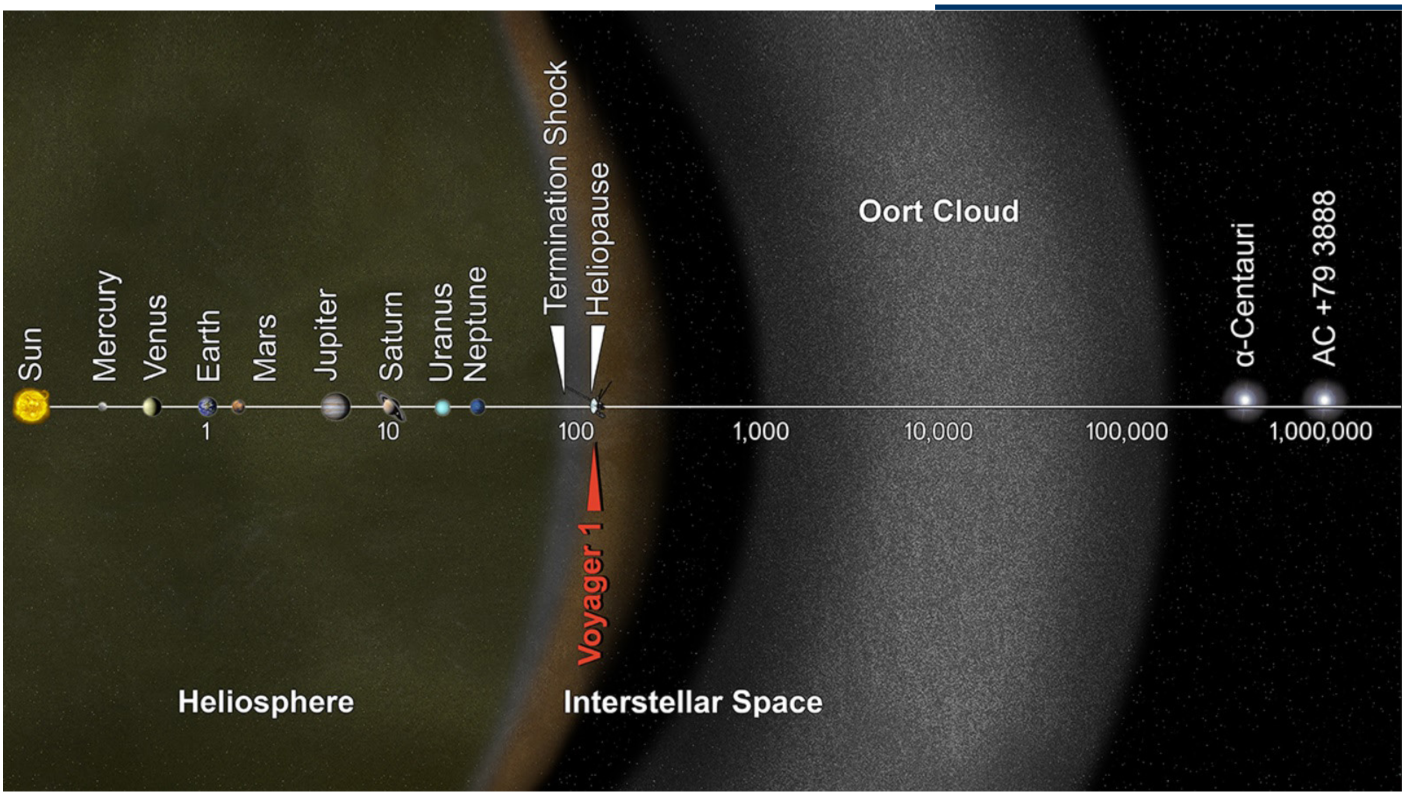
The paper "raises many technical and ethical questions" in a field which is purely investigatory at the moment but which becomes a very live question as soon as we have the capability to send anything to destinations beyond our solar system,

[1] Lyndon B Johnson was believed to have remarked in 1973 that Gerald R Ford could not accomplish this, allegedly because he had played a lot of American football in his youth - and did not wear a helmet. Johnson had decided not to run for a further term as president. Ford became president upon the resignation of Richard M Nixon. Ford had, despite the football, graduated third top of his class at Yale Law School so Johnson's remark clearly exhibited more wit than truth.

[2] www.researchgate.net/profile/Gregory-Harrison/publication/364475841_Establishing_A_Landmark_in_Space_-_Spacetime_Zero/links/6351b7a86e0d367d91af0a1d/Establishing-A-Landmark-in-Space-Spacetime-Zero.pdf

[3] www.centauri-dreams.org/2022/12/16/the-ethics-of-directed-panspermia/

[4] www.liebertpub.com/doi/10.1089/ast.2021.0188



About 1,000 AU is the inner edge of the Oort cloud.
Credit: NASA www.nasa.gov/mission_pages/voyager/multimedia/pia17046.html

The Pointing Problem

In *Interstellar Communications The Pointing Problem*, Paul Gilster outlines the difficulties of an interstellar downlink [1] are not just the distance (fighting the inverse square law, especially for tiny probes like the Breakthrough Starshot proposals) but also the need to be economical by making sure that as much of the transmitted signal is pointed towards its home receiver on or near Earth. The Johns Hopkins team working on their Interstellar Probe - intended to function all the way to 1,000 AU (the inner edge of the Oort cloud) are thinking of X-band microwave rather than laser for this very reason.

The problem divides into guidance and control. Guidance of the downlink transmitter requires very precise orientation information and star maps look like the best option. Control has several options. Reaction wheels conserve thrust propellant but may be unreliable for a 50 year mission. Will the interstellar magnetic field provide something to push against? The Hubble telescope, for example, uses reaction wheels as the primary method and magnetic torquers against the Earth's magnet field when the reaction wheels reach their limits. Much more in Paul Gilster's article.

Spotting another 1I/'Oumuamua

In *Physical Considerations for an Intercept Mission to a 1I/'Oumuamua-like Interstellar Object*, Siraj et al [2] primarily discuss detection of another 'Oumuamua-like ISO with some brief consideration of preparations to intercept it. They touch on papers from several sources discussing such missions including three by the i4is Project Lyra team. They mention one existing mission project, the ESA Comet Interceptor. This seems, so far, to be the only definitely committed mission which might intercept an ISO although its primary stated mission is to study a Solar System comet.

[1] www.centauri-dreams.org/2022/12/07/interstellar-communications-the-pointing-problem/ and see also *The Interstellar Downlink* in Principium 31 November 2020

[2] Authors:Amir Siraj, Mark Elowitz, Abigail White and Abraham Loeb (all Harvard), Amaya Moro-Martın (Space Telescope Science Institute and Johns Hopkins University) and Wesley A Watters (Wellesley College), arxiv.org/abs/2211.02120

Space Colonisation and Exonationalism

Jack David Eller of the Global Center for Religious Research (GCRR), Denver, considers *Space Colonization and Exonationalism: On the Future of Humanity and Anthropology* (www.mdpi.com/2673-9461/2/3/10/htm). He suggests that "As humans resume their push into space, anthropology is set to become unbound from the earth itself" and he considers how anthropology contributes to understanding the present and future of space colonisation (beginning at least as early as the 1950s) and current analysis of law, sovereignty, and nationalism in space. He predicts the emergence of exonationalism, in which generations of colonists will shift their affiliations to their non-terran homes and ultimately seek independence from the Earth thus reshaping our definition of the human and hence the practice of anthropology.

He suggests Ursula Le Guin's 1974 novel *The Dispossessed* represents a useful thought experiment (in this case establishing a variety of pure communism rather than the Marxist variety). However he seems to be using an example of separation driven by a political motive rather than less ideological European style settlement in America, which subsequently provided a substrate upon which political/religious separation became attractive - as in the Plymouth plantation.

He cites early work on space anthropology citing the books, *Toward an Extraterrestrial Anthropology* and *Cultures Beyond the Earth*, 1975, Magoroh Maruyama (Editor) - a citation search for which leads to a fairly extensive literature.

Eller reviews anthropology as it has been applied to space in recent years and politics beyond Earth. Longer term he expects "a dramatic cultural rediversification of humankind" [1]. He imagines the likes of SpaceX and Blue Origin as the equivalents of the British and Dutch East India Companies with their own political administration and armed forces but suggests that their independence from the Earth nation from which they came would be hard to thwart - in contrast with the British and Dutch companies which were rapidly nationalised when they proved inconvenient. This looks questionable in the case of the inner Solar System where near-Earth polities will be kept on a tight rein given their strategic value thus making the exercise of military power as far as Mars a relatively low-energy and short term proposition - with journey times from Earth to Mars being less than those from Europe to India under sail.

This is a substantial and thoughtful piece, perhaps deserving of a more thorough review in Principium.

Systems Design of Nano/Picosatellites

Tiny spacecraft are key to laser propelled interstellar travel and attention to systems engineering is vital. The paper *Systems Design and Integration of Small Scale Nano and Picosatellites* [2] by a team from Cornell University conducts a broad systems review of this technology. Their perspective is Earth satellites but many of the issues would also apply to a tiny probe intended for interstellar mission and the project which is the basis for the paper is specifically focused on the requirements arising from the ideas of Breakthrough Starshot. There are clear parallels with the Glowworm/Pinpoint work of i4is.

The suggested design model is a "Vee" diagram (a development of the software engineering "Waterfall" model which formalises top-down design and build followed by bottom-up testing).

The paper develops much of a design for chipsat communication including suggested protocol elements and modulation techniques.

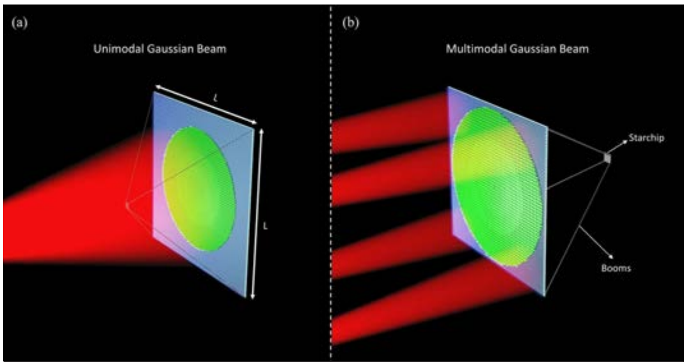
Space Futures Initiative

Principium has devoted attention to relatively short-term non-technical issues which seem relevant to the long term objective of creating a Solar System society as a foundation upon which we can build a long term interstellar future for our species [3]. In *Space Governance: Risks, Frameworks and Futures* Carson Ezell (Harvard) of the Space Futures Initiative (spacefuturesinitiative.org) has published a substantial paper [4] describing the space governance landscape and offering novel long term ideas to "improve the norms, values, and institutional structures that guide future spacefaring".

[1] From *Anthropology and the Humanization of Space*, B R Finney - Acta Astronautica, Volume 15, Issue 3, March 1987 No open source found.
[2] Naumann et al, July 2022, www.preprints.org/manuscript/202207.0368/v1
[3] Examples: Max Daniels on *Territory in Outer Space* in Principium 24 February 2019, *The Artemis Accords: what comes after the Moon?* P32, February 2021 and *Finding new ways to share resources in space* P37, May 2022
[4] *Space Governance: Risks, Frameworks, and Futures.* August 2022, spacefuturesinitiative.org/images/Space_Governance_Risks_Frameworks_and_Futures.pdf

Metamaterials for photon sails

In *Increasing the stability margins using multi-pattern metasails and multi-modal laser beams* [1] Mohammadrasoul Taghavi & Hossein Mosallaei of Northeastern University, Boston, explore the use of metasails for nanocraft to reach very high velocities by achieving stable beam-riding, minimising acceleration time and effective thermal management via radiative cooling. They assert that flat macroscopic structures are dynamically unstable - like an egg balanced on its end - but conical and parabolic structures can remain in the beam area during the acceleration period. However there remain materials science challenges which might be overcome using metamaterials which also have attractive optical properties.
They propose two possible configurations with the nanocraft either placed on the beamed side (tractor configuration) or the shadow side (pusher configuration) of the sail.



tractor sail (left) and pusher sail (right) Credit: Taghavi & Mosallaei

Their paper discusses in detail - nanoscale photonic unitcell design and an optomechanical analysis framework. It advocates a dual-pattern metasail with uni-modal beam with the nanocraft placed at the back-side of a sail (pusher configuration) using an all-dielectric metasurface.

Worldship ethics for the Next Generation

In *Human Enhancement and Reproductive Ethics on Generation Ships* [2] Steven Umbrello (Delft University of Technology and Eurac Research) and Maurizio Balistreri (Università degli Studi di Torino) look at how genetic enhancement interventions can and should be used not only to ensure that future generations of offspring on the ships, and eventual exoplanet colonies, live a minimally good life but that their births are contingent on them living genuinely good and fulfilling lives. They go on to suggest that their optimistic conclusion in the worldship scenario implies that this also supports the notion of human enhancement on Earth. They discuss the ethics of human genetic enhancement (a massive subject in itself) and suggest it might mitigate the specific ethical issue of subsequent generations who were not able to choose this inevitably limited environment. These are deep philosophical and ethical waters. The authors suggest that genetic optimisation of the worldship population might relieve some of these difficulties but do not go into the specific modifications which might support this.

The Contact Era

In *The Fermi Paradox revisited: Technosignatures and the Contact Era* [3], Amri Wandel of the Hebrew University of Jerusalem suggests a solution to the Fermi Paradox - that probes or visits from putative alien civilisations are unlikely until a civilisation reaches a certain age after the onset of radio communications which he calls the Contact Era. He suggests that the expanding sphere of our transmissions, the radiosphere, must attract their interest. Therefore, unless civilisations are highly abundant, the Contact Era will be a few hundred to a few thousand years away. He applies this also to transmissions (ie SETI) as well as physical probes and concludes that civilisations are unlikely to be able to intercommunicate unless their communicative lifetime is at least a few thousand years. He argues that alien civilisations will not bother to explore merely biotic planets so our biosignature (a few hundred million years old) will be ignored since biotic life is probably common. Given that Earth-like exoplanets seem to be common he suggests that mere biosignatures may not be uncommon enough to be worth investigating. Since technosignatures will, by default, propagate isotropically, directed anisotropic signals will be very much more likely to lead to first contact and deliberate beams are likely to be directed specifically to us from our radiosphere.

[1] space.us10.list-manage.com/track/click?u=abbef0b5fff9a0ffa23d50307&id=0ce738af34&e=10c386d612
[2] www.nature.com/articles/s41598-022-24681-w
[3] arxiv.org/abs/2211.16505

CETI possibilities

Communication with extraterrestrial intelligence (CETI) is both technically difficult and politically controversial. Applying probability models to the technical issues, Reginald D Smith has published *Communicating extraterrestrial intelligence (CETI) interaction models based on the Drake Equation* [1]. The Drake Equation has always been a "thought experiment" or a "rule of thumb" but early discussions analysed it as potentially deterministic. Smith points to later work which has taken a statistical approach, including Claudio Maccone's 2010 paper, *The Statistical Drake Equation* [2], and its successors. The author applies a Poisson distribution [3] to model how ETI populations are affected by the number which can communicate with each other. He also cites the Allee effect, which observes that animal populations prosper as the number of individuals rise up to a point of overcrowding. This suggests that ETIs profit from intercommunication and, where such civilisations are sufficiently frequent within a communicating volume of space, then the Allee effect modifies the Drake Equation by enabling such a communicating community of civilisations to outlast some or all of its individual members.

Breakthrough Listen at MeerKAT

The Breakthrough Starshot interstellar probe work will be familiar to Principium readers. Another initiative within the Breakthrough programme, Breakthrough Listen, devoted to SETI, has just announced access to the MeerKAT radio telescope array in South Africa [4]. Since the Listen computing system has access to MeerKAT in "commensal" mode this yields a 24*7 year round data stream. The technical challenges the Listen team have overcome to deal, in real time, with this deluge of data can be imagined! More in *The Breakthrough Listen Search for Intelligent Life: MeerKAT Target Selection*, (arxiv.org/abs/2103.16250). Czech et al 2021.

It's not ETI (probably)

The journal *Astrobiology* has a collection of articles, *Special Collection: Interstellar Objects in Our Solar System*, Volume 22, Issue 12 / December 2022. (www.liebertpub.com/toc/ast/22/12).
The covering editorial is *Astrobiological Implications of Interstellar Material in the Solar System* (www.liebertpub.com/doi/full/10.1089/ast.2022.0088).
Here we review just two of the ten in this collection.

Bayes vs Loeb?

Charles H Lineweaver of the Australian National University evaluates the two hypotheses for the origin of 1I/'Oumuamua in *The 'Oumuamua Controversy: Bayesian Priors and the Evolution of Technological Intelligence* (www.liebertpub.com/doi/full/10.1089/ast.2021.0185). He applies the "Sagan Standard" (Carl Sagan in 1980 said "extraordinary claims require extraordinary evidence") via the approach of Thomas Bayes. The Bayesian prior probability that ETIs are detectable is judged very much lower than the prior probability of a natural explanation. Only with such extraordinary evidence to counter the low prior odds can the posterior odds of artificial origin be plausible. He is thus suggesting that, since we have not yet found an alien wristwatch (or perhaps had a flying saucer land on Worthy Farm during the Glastonbury Festival?) we cannot shout "It's ETI!"
To show how Bayesian reasoning works he recalls a news item "75% of Americans hospitalized with COVID are overweight" leading to the facile conclusion that the overweight are more vulnerable to COVID. But what if 80% of Americans are overweight? If so it suggests, counter to intuition, that overweight Americans are slightly less vulnerable since the 20% of non-overweight Americans must be contributing disproportionately to the COVID numbers.
He rejects the idea that a single instance of intelligent life, ourselves, significantly increases the

[1] International Journal of Astrobiology, Cambridge University Press: 02 December 2022. Open access at: www.researchgate.net/profile/Reginald-Smith-4/publication/353838345_Communicating_extraterrestrial_intelligence_CETI_interaction_models_based_on_the_Drake_Equation/links/6208075f634ff774f4c6ec7c/Communicating-extraterrestrial-intelligence-CETI-interaction-models-based-on-the-Drake-Equation.pdf
[2] Acta Astronautica, Volume 67, Issues 11–12, 2010
[3] As in the use of random arrival times in queuing theory. Applied to processes as diverse as call frequency at a telephone exchange, loading of a packet switching network and radioactive decay.
[4] See also *Alpha Centauri: Getting There – and What to Expect When We Do* – S Pete Worden in Principium 35 | November 2021 pages 24-25, reported in *Interstellar Research Group Symposium 2021*, Bart Leahy & Joseph Meany and IAC conference reports: Principium 23, November 2018, pages 28, 29, P28, February 2020 pages 27, 31. P30, August 2020, page 37, P38, August 2022 pages 32, 34

prior probability of intelligent life elsewhere. In effect, biology is not physics, since it is not subject to deterministic processes - at least at the macro level. If this is so then the prior probability of intelligent life is uncertain so does not contribute much to the probability that "It's ETI!" But he also points out that a single incontrovertible piece of pro-ETI evidence almost inverts the Bayesian result. It thus 'upsets the applecart'; so despite most of the above he concludes with -
"I support SETI and efforts to optimize telescopes to improve searches for interstellar objects (simultaneously improving detection of Near Earth Objects (NEOs)), and to prepare a mission to get close-up images of fast-moving interstellar objects. I support these efforts because when we have the technology to explore new parameter space relatively cheaply, we should do it. And because I agree with Haldane ('The universe is not only queerer than we suppose, it is queerer than we can suppose', 1927)".

Telescopes vs Probes?
Ben Zuckerman argues that *Oumuamua Is Not a Probe Sent to Our Solar System by an Alien Civilization* (www.liebertpub.com/doi/10.1089/ast.2021.0168).
He aims to support the view "that the accomplishments that can be achieved with large space telescopes/interferometers in the alien's planetary system will completely quench any motivation for construction and launch of an 'Oumuamua-like probe. The absence of any such motivation attests that 'Oumuamua is not an alien creation".
In other words, why would they (or we) send a probe when telescopes can tell us all we need to know? He discusses the feasibility of an artificial Oumuamua carrying a large optical telescope without saying why it might need one. He ignores the possibility that Oumuamua may be wreckage of a failed mission - possibly way off course. He assumes a deliberate flyby and "fleeting capabilities of any such flyby probe are vastly inferior to the power of space telescopes operational for eons of time in the interplanetary space of the alien civilization" but appears to cite only a 1979 piece about future space telescope capabilities *An Infinitely Expandable Space Radio Telescope*, Buyakas et al, Acta Astronautica 6:175.

In the same issue there are other papers including - *Self Replicating probes - Picogram-Scale Interstellar Probes via Bioinspired Engineering* (www.liebertpub.com/doi/10.1089/ast.2022.0008)
- and others covering broader issues including several on panspermia.

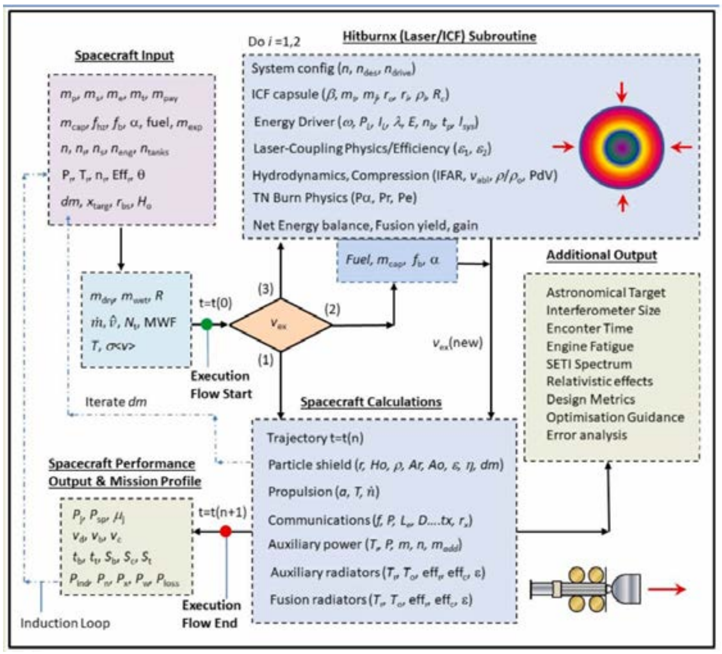
A Nuclear fusion breakthrough?

The news relevant to interstellar studies which hit the headlines was the net production of energy at the US National Ignition Facility [1]. Inertial confinement fusion is one of our best hopes for the propulsion of large scale interstellar probes. In *Nuclear fusion breakthrough: What does it mean for space exploration?* (www.space.com/nuclear-fusion-breakthrough-spacetravel) space journalist Leonard David looks at the achievement in terms of its propulsion applications.
He quotes physicist Fatima Ebrahimi at the Princeton Plasma Physics Laboratory "Fusion energy gain of greater than one is quite an achievement" and Richard Dinan of Pulsar Fusion in the UK "Fusion propulsion is a much simpler technology to apply than fusion for energy. If fusion is achievable, which at last the people are starting see it is, then both fusion energy and propulsion are inevitable,"
- and Ralph McNutt at the Johns Hopkins University Applied Physics Laboratory (JHU-APL), hailing the achievement but cautioning excessive optimism, recalling early attempts to use fission power in space which have yet to produce a working power source in space.
The Economist remains sceptical, stating that *Controlled fusion is little nearer now than it was a week ago* (www.economist.com/science-and-technology/2022/12/13/controlled-fusion-is-little-nearer-now-than-it-was-a-week-ago).
So, a milestone but not yet a winning post - and perhaps not even a lap marker?

[1] *Experimental achievement and signatures of ignition at the National Ignition Facility*, A B Zylstra et al Physical. Review E. 8 August 2022, https://journals.aps.org/pre/abstract/10.1103/PhysRevE.106.025202 no open publication found

Fusion for a 1,000 AU mission

By the time we reach the second half of the present century, Kelvin Long (co-founder of i4is) believes that practical fusion propulsion will make feasible a mission to 1,000 AU, the beginning of the Oort Cloud of long-period comets. He has published *Sunvoyager: Interstellar Precursor Probe Mission Concept Driven by Inertial Confinement Fusion Propulsion*, Jan 2023, in the Journal of Spacecraft and Rockets [1], an online journal of the American Institute of Aeronautics and Astronautics. He has developed a software tool HeliosX [2] to compute the system parameters for the mission. It's written in Fortran 95. Fortran remains the preferred choice for many scientists and engineers, 65 years since its 1957 origin. The HeliosX tool analyses and reports the major elements of the whole spacecraft system as this flow diagram (right) shows.

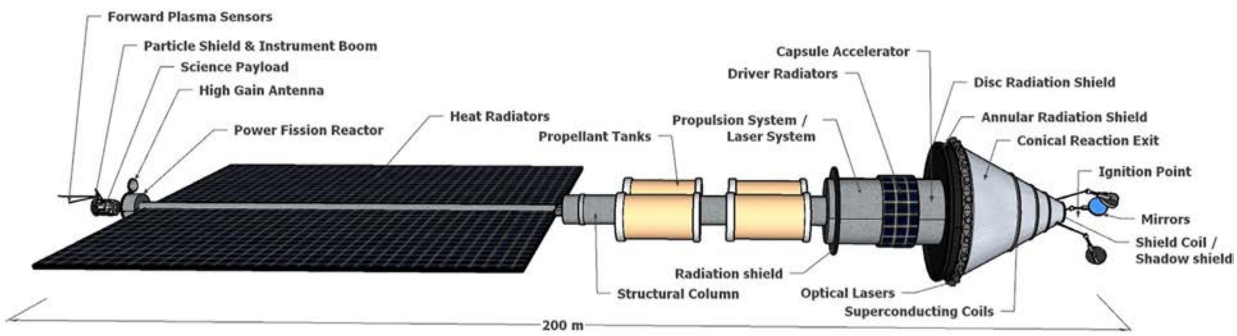


Flow diagram of code architecture for HeliosX.
Credit (caption and image): K F Long

The Sunvoyager paper sets three science objectives of this initial mission -

- Optical observation of the nearest stars and associated exoplanets through the use of gravitational lensing and the transit method.
- A flyby of a deep space dwarf planet that has not been previously visited.
- Imaging of deep space interstellar asteroids such as 1I/'Oumuamua

The proposed vehicle configuration is -



Concept design layout of Sunvoyager spacecraft configuration. Credit (caption and image): K F Long

- note that the propulsion system is on the right and the payload on the left. The conical propulsion unit is based on the 2003 VISTA proposal [3] which explains "The conical spacecraft design permits nearly all of the neutron and x-ray energy to escape to space because the spacecraft structure lies in the shadow of the thermal shield for the superconducting magnet coil."

Kelvin intends further analysis of the propulsion system optimising for maximum thrust efficiency and minimization of radiation exposure to the material structure. The cruise velocity would be 0.005c, much faster then our fastest probes; Voyagers requiring 40 years to reach just 150 AU [4]. Sunvoyager is therefore a true interstellar precursor proposal.

More from Paul Gilster at - www.centauri-dreams.org/2023/01/06/sunvoyager-a-fast-fusion-mission-beyond-the-heliosphere/.

[1] arc.aiaa.org/doi/10.2514/1.A35539
[2] HeliosX: Inertial Confinement Fusion Code for Advanced Space Propulsion & Interstellar Mission Analysis, Acta Astronautica, Volume 202, January 2023, www.sciencedirect.com/science/article/pii/S0094576522005598?via%3Dihub
[3] VISTA – A Vehicle for Interplanetary Space Transport Application Powered by Inertial Confinement Fusion, C D Orth, Lawrence Livermore National Laboratory, 2003. www.osti.gov/biblio/15015945
[4] At 0.005c a probe to Alpha Centauri, 4 light-years away would take approximately 4/0.005 = 800 years. But in the Voyager timescale a probe at Sunvoyager velocity would reach 40*0.005 = 0.2 light years or 63,240*0.2 = 12,648 AU

IAC 2022

72nd International Astronautical Congress 2022 The Interstellar Presentations - part 2

edited by John I Davies

This year the International Astronautical Federation held the 2022 International Astronautical Congress in Paris 18-22 September. Here is our second report on items which are likely to be of special interest to Principium readers. Some are explicitly interstellar in topic but others are important in contributing to our interstellar goal including innovations in propulsion, exploitation of resources in space, deep space communication and control, enhanced and economical access to space, etc.

This is the second of two reports on the Congress. The first in our previous issue, Principium 39, in November 2022. Our reporters, for both reports, are Adam Hibberd, Al Jackson, Alan Cranston, Cassidy Cobbs, Dan Fries, Graham Paterson, John Davies, Michel Lamontagne, Patrick Mahon and Samar AbdelFattah.

The reports include - Code - the unique IAC code, Paper title, Speaker, institutional Affiliation and Country. Links to the abstract, paper and video/presentation on the IAF website (login required) and to open publication where found.

Please contact john.davies@i4is.org if you have comments, find discrepancies or have additional items we may have missed at the Congress.

The Congress was divided into these main subject areas -

A1. IAF/IAA SPACE LIFE SCIENCES SYMPOSIUM

A2. IAF MICROGRAVITY SCIENCES AND PROCESSES SYMPOSIUM

A3. IAF SPACE EXPLORATION SYMPOSIUM

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

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

A6. 20th IAA SYMPOSIUM ON SPACE DEBRIS

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

B1. IAF EARTH OBSERVATION SYMPOSIUM

B2. IAF SPACE COMMUNICATIONS AND NAVIGATION SYMPOSIUM

B3. IAF HUMAN SPACEFLIGHT SYMPOSIUM

B4. 29th IAA SYMPOSIUM ON SMALL SATELLITE MISSIONS

B5. IAF SYMPOSIUM ON INTEGRATED APPLICATIONS

B6. IAF SPACE OPERATIONS SYMPOSIUM

C1. IAF ASTRODYNAMICS SYMPOSIUM

C2. IAF MATERIALS AND STRUCTURES SYMPOSIUM

C3. IAF SPACE POWER SYMPOSIUM

C4. IAF SPACE PROPULSION SYMPOSIUM

D1. IAF SPACE SYSTEMS SYMPOSIUM

D2. IAF SPACE TRANSPORTATION SOLUTIONS AND INNOVATIONS SYMPOSIUM

D3. 20th IAA SYMPOSIUM ON BUILDING BLOCKS FOR FUTURE SPACE EXPLORATION AND DEVELOPMENT

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

D5. 55th IAA SYMPOSIUM ON SAFETY, QUALITY AND KNOWLEDGE MANAGEMENT IN SPACE ACTIVITIES

D6. IAF SYMPOSIUM ON COMMERCIAL SPACEFLIGHT SAFETY ISSUES

E1. IAF SPACE EDUCATION AND OUTREACH SYMPOSIUM

E2. 50th STUDENT CONFERENCE

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

E4. 56th IAA HISTORY OF ASTRONAUTICS SYMPOSIUM

E5. 33rd IAA SYMPOSIUM ON SPACE AND SOCIETY

E6. IAF BUSINESS INNOVATION SYMPOSIUM

E7. IISL COLLOQUIUM ON THE LAW OF OUTER SPACE

E8. IAA MULTILINGUAL ASTRONAUTICAL TERMINOLOGY SYMPOSIUM

E9. IAF SYMPOSIUM ON SECURITY, STABILITY AND SUSTAINABILITY OF SPACE ACTIVITIES

E10. IAF SYMPOSIUM ON PLANETARY DEFENSE AND NEAR-EARTH OBJECTS

GTS. GLOBAL TECHNICAL SYMPOSIUM

LBA. LATE BREAKING ABSTRACTS

◀ The Reports

In this issue, sorted by IAC22 reference-

IAC22 reference	Title	Presenter	Institution	Country	P#
A.1.6.4.x73104	Space exploration of icy moons to determine their astrobiological potential	Athena Coustenis	Paris University	France	30
A.3.5.2.x71874	Exploration of Venus Using Bioinspired Flier, BREEZE	Mr Nicholas Noviasky	University at Buffalo	USA	28
A3.5.4.x70283	Feasibility study of a robotic space mission for searching trace of life on Europa	Mr. Mario Rizzi [1]	Politecnico di Torino	Italy	22
A4.2.7.x70624	SETI Space Telescope Mission Concepts Designed Around Upcoming Fully-Reusable Launch Vehicles	Mr Eric Michaud	MIT	USA	23
A5.4-D2.8.2.x72880	NASA Envisioned Future Priorities for In-Space Transportation	Mr John Dankanich	NASA	USA	41
A5.4-D2.8.4.x68378	Mission to Mars Using Space-Sourced Propellant	Dr Jan Thoemel	University of Luxembourg	Luxem-bourg	36
C2.3.8.x73418	Dynamic Stability of Flexible Lightsails for Interstellar Exploration	Dr Michael Kelzenberg	Caltech	USA	40
C3.4.1.x73419	Power for Interstellar Lightsails	Mason Peck et al	Cornell University	USA	32
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D4.1.12.x70259	Advancements in Laser Propulsion for Relativistic Lightsail Missions	Mr Wesley Green	Breakthrough Initiatives, Starshot	USA	39
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◀ The Papers

IAF ref	title of talk/paper	presenter	institution	nation
A3,5,4,x70283	Feasibility study of a robotic space mission for searching trace of life on Europa	Mr Mario Rizzi [1]	Politecnico di Torino	Italy

IAF abstract: iafastro.directory/iac/paper/id/70283/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A3/5/manuscripts/IAC-22,A3,5,4,x70283.pdf

IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A3/5/presentations/IAC-22,A3,5,4,x70283.show.pptx

Open paper: none found

Reported by: Adam Hibberd

Does Europa, moon of Jupiter, harbour life? Well this feasibility study into how a mission might be realised would discover yea or nay, beyond any doubt, right? Wrong!

This €6.9bn project called EREBUS (that is Europa Research and Exploration for Biosignatures Under the Surface) would launch in the late '30s and exploit the VEEGA interplanetary sequence of encounters to get to Jupiter – some of you might recognise this as the same well-trodden route also elaborated in a certain Project Lyra paper ('without a Solar Oberth').

The mission has 3 elements:

1) An orbiter

2) A lander

3) A probe for deep subsurface exploration

Here's the suggested instrumentation for the three components -

Table 1. Instrumentation matrix and payload allocation (L=Lander, O=Orbiter, S=Subsurface)

	Goals			
Instruments	1	2	3	4
Focusable stereo cameras		L	L	
Seismometer		L	L	
Thermal infrared imager		O	O	O
UV spectrometer		O	O	O
Long range HRES camera			O	O
Magnetometer			O	O
Radio Science Investigations			O	O
Radiation monitor			O	O
Mass spectrometer	S	S	S	
Nanopore sequencing device	S			
DUV Raman spectrometer	S	S		
Subsurface camera	S	S		
Microscope for life detection	S			
Ph measurement transistor			S	
Radiation monitor			S	
IR thermometer		S	S	
Passive acoustic system		S		
Pressure transducer			S	

Goals:

1. To search for life on Europa
2. To assess habitability of Europa
3. To characterise water worlds around gas giants
4. To improve the understanding of the Solar System

[1] Co-Authors: **Politecnico di Torino:** Mr Federico Giraldo, Mr Matteo Nobili, Mr Leonardo Ricci, Mr Antonio Rotondi, Mr Baptiste Rubino-Moyner, Ms Min CUI **University of Leicester:** Mr Jose Cavero, Mr Sedat Izcan, Mr Thomas Lovell, Mr Nihar Modi, Ms Asnate Plocina, Mr Alexander Smith, Mr Parin Vyas, **ISAE-Supaero University of Toulouse**: Mr Vincent Bourinet, Mrs Pauline Carpi, Mr Antonin Lecomte, Mr Ryan Dahoumane, Mr Nicolas Pironnet, Mr Julien Rondey, Mr Sacha Sylvestre, Mr Guillaume Truong-Allié.

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The whole thing looks entirely sensible and credible but there are two factors which strike me about the venture. Firstly, what happens if there is a negative result from the subsurface probe? Would that mean absence of life? Clearly not because we may well have simply been looking in the wrong location at the wrong time - in which case this €6.9bn project would have been a complete and utter waste of effort, time and more-to-the-point money. Secondly, look at that launch date again: late ‘30s. By this time the exponential acceleration of digital technology, elaborated by Ray Kurzweil, will have had all sorts of consequences on the nature of robotic technology and for that matter, AI.

Who knows what kinds of robots may have emerged? What weird and wonderful tasks they would be capable of? How powerful their minds would be? There is a hell-of-a-lot of unpredictability and vagueness here which clearly renders any high-minded plans for robotic exploration, made at this point-in-time, almost completely extraneous if not pointless.

IAF ref	title of talk/paper	presenter	institution	nation
A4,2,7,x70624	SETI Space Telescope Mission Concepts Designed Around Upcoming Fully-Reusable Launch Vehicles	Mr Eric Michaud	MIT	USA

IAF abstract: iafastro.directory/iac/paper/id/70624/summary/

IAF cited paper: none available

IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A4/2/presentations/IAC-22,A4,2,7,x70624.show.pptx

Open paper: none found

Reported by: Adam Hibberd

In this presentation, the author outlines his intention of delving into the problem of using cheap, reusable launch vehicles, chiefly the SpaceX Starship, for launching radio telescopes intended for SETI research, into either high Earth orbits or even better, to the far side of the Moon, where a telescope is protected from interference (RFI). A further advantage of such a location is that low frequency radio waves would not be affected by the Earth’s Ionosphere, which is a huge plus for SETI research. Two existing lunar observatory proposals are then treated briefly, namely the FARSIDE project, which would exploit the Blue Origin lunar lander and deploy 128 dipole antennae using 4 rovers (3 tonnes); and then the LCRT (Lunar Crater Radio Telescope) which would be pretty close in design to the now non-operational Arecibo.

So next the target launcher, the SpaceX Starship rocket, is analysed. It will have a 100+ tonne lift capability to LEO, a huge cargo volume potential (1000+ m3) and would be cheap – somewhere around $10M per launch initially but then reducing to $1-2M per launch with time. To get a grasp of the capability of Starship as far as lunar missions are concerned, at this point in the presentation Eric quotes Aarti Matthews, Director of Starship Crew and Cargo Programs: “Starship can land 100 tonnes on the lunar surface…”

Furthermore the Starship has been adopted by NASA as the HLS (Human Landing System) for the proposed Artemis III architecture. Essentially this comprises a Starship (designed for human life-support) waiting at the NRHO (Near Rectilinear Halo Orbit). It would previously have been inserted into LEO and sufficiently stocked with propellant (by a total of 8 Starship fuelling missions) to allow it to move into the NRHO. A crewed Orion vehicle would then arrive (courtesy of a NASA SLS launch) at the Starship and there would be transfer of crew to the Lunar Starship. This Starship would have enough fuel and a lander to allow a surface expedition to be undertaken. On completion there would be a lift-off from the lunar surface, a return to the NRHO, and transference of crew back to the Orion vehicle. The Orion would then travel back to Earth with the human occupants safely onboard.

Finally Eric estimates the cost of using the several Starships as a means of fuelling in LEO as between $10M and $90M. In contrast a fleet of Falcon 9’s would cost $67M and of Falcon Heavies would be $97M.

To summarise, a presentation altogether lacking in detail and specifics but concentrating on cost and overall architecture. The author can be forgiven perhaps due to the sheer scarcity of useful information and specifications available about the up-and-coming Starship launch system.

IAF ref	title of talk/paper	presenter	institution	nation
D4,4,9,x69502	The Pragmatic Interstellar Probe Study: Results	Dr Ralph L McNutt Jr	Johns Hopkins University Applied Physics Laboratory (JHU-APL)	USA

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

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

Open paper: none found

Reported by: Al Jackson

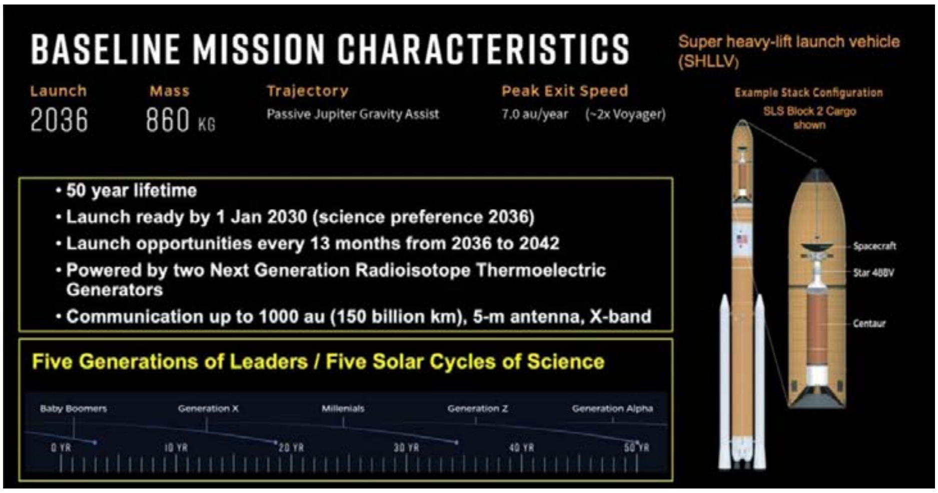
In 1987 JPL proposed a mission to send a nuclear powered spacecraft to 1,000 astronomical units (TAU). This would have been a dedicated unmanned probe to study 'near' interstellar space, quite apart from solar system probes like Voyager and New Horizons. There have been several detailed studies and proposed 'interstellar probes' since the 1980s (Interstellar probe, Wikipedia, en.wikipedia.org/wiki/Interstellar_probe#Functional_spacecraft).

In 2018 NASA's Heliophysics Division tasked the Johns Hopkins University Applied Physics Laboratory (APL) with taking a renewed look at a mission focused on mapping pragmatic possibilities to community-wide science goals and measurement approaches for input to the Survey. Adopted requirements include a launch readiness date of no later than 1 January 2030; a downlink of science data from no less than 1,000 au; available power of 600 watts at launch and half that at mission's end; and a mission lifetime, by design, of 50 years. This effort is supported by seven ongoing engineering studies: Longevity, examining historical spacecraft lifetimes/failures, long-lasting systems, and failure modes assessment; Instruments, providing candidate payload components to assess how those will levy requirements back on the spacecraft; Trajectory and launch vehicle trades to determine achievable solar system escape speeds; communication and guidance and control (G&C), assessing best strategies for maximizing the science data downlink from up to 1000 au; heat shield materials and construction, to determine how close and with what mass the spacecraft could actually approach to the Sun to execute an Oberth manoeuver (one of the trajectory trades); Mechanical layout, to accommodate baseline payloads and all other trades, to estimate achievable solar-system escape speeds; and, power system configurations to meet power requirements, based upon the Next-Generation Radioisotope Thermoelectric Generator (NG-RTG), to meet power and longevity requirements.

The mission requirements have narrowed some from the initial study; focus now is on the heliosphere.

1. How is our heliosphere upheld by the physical processes from the Sun to the very local interstellar medium?
2. How do the current interstellar medium properties inform our understanding of the evolutionary path of the heliosphere?
3. How does the Sun's activity as well as the interstellar medium and its possible inhomogeneity influence the dynamics and evolution of the global heliosphere?

All the studies for this mission have reached a high level of maturity and a final report will be given to NASA in the 2023 to 2024 timeframe.



Summary and overview of mission implementation that addresses all top-level engineering requirements. Credit (image and caption): McNutt et al. Fig. 9.

IAF ref	title of talk/paper	presenter	institution	nation
D4,4,5,x72336	Performance Map for Laser-Accelerated Sailcraft Missions	Dr Kevin Parkin	Parkin Research LLC	USA

IAF abstract: iafastro.directory/iac/paper/id/72336/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/4/manuscripts/IAC-22,D4,4,5,x72336.pdf

IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/4/presentations/IAC-22,D4,4,5,x72336.show.pptx

Open paper: none found

Reported by: Al Jackson

The Breakthrough Starshot research program envisions a laser-propelled sail that will probe our neighboring stars within a human lifetime. Starshot spacecraft weigh no more than a few grams and are accelerated by photon momentum transfer with a beam generated by a kilometer-scale, ground-based 100 GW coherent phased-array laser to 20% the speed of light. Many questions arise in modeling how a laser-propelled sail can be designed for a star flight mission.

A system model is formulated around the propagation of a beam from a ground-level beamer to a sailcraft in space above it. The sailcraft begins at a given initial displacement above the beamer. This displacement, in combination with the beamer diameter, is used by a beam propagation model to determine the fraction of transmitted power that reaches the sailcraft. A material/optical model calculates how much of the power that is incident on the sailcraft is reflected or absorbed. A relativistic equation of motion then translates this power into acceleration. The equation of motion is analytically propagated forward in time until the sailcraft reaches its desired cruise velocity. The last photons arriving at the sailcraft are traced back in space and time to determine when beam cutoff occurs at the beamer. Several system parameters are optimized to ensure that the sailcraft actually reaches cruise velocity and does so using a minimum-cost beamer. This cost optimization reduces the dimensionality of the model.

At its core, the system model describes a laser beam's propagation from a ground-level beamer (beam director) to a spaceborne sailcraft (sail and craft, which may be discrete or integrated and the sailcraft's resulting motion. It relates key design parameters that determine the system capital expense and operational expense. Optimizers then vary the inputs to find values that minimize expenses.

Table 1: System model constants

1.06 µm wavelength

60 000 km initial sail displacement from laser source

0.2 g m^{-2} areal density

10^{-8} spectral normal absorptance at 1.06 µm

70% spectral normal reflectance at 1.06 µm

625 K maximum temperature

0.01 total hemispherical emittance (2-sided, 625 K)

\$0.01 W^{-1} laser cost (k_l)

\$500 m^{-2} optics cost (k_a)

\$50 kWh^{-1} storage cost (k_s)

\$0.1 kWh^{-1} grid energy cost (k_g)

100% grid to storage efficiency (η12)

50% storage to laser efficiency (η23)

70% transatmospheric propagation efficiency (η_a)

100 operations included in cost minimization (n_o)

System model constants. Credit: Parkin

IAF ref	title of talk/paper	presenter	institution	nation
D2,4,9,x67466	Interplanetary transfer network design and technology roadmap for a sustainable off-world human community	Mr Koldo Zuniga	Cranfield University	UK

IAF abstract: iafastro.directory/iac/paper/id/67466/abstract-pdf/IAC-22,D2,4,9,x67466.brief.pdf?2022-03-30.10:23:43

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D2/4/manuscripts/IAC-22,D2,4,9,x67466.pdf

IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D2/4/presentations/IAC-22,D2,4,9,x67466.show.pptx

Open paper: none found

Reported by: Graham Paterson

The first half of the 21st century should see the first human landings on Mars and the start of establishing of bases and colonies. Many studies have been done of possible trajectories for these space missions, indeed this would run into hundreds over the past 50 years. Critical to the success of these colonies will be the establishment of interplanetary transfer networks for cargo and crew, and eventually even for space tourists in the late 21st century. The work by Alvarez is from an MSc thesis studying the requirements for fast transfers in terms of engine technologies and dry mass fractions (DMF). The engine technologies are identified by the specific impulse (ISP) required for each deltaV (ΔV).

Table 2: Typical journeys durations the colonization of America. Similar trip lengths could be expected on a mature interplanetary transportation network between Earth and Mars.

Interplanetary transportation network between Earth and Mars.				
Journey	Year	Transportation	Duration	Ref.
SEA TRANSPORT				
Plymouth to Massachusetts ("Mayflower")	1620	Sailing Ships	10+ weeks	[15]
Liverpool to New York	1800	Sailing Ships	6-14 weeks	[16]
Liverpool to New York	1870	Steamships	2 weeks	[16]
ROAD TRANSPORT				
New York to Chicago	1830	Railroad	6 weeks	[17]
New York to L.A.	1857	Railroad	4 weeks	[17]
New York to L.A.	1930	Railroad	3-4 days	[17]

Note 1: Depending on adverse winds and bad weather. Also, westward trips were longer than eastward trips.

A prior example - American colonisation

Credit (caption and image): Zuniga et al

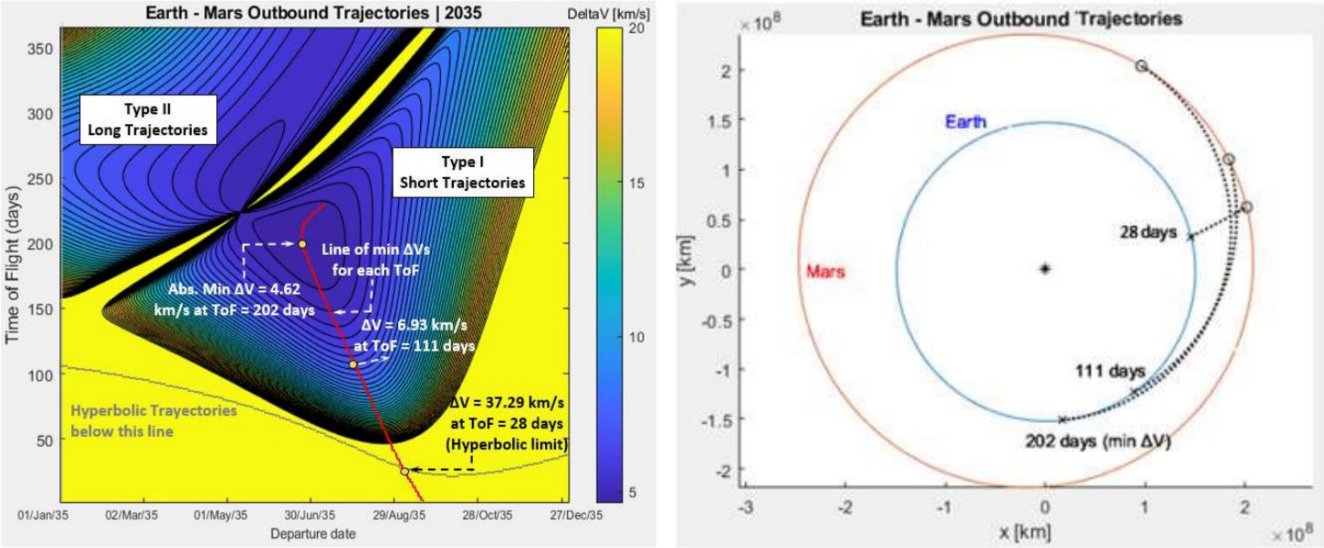
Refs are in the paper

After setting out the scope of the paper and key previous studies, Alvarez goes on to discuss current and future propulsion technologies, concentrating on the following (all ISP values from Alvarez):

- Chemical propulsion
- Solid core nuclear thermal (NTP) with ISP levels around 1,000 s
- Nuclear Electric Propulsion (NEP) with ISP levels in the 5,000 s range
- Advanced fission NTP at ISP around 10,000 s

For each analysis, the core equation used was Tsiolkovsky's Equation $\Delta V = g_{ISP} \text{ Ln } (m_o/m_f)$.

Alvarez used impulsive trajectory design, all departing from a 400 km LEO followed by a heliocentric cruise and terminating at a parking orbit around the target planet. It was assumed that the interplanetary transfer problem could be treated stand alone, without any discussion of Ground To Orbit or Orbit To Ground transfer. In each case departure windows are chosen as centred around optimal planetary alignments and the time of flight (TOF) selected as long enough to contain a minimum energy trajectory.



Example "pork chop" plot and trajectories

Three scenarios of EARTH - MARS one-way trajectories ranging from very fast to min. energy: 202 days min energy transfer, 111 days transfer and a 28 days parabolic transfer.
Left chart is a one-way Pork-Chop plot with selected trajectories marked over the min ΔV line.
Right chart is a 2-D graphical representation at scale of these trajectories.

Credit (caption and image): Zuniga et al (Figure 5)

Departure windows are set for 2034 and 2035 for a one-way impulsive trip. For round trips departure windows are set for 2035-2038. The analysis splits the trajectory into patched conics and a Lambert arc. Finally, Alvarez discusses his criterion for a minimum Dry Mass Fraction (DMF). Dry Mass Fraction can be defined as the ratio of final mass to initial mass. Somewhat arbitrarily, in this reviewer's opinion, Alvarez selects 75% as his minimum DMF. This may be ambitious.

Alvarez used the methodology to analyse one-way trips between Earth and Mars, resulting in a series of pork-chop plots. The results showed that a chemical propulsion system would result in a 200-day TOF at a DMF of 40%. His solid core fission NTP analysis yielded the same TOF but with a 60% DMF. These were below his arbitrary 75% threshold. Alvarez found that 60-day one day trips at a DMF of 75% could be achieved with an NEP at ISP = 5,000 s. Similarly, a TOF of only 1 month would be feasible at this DMF with advanced NTP propulsion systems at ISP = 10,000 s. Interestingly, he found that trading off DMF to shorten transfer times is especially effective close to minimum energy trajectories. He found that a 40% DMF, 200-day mission could be reduced by 70 days with a 10% decrease in DMF. This suggests the trade off spaces available for designers of such missions.

Alvarez reached similar conclusions for Earth – Venus and Earth – Jupiter trajectories. Venus allows for faster transfers but needs higher ISP's than Mars. For example, Alvarez reported a 130-day TOF with an ISP of 2,500 s and DMF 75%. Jupiter, however, has a very long min energy transfer time of just under 3 years. Fast trajectories to Jupiter at 75% DMF were found to require very advanced systems of at least 10,000 s.

Alvarez then went on to analyze two-way trajectories by combining outbound and inbound analyses with a planetary stop over period. He found that the absolute minimum ΔV leads to an 800-day mission time, where Mars and Earth align with the 26-month synodic period. At these mission times planetary stay times had negligible impact. A local minimum of 500 days mission time could be achieved by decreasing DMF from 75% to 72%. It was found that adding a refueling operation during the stop over resulted in a significant improvement, enabling round trips as short as 260 days with 75% DMF. When applied to Venus he found a similar behaviour to Mars except that the commuting time is less at the cost of higher specific impulse. However, Earth – Jupiter networks were shown to be unfeasible until advanced propulsion systems with at least 10,000 s specific impulse become available and crew-rated.

The paper was interesting to read, although the organisation could have been improved in several places and the selection of a 75% DMF seemed somewhat arbitrary. The paper demonstrates that when even NEP propulsion systems become crew-rated significant fast networks between Earth and Mars, as well as Earth and Venus, would be possible. The implication of this is that while the first manned missions will likely use chemical propellants, the advancement of nuclear propulsion should be a high priority for the efficient establishment of a Mars colony and the eventual establishment of colonies around more distant worlds in the Solar System.

IAF ref	title of talk/paper	presenter	institution	nation
A.3.5.2.x71874	Exploration of Venus Using Bioinspired Flier, BREEZE	Mr Nicholas Noviasky	University at Buffalo	USA

IAF abstract: iafastro.directory/iac/paper/id/71874/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A3/5/manuscripts/IAC-22,A3,5,2,x71874.pdf

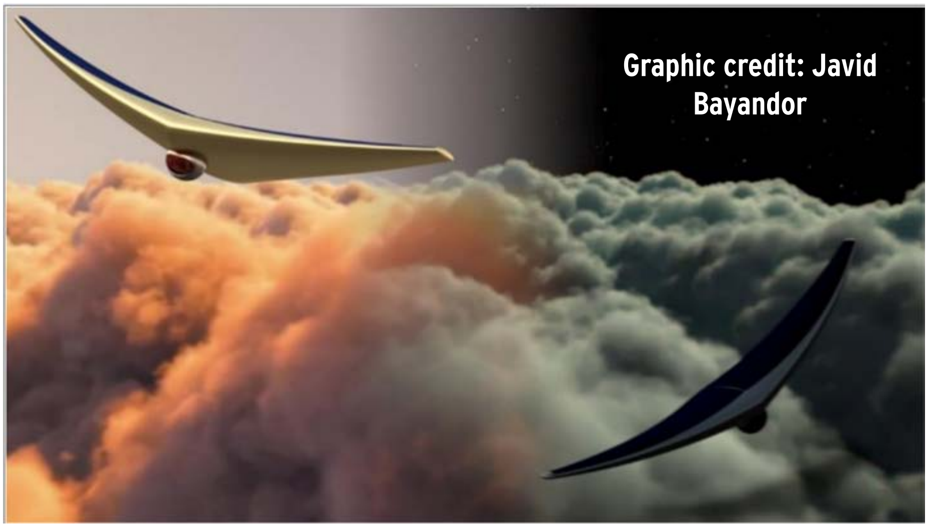
IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A3/5/presentations/IAC-22,A3,5,2,x71874.show.pptx

Open paper: none found

Reported by: Graham Paterson

Venus is an important target for scientific exploration. Although of similar size to Earth the planet itself is very different with an extremely thick Carbon Dioxide layer and clouds of sulphuric acid, the effect of which is to trap heat and lead to the hottest temperatures in the solar system as well as an atmospheric pressure nearly 90 times what is experienced on earth. It is also one of only two planets with a retrograde rotation, as well as the rotation rate itself being very slow – in fact a day on Venus lasts 243 days, in contrast to a year lasting 225 days! It is of extreme scientific value to better understand this world. Recently observations of unusual chemistry, especially phosphine, in the atmosphere have raised again the possibility that there may be some form of life on the planet, although this is unlikely. The NASA Innovative Advanced Concepts program funded a Phase 1 study at SUNY Buffalo on a project known as BREEZE. This is a splendid acronym for Bioinspired Ray for Extreme Environments and Zonal Exploration! The concept has now been selected for phase II, and is an excellent candidate for the Venus Climate Mission. The researchers report that Venus was selected due to its thick atmosphere but the concept is also viable for Titan and indeed even the Earth. Two of the lead researchers wrote this paper which will now be summarized with comments.

BREEZE is intended to be an inflatable structure with sufficient buoyancy to remain aloft in the thick Venusian atmosphere at altitudes around 50 km, and using actuators inspired by manta rays on Earth it will have a propulsion capability, allowing it to traverse the planet riding the zonal winds and being able to resist the North South meridional winds, which can trap balloons near the polar vortex.


Graphic credit: Javid Bayandor

The authors give an overview of the Entry, Descent and Inflation (EDI) procedure. This begins the same way as the EDL procedures familiar on Mars missions. An entry module will separate from an Orbiter and enter the atmosphere, simultaneously heating up and decelerating eventually to subsonic speeds. At this point the heat shield and back shell are released, with a parachute being deployed to further reduce speed and begin to pull BREEZE away from its external frame. Once far enough free it will begin to inflate and orient itself in the atmosphere. This is a very novel procedure with a high risk involved. Once fully inflated, aligned and checked out, BREEZE will begin to traverse the zonal winds.

Next the authors state that a nominal flight plan would be a uniform spiral starting initially near the equator and moving towards the poles. Although not stated in the paper, the NASA website states that it will be able to circumnavigate the planet every 4 to 6 days. The manta ray inspired propulsion will allow it to overcome the meridional winds, although the authors state that the thrust capabilities will not be needed continuously. The capability of thrusting mean that BREEZE is not simply riding winds, unlike a balloon. BREEZE is intended to have solar panels which it will recharge when on the day side of the planet. The flapping effect will be accomplished by tensioning cables acting as actuators, placed inside the craft to avoid the corrosive atmosphere.

The authors then report the science objectives as being

- Study of Venusian atmospheric chemistry
- Detailed surface scanning
- Examining the magnetosphere
- Searching for active volcanic activity

To accomplish this the flier will be equipped with a suite of standard scientific instrumentation such as spectrometers, magnetometers and a multiband radar.

In phase I the authors carried out dynamic simulations using CFD techniques to analyze the flight concepts. However there is much to be done as it moves into Phase II and the authors list the following as goals they need to accomplish:

- Improving FEA modelling
- More extensive use of CFD analysis
- Analysis of the aerodynamics of the inflation phase on EDI
- Development of prototype models for wind tunnels
- More detailed studies of the heat shield and entry modules
- Hypersonic simulations for various high lift/drag entry vehicles
- Methods for aligning BREEZE correctly so that the flier doesn't experience large accelerations on inflation
- Studies on correctly distributing forces over the vehicle

The paper gives only a brief overview of the project, but NASA and SUNY Buffalo have online resources for further study. This is a promising concept, applicable to other worlds with thick atmospheres, although there will need to be extensive modelling, testing using scale models and flight prototypes, especially with the inflation procedures on EDI. Phase I elevated the concept from TRL1 to TRL2. Phase II will elevate it to TRL 4. A highly innovative and promising concept for the future.

Web references:

University at Buffalo www.buffalo.edu/news/releases/2019/11/009.html

NASA www.nasa.gov/directorates/spacetech/niac/2022/BREEZE/

IAF ref	title of talk/paper	presenter	institution	nation
A.1.6.4.x73104	Space exploration of icy moons to determine their astrobiological potential	Athena Coustenis	Paris University	France

IAF abstract: iafastro.directory/iac/paper/id/73104/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A1/6/manuscripts/IAC-22,A1,6,4,x73104.pdf

IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A1/6/presentations/IAC-22,A1,6,4,x73104.show.pptx

Open paper: none found

Reported by: Graham Paterson

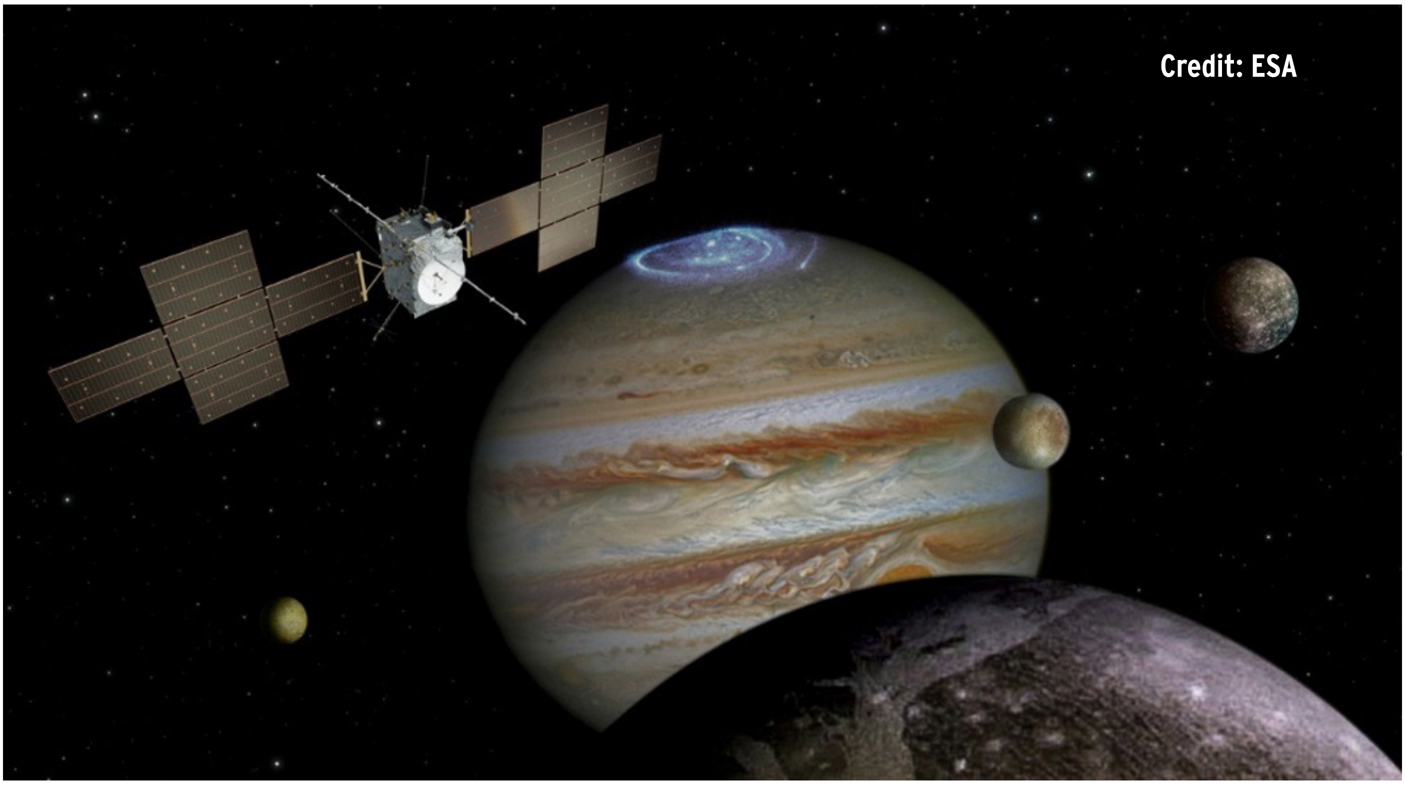
It has been known for some time that some of the icy moons of Jupiter and Saturn may harbour subsurface oceans, although up to 14 worlds in the solar system may have substantial oceans, including of course the Earth. The presence of liquid water on these bodies holds out promise of the tantalising prospect of life on some of these moons. The paper by Athena Coustenis is a short but information rich summary of how space missions are shortly to determine the astrobiological potential of these bodies.

In the paper she first sets the scene by selecting Titan and Enceladus from Saturn, and the Jovian moons Ganymede and Europa. She points out that all these environments may satisfy many of the classical criteria for habitability, namely liquid water, energy sources and nutrients over a long period. All four are likely to harbour subsurface oceans.

Coustenis then lists some open questions for these icy moons. Among these are the following:

- Are the silicate mantles of Europa and Ganymede as well as the liquid sources of Titan and Enceladus geologically active? (If so they may be the equivalent of hydrothermal systems.)
- How does Titan function as a system?
- What is the complexity of the chemistry on Titan?
- What is the source of geysers on Enceladus?

Coustenis then details the JUICE space mission to Jupiter and provides some background to the Dragonfly mission to Titan.



JUICE (Jupiter Icy Moons Explorer) is an ESA mission due to launch in early 2023. The mission will feature:

- A 7.6 year cruise phase after launch from earth, arriving at Jupiter in 2031
- Use of gravity assists to perform a tour of the Jovian system
- Two targeted flybys of Europa, studying on life critical chemistry
- One targeted flyby of Callisto
- Orbital insertion around Ganymede in 2034
- Determining characteristics of the hypothesised liquid water subsurface ocean
- Characterising the interactions within the Jovian system
- Targeted impact on Ganymede to end the mission in December 2034

Turning next to Dragonfly, Coustenis notes that this will land a mobile rotorcraft lander to study different environments on Titan and have the potential to revisit sites. The craft will study prebiotic chemistry.

Coustenis then ends by stating the tantalising prospect of liquid water sources being combined with nutrients and geological activity which may be the equivalent of hydrothermal systems and perhaps being suitable habitats for life itself.

I found the paper to be short, information rich and an excellent summary of why we are going to the icy moons, what we are looking for, and some implications of what we might find.

Websites:

JUICE: sci.esa.int/web/juice/

Dragonfly: dragonfly.jhuapl.edu/

IAF ref	title of talk/paper	presenter	institution	nation
C3,4,1,x73419	Power for Interstellar Lightsails	Mason Peck et al	Cornell University	USA

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

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/C3/4/manuscripts/IAC-22,C3,4,1,x73419.pdf

IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/C3/4/presentations/IAC-22,C3,4,1,x73419.show.pptx

Open paper: none found

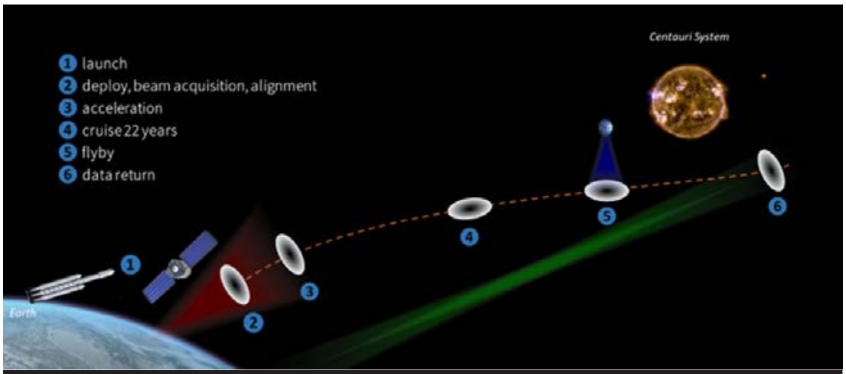
Reported by: Patrick Mahon

This paper focuses on one particular aspect of spacecraft design – the power and energy system – for the Breakthrough Starshot programme. As Principium readers will know well, Starshot aims to use a powerful laser to propel a swarm of gram-scale lightsails to the Alpha Centauri system at one-fifth the speed of light, enabling the journey to be completed in around 20 years [1]. How to power these tiny spacecraft is one of the many major challenges that needs to be overcome if Starshot is to be successful.

The paper has been produced by a group of 11 authors from a range of leading American institutions, including the Breakthrough Initiatives, NASA and six universities, so its conclusions seem likely to be soundly based.

Taking a systems engineering approach, the authors consider the power and energy generation and storage requirements for a minimum viable mission to Alpha Centauri, then identify the various technological options available now or in the near term that might satisfy these requirements.

The Starshot mission profile is shown in Figure 1. Key elements of the mission from the perspective of power and energy are:



Credit (caption and image): Peck et al (Figure 1)

• Spin control – the minimum viable mission spins the sail (eg at 10 revolutions per minute) to ensure the ultra-thin sail material doesn't deform or collapse while the laser is accelerating it to 0.2c. This spin needs to be reduced afterwards, to make attitude control easier.

• Guidance, navigation and attitude control – the main issue here is attitude control. There is a need to change the direction of the sail several times during the mission, pointing it at the ground-based laser during the acceleration phase, then aligning it edge-on to the direction of travel during the cruise phase, to minimise damage to the sail material. In addition, there is a periodic need to repoint at Earth for communications purposes. Then, when the spacecraft reaches the Alpha Centauri system, it needs to be able to point the imaging system at the designated target (which may be a star, exoplanet, or other object of interest). Finally, once the flyby of the system has been achieved, the spacecraft needs to be pointed at Earth so that the captured imagery can be sent back.

• Computation – at minimum, this includes the power needed to control the spacecraft throughout the mission, plus the power needed to store the imaging data while it is waiting to be transmitted back to Earth.

• Imaging – the science objective is for each sailcraft to capture at least 100 kbits of imaging data at the target. This takes power.

• Communications and data return – the spacecraft needs to communicate with Earth periodically. Then, at the end of the mission, the image data needs to be returned to Earth following the flyby of the target system.

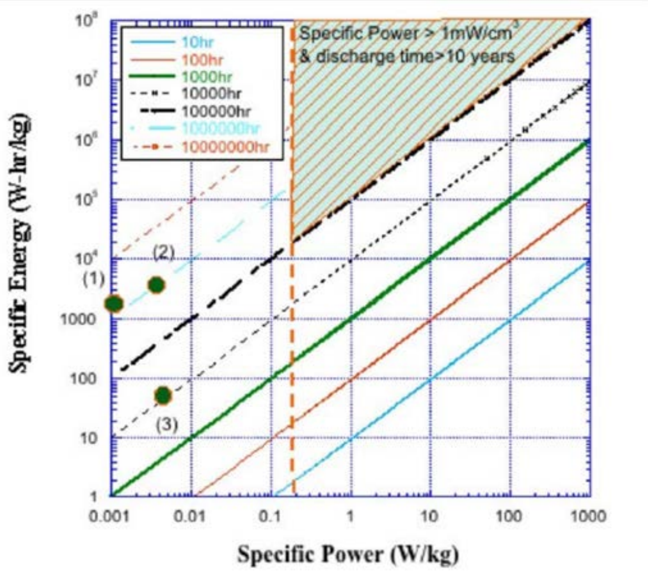
[1] Breakthrough Initiatives (2016), Starshot. breakthroughinitiatives.org/initiative/3

One additional constraint is vital. To achieve the target velocity of one-fifth the speed of light, the reference vehicle design involves a 4-metre diameter sail weighing no more than 3.6 grams in total. In line with spacecraft engineering norms, the power and energy system is designed to take up no more than 10% of this mass budget – ie 360 mg. This creates significant constraints on the technological options that may be suitable.

The paper considers a range of technologies for generating energy during the mission, to top up whatever energy is stored on board at launch. These include scavenging energy from the interstellar medium (ISM), either electromagnetically or thermally, or the use of photovoltaics to generate energy from the starlight in the target system. Tiny Radioisotope Thermoelectric Generators (RTGs), based on the same technology as those that powered the Voyager probes, are possible, if sufficient levels of miniaturisation can be achieved. The paper rules out two fascinating, but much more speculative alternatives: bioluminescence and antimatter.

A number of energy storage technologies are also considered, with the design requirement being the ability to store 0.5 mWh for at least 20 years. The options they consider as potentially viable include superconductors, tiny hydrogen fuel cells, and betavoltaics (which are a type of battery made from radioactive materials that give off beta radiation, or electrons, which can generate a current as the material naturally decays over time). They rule out chemical batteries and the use of fission, fusion or antimatter.

The paper concludes that there are no show-stoppers to achieving the power and energy generation and storage requirements for a minimum viable Starshot mission, using available or near-term technologies. Finally, they propose the outlines of a future research campaign to drive the innovations needed to make this aspect of the Starshot concept a reality.



Betavoltaic Performance. (1)SiC Tritrium converter [21], (2) diamond/Ni63 converter [28], and (3) Si/Pm147 converter [29]. The triangular region shows the goal of specific power greater than 1 mW/cm and discharge time > 10 years. (note: for this graph the density of SiC was used for all materials). Credit (caption and image): Peck et al (Figure 3) References are in the paper.

IAF ref	title of talk/paper	presenter	institution	nation
D4,4,1,x70268	10%: The First 10 Years of the 100 Year Starship	Jason D Batt	100 Year Starship	USA

IAF abstract: iafastro.directory/iac/paper/id/70268/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/4/manuscripts/IAC-22,D4,4,1,x70268.pdf

IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/4/presentations/IAC-22,D4,4,1,x70268.show.pptx

Open paper: This paper has also been published as the opening essay in the book 'The First Ten Years: Selected Papers from the 100 Year Starship Symposia' (100YSS, January 2023), which reprints selected papers from the four 100YSS Symposia that took place annually between 2012 and 2015.

Reported by: Patrick Mahon

The 100 Year Starship (100YSS) organisation was set up in 2012 – the same year as i4is – with a $500,000 grant from NASA and DARPA. Their aim was to promote research and other activities investigating the possibilities for achieving human interstellar flight within the next century. The money was awarded to the Dorothy Jemison Foundation for Excellence, led by former NASA astronaut Dr Mae Jemison.

This paper, written by 100YSS's Creative and Editorial Manager, summarises the organisation's activities over its first decade. 100YSS was launched with a document setting out six challenges that will need to be overcome if its mission is to be achieved. These are:

• Developing safe, reliable and cost-effective interstellar transportation;

• Enabling safe and healthy space communities on the journey;

• Accelerating human productivity, through AI, robotics, etc;

• Supporting the commercialisation of space exploration;

• Enabling vibrant in-system planetary development; and

• Doing all this in a way that enhances life on Earth.

While addressing these six challenges, the organisation also aimed to promote inclusivity, and engage with the wider community, beyond spaceflight enthusiasts.

The paper then lists the various activities that 100YSS has undertaken since 2012. In brief, they have:

• Set up a website (www.100YSS.org);

• Organised four public symposia – in 2012, 2013, 2014 and 2015 – and published the proceedings of each;

• Set up the Canopus Award for Excellence in Interstellar Writing in 2015;

• Developed the 'Look Up: One Sky' initiative and 'Skyfie' app in 2017, to encourage the general public to observe the heavens;

• Run a number of educational activities for children and students;

• Organised a 'Crucible' on 'The Virtual Human' in 2015, and workshops in 2013 and 2020;

• Helped bring together the people who subsequently set up the Breakthrough Starshot programme; and

• Participated in several activities run by other organisations between 2012 and 2018. Seven examples are listed.

Plans for the next ten years include:

• Organised a 'Nexus' conference in Nairobi, which will take place between 31 January and 4 February 2023; and

• Launching 'The Way Institute' to undertake the R&D needed to develop the knowledge base we will need.

The author concludes by looking ahead to the work that will need to be done over the next 90 years, if the mission of 100YSS is to be achieved.

IAF ref	title of talk/paper	presenter	institution	nation
D4,3,1,x67635	KEYNOTE: Space Elevators as a Transformational Leap For Human movement off-planet	Dr Peter Swan	International Space Elevator Consortium	USA

IAF abstract: iafastro.directory/iac/paper/id/67635/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/3/manuscripts/IAC-22,D4,3,1,x67635.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/3/presentations/IAC-22,D4,3,1,x67635.show.pptx

IAF cited video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/3/lecture/IAC-22,D4,3,1,x67635.lecture.mp4

Open paper: none found

Reported by: John I Davies

Dr Swan invokes the constraint on virtually all space activity, the Tsiolkovsky rocket equation. Space Elevators have the potential to eliminate this constraint for the gravity well within which all bodies of a significant size dwell. This revolutionises the economics of access to space with consequences from power satellites for green energy on Earth to solar system settlement and possibilities for interstellar missions.

◀ We reported his other talk to IAC22 in our previous issue P39 [1]. He estimates that current ideas for rocket based expansion imply enormous numbers of launcher, for example -

Vision	Objective	Number of 20 tonne launches to GEO
Musk (SpaceX)	Mars	50,000
Bezos (Blue Origin)	NSS to L-5	210,000
Space Based Solar Power	GEO	150,000

The attractions of the apex anchor of such a system have been described in our P39 report, cited above.

Dr Swan believes that elevators will replace rockets for the "heavy lift" into space but they will retain a role for fast and light launches - and of course for the onward journey to the Solar System and beyond.

ISEC Studies

2022	Dual Space Access Architecture – just starting
2021	Design Considerations for the Space Elevator Climber-Tether Interface - in progress
2021	Space Elevators are the Green Road to Space
2020	Space Elevators are the Transportation Story of the 21st Century
2020	Today's Space Elevator Assured Survivability Approach for Space Debris
2019	Today's Space Elevator, Status as of Fall 2019
2018	Design Considerations for a Multi-Stage Space Elevator
2017	Design Considerations for a Software Space Elevator Simulator
2016	Design Considerations for Space Elevator Apex Anchor and GEO Node
2015	Design Considerations for a Space Elevator Earth Port
2014	Space Elevator Architectures and Roadmaps
2013	Design Considerations for a Space Elevator Tether Climber
2012	Space Elevator Concept of Operations
2010	Space Elevator Survivability, Space Debris Mitigation

Completed studies on www.isec.org in pdf format are free

	Other Study Reports
2019	The Road to the Space Elevator Era - IAA IAA = International Academy of Astronautics (https://iaaspace.org)
2014	Space Elevators: An Assessment of the Technological Feasibility and the Way Forward - IAA
2014	The Space Elevator Construction Concept – Obayashi Corporation (https://www.obayashi.co.jp/en/news/detail/the_space_elevator_construction_concept.html)

9/19/22 8

www.isec.org

ISEC has been researching, designing and advocating this route to a Solar System civilisation - and its many attractions on the way - since 2010, See the summary of work cited by Dr Swan above.

[1] News Feature: IAC 2022: The Interstellar Presentations. Part 1 i4is.org/wp-content/uploads/2022/11/72nd-International-Astronautical-Congress-2022-The-Interstellar-Presentations-part-1-Principium39-2211291202opt-5.pdf

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IAF ref	title of talk/paper	presenter	institution	nation
A5,4-D2.8,4,x68378	Mission to Mars Using Space-Sourced Propellant	Dr Jan Thoemel	University of Luxembourg	Luxembourg

IAF abstract: iafastro.directory/iac/paper/id/68378/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A5/4-D2.8/manuscripts/IAC-22,A5,4-D2.8,4,x68378.pdf

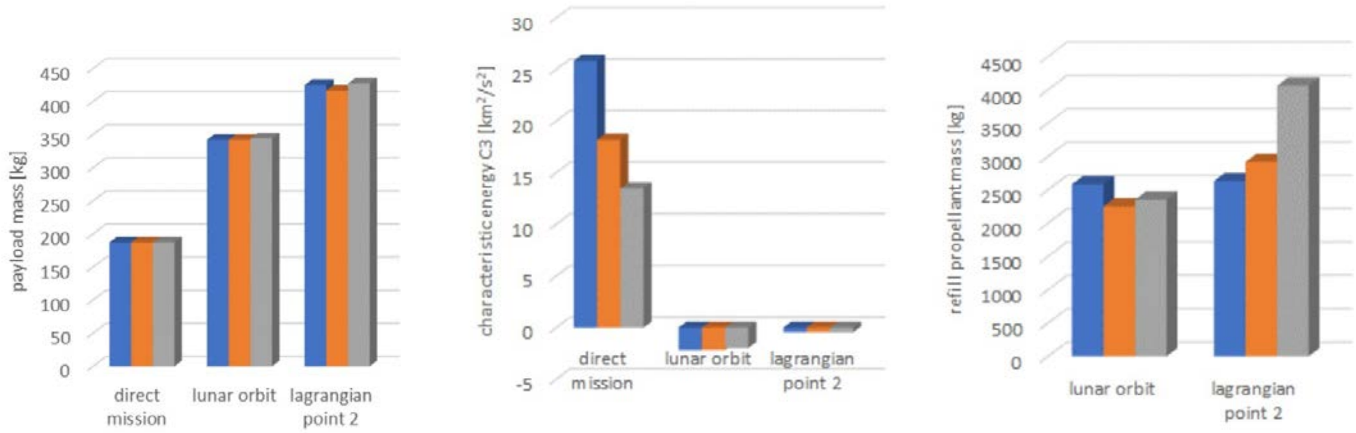
IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A5/4-D2.8/presentations/IAC-22,A5,4-D2.8,4,x68378.show.pptx

Open paper: none found

Reported by: John I Davies

Given the voracious appetite of chemical rockets, engineers and dreamers have often conceived an "interplanetary filling station" to avoid the necessity to take fuel for the whole journey and thus avoid the diminishing returns from increases in fuel capacity. Typically we use multistage rockets and, more recently, the idea of a refuelling vehicle as envisaged by SpaceX for a Mars mission. But maybe there is fuel to be had out there? Dr Jan Thoemel and colleagues (including our i4is Technical Director, Andreas Hein) have conducted a study of some possibilities. Specifically they aim for reduction of loaded propellant and increase of payload mass to allow an increase payload and a smaller launcher. Taking the Mars case, they studied a direct mission (to provide a benchmark), a Lunar Orbit Depot (in a 20,000 km altitude-near-equatorial-lunar orbit) and a Sun-Earth-Lagrangian Point 2 Depot (L2 is the location of JWST, the Gaia astrometry vehicle and the planned ESA Comet Interceptor) - and departure windows 2026/2028/2030.

The results were striking -



Left to right - for each of three departure windows 2026/2028/2030.
Figure 7 comparison of allowable payload mass for direct missions to Mars and for missions using space-sourced propellant stored in depots either in lunar orbit or in the Sun-Earth Lagrangian point 2.
Figure 8 comparison need characteristic energy, C3, for direct missions to Mars and for missions towards the propellant depot location either in lunar orbit or in the Sun-Earth-Lagrangian point 2.
Figure 9 required refill - propellant mass for missions to Mars with propellant depots either in lunar orbit or in the Sun-Earth-Lagrangian point 2.
Credit (captions and images): Thoemel et al

Payload mass advantage of refuelled missions is clear. The paper remarks "Here, the SEL2 depot wins for payload size. The lunar orbit scenario is however optimal for the reduction in launch energy. It also wins for the need of the least amount of refill propellant amount." Once we have the in-situ resource utilisation (ISRU) capability to fill the depots the strategy becomes clear.

IAF ref	title of talk/paper	presenter	institution	nation
D4,3,4,x69339	Space Elevator tether materials: An overview of the current candidates	Dr Adrian Nixon	Nixene Publishing	UK

IAF abstract: iafastro.directory/iac/paper/id/69339/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/3/manuscripts/IAC-22,D4,3,4,x69339.pdf

IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/3/presentations/IAC-22,D4,3,4,x69339.show.pptx

Open paper: none found

Reported by: John I Davies

Clearly for a viable space elevator the Earth to GEO (and beyond) tether must bear the inevitable stress upon it. Dr Nixon and collegues examined manufacturing progress in making materials that have the strength necessary to form the tether. They identify two categories, nanotubes and 2D materials. The demand is for a tensile strength of 100 GPa [1] or more and a continuous length of 100,000 km.

Some candidate materials mentioned in the paper -

• Graphene 130 GPa

• carbon nanotubes 200 GPa (theoretical) 77 GPa (in current practice)

• hexagonal boron nitride 100 GPa

Since these are all polymers and only a single cable would have the required strength this means a single molecule must comprise the tether. Companies in Luxembourg, USA and South Korea are working in this technology and ISEC team believe that "the trajectory to a high-quality industrial product is clear".

Figure 5: General Graphene Inc roll-to-roll graphene production line Credit (captions and images): Nixon et al / General Graphene Inc

[1] GPa = gigapascals. A pascal is 1 newton of force over one square metre. Since one one square metre is 100*100=10,000 square cm, 10 kilopascals is one newton per square cm, 10 megapascals is 1,000 newtons/cm² and 10 gigapascals is a million newtons/cm². So the usual materials for things like bridge suspension cables will not do!

IAF ref	title of talk/paper	presenter	institution	nation
D4,4,11,x70087	The Pragmatic Interstellar Probe Study: The Evolutionary Journey of our Habitable Astrosphere	Dr Pontus Brandt	Johns Hopkins University Applied Physics Laboratory	USA

IAF abstract: iafastro.directory/iac/paper/id/70087/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/4/manuscripts/IAC-22,D4,4,11,x70087.pdf

IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/4/presentations/IAC-22,D4,4,11,x70087.show.pptx

Open paper: none found

Reported by: John I Davies

The title of Dr Brandt's paper is "Pushing the Frontier of Solar & Space Physics: Exploration of the Heliosphere and Very Local Interstellar Medium (VLISM) by an Interstellar Probe" and he asserts that "The interaction of our protective heliosphere and the Very Local Interstellar Medium (VLISM) is the least explored and most rewarding frontier of space physics". In particular he warns that " recent supernovae have left the entire solar system exposed to extreme fluxes of interstellar material and cosmic radiation with potentially game-changing implications on evolution of our home" and the heliosphere is our first line of defence. So the objectives of the JHU-APL Interstellar Probe are both scientic discovery of the neighbourhood in which our Solar System lives and the prctical matter of the survival of our civilisation and species.

The paper sets out three Science Questions -

1: How is the heliosphere upheldby the physical processes from the Sun to theVLISM, and how do those globally manifest themselves?

2: How does the Sun's activity, the interstellar medium and its possible inhomogeneity influence the dynamics and evolution of the global heliosphere?

3: How do the current VLISM properties inform our understanding of the evolutionary path of the heliosphere?

- and some Cross-Divisional Opportunities including flybys of one or two of the 130 unexplored dwarf planets or thousands of smaller Kuiper Belt Objects, observations of the unseen circum-solar dust disk and measurements of the extra-galactic background light in the otherwise obscured 1-100 µm range,

The current example uses a baseline trajectory with launch in 2036 at 180˚ ecliptic longitude and -20˚ ecliptic latitude transecting the heliosphere at 7.0 au/year in an unexplored direction, potentially including dwarf planet 90482 Orcus and its moon Vanth [1].

The JHU-APL Interstellar Probe will not be cheap (upfront cost $1.7B and $289M per decade) but it looks like a worthy successor to the Pioneers and Voyagers and it has significant support from ESA, see next report.

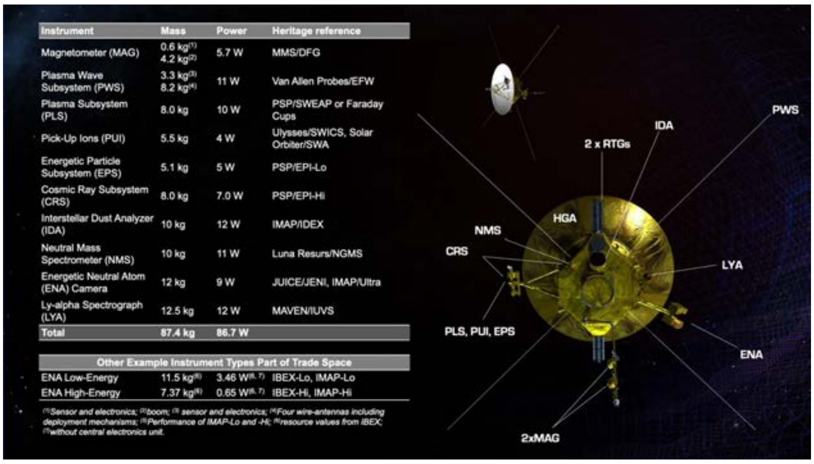


Figure 3: Example baseline spacecraft design including the 5-m HGA, two RTGs, magnetometer booms, four spin-plane PWS wire antennas, charged particle suite and ENA camera on pedestals and body mounted instruments graphene production line
Credit (caption and image): Brandt / JVU-APL

[1] Almost twins of Pluto and its satelleite Charon though in an apparently closer orbit, see Hubble video commons.wikimedia.org/wiki/File:Orcus-Vanth_orbit.gi

IAF ref	title of talk/paper	presenter	institution	nation
D4,1,12,x70259	Advancements in Laser Propulsion for Relativistic Lightsail Missions	Mr Wesley Green	Breakthrough Initiatives, Starshot	USA

IAF abstract: iafastro.directory/iac/paper/id/70259/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/1/manuscripts/IAC-22,D4,1,12,x70259.pdf

IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/1/presentations/IAC-22,D4,1,12,x70259.show.pptx

Open paper: none found

Reported by: Dan Fries

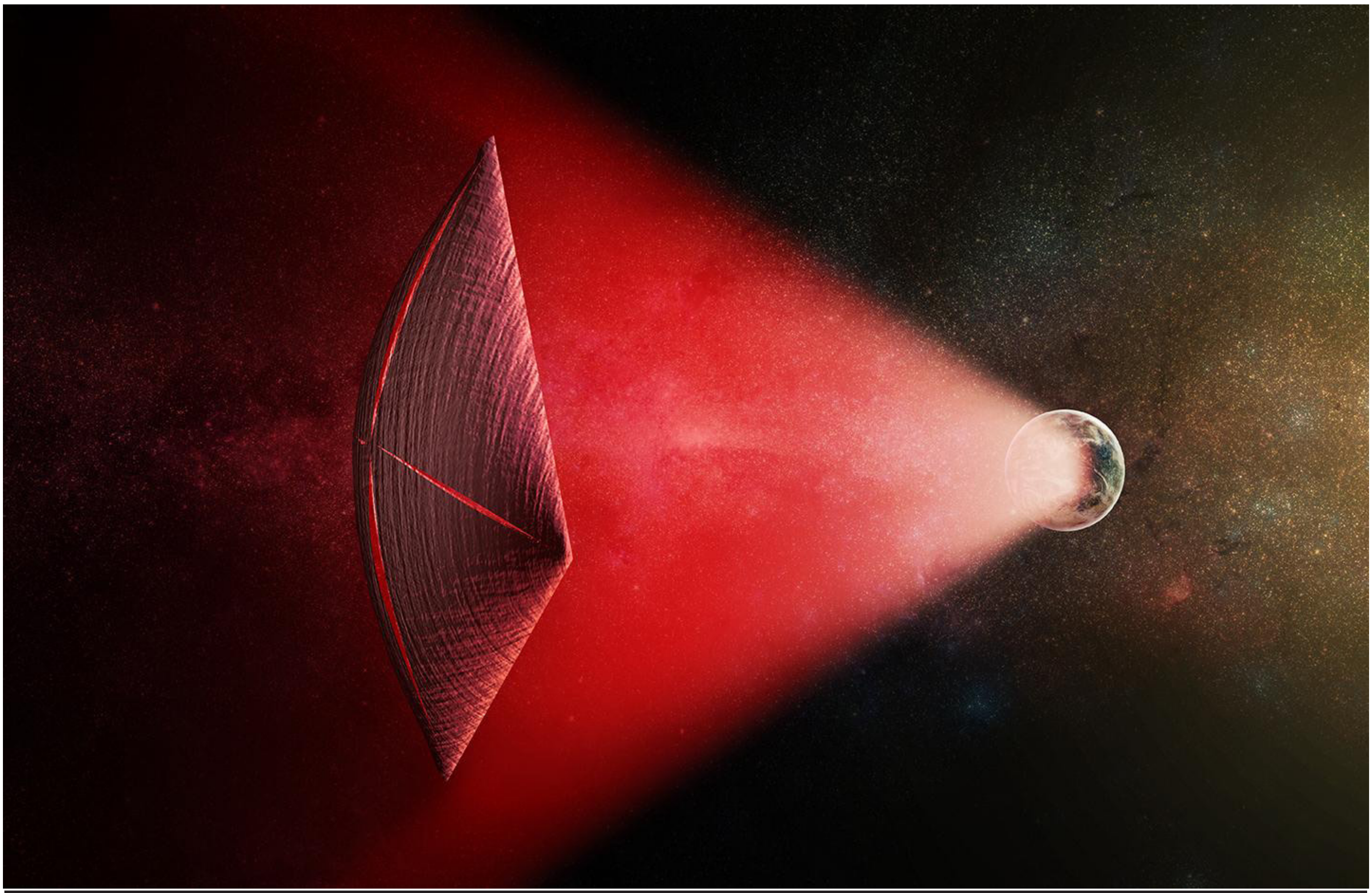


Figure 1: Artistic rendering of the Breakthrough Starshot ligthsaiil illuminated by laser light from earth. Credit: M. Weiss/CfA and www.universetoday.com/151478/sending-a-spacecraft-to-another-star-will-require-a-million-lasers-working-together/L

In this report, Green describes a baseline architecture for the laser array of the Breakthrough Starshot, and its design sensitivity to the cost of laser power in $/Watt. The conceptual mission described considers a metre scale lightsail, weighing a few grams, and a ground-based gigawatt class, kilometre-scale laser, called the `photon engine', used to accelerate the spacecraft towards Alpha Centauri at 20% of the speed of light. It has been established in the past that the most viable laser architecture is a coherent phased array, consisting of many individual laser sources driven together, and Green considers only this concept, neglecting, for the moment, approaches that could help reaching beyond diffraction limited optics. The total photon engine cost goal is around $10 billion, resulting in a baseline array diameter of 2,800 m, a total laser power of 200 Gigawatt, a sail diameter of 4 m, and a launch (acceleration) duration of 8 minutes. An orbital laser beacon is required to track the night sky during launch and reduce the effect of atmospheric turbulence on laser beam propagation.

◀ Green states that a cost basis of $0.01/W should be possible, based on historical trends, but $0.12/W appears to be a more realistic cost basis. Using the Parkin system model [1] to optimize the photon engine, he finds that a higher cost basis leads to a lower total laser power, ie a longer acceleration period, and a larger array diameter. He also finds that a more complex system (more degrees of freedom), to compensate for atmospheric turbulence, leads to higher power requirements for each individual laser source, between 363 to 2,219 Watts for the cost range considered, and the possibility to use smaller apertures. These trends necessitate a larger amount of laser sources, if the compensation system is simple, reaching into the billions. The total cost for the highest cost base can reach $25 billion, which, Green argues, is still viable.

The identified power requirements allow for the utilisation of single-frequency fibre amplifiers, which can currently reach up to 500 W output power, and avoid massive Megawatt class laser systems. However, the size of the array requires compensation of the laser path length, which will be challenging for millions of individual lasers, and the component costs per laser are currently not considered. Finally, to reduce total cost, Green mentions it might be interesting to explore technologies or concepts that allow for longer launch durations, reducing the overall power and atmospheric correction requirements.

It is fascinating to see that phased array and laser technology has come to a point where an interstellar, large-scale mission, such as Starshot, could be comparable in cost to a NASA flagship mission. There are many outstanding questions, such as whether a terrestrial laser source of this size could unexpectedly influence atmospheric dynamics, whether materials can withstand such laser powers, whether we can develop a laser source that is not diffraction limited, and, of course, whether we can lower the cost per unit laser power sufficiently. Plenty of inspiration for researchers to look for answers.

IAF ref	title of talk/paper	presenter	institution	nation
C2,3,8,x73418	Dynamic Stability of Flexible Lightsails for Interstellar Exploration	Dr Michael Kelzenberg	Caltech	USA

IAF abstract: iafastro.directory/iac/paper/id/73418/summary/

IAF cited paper: none available

IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/C2/3/presentations/IAC-22,C2,3,8,x73418.show.pptx

Open paper: none found

Reported by: Dr Dan Fries

The research by Kelzenberg et al. addresses the question of dynamic stability of a thin membrane structure used as a laser sail for the Breakthrough Starshot mission architecture. The promise of this architecture is to accelerate a gram-sized spacecraft to relativistic speeds, sending it across interstellar distances, using the radiation pressure from a high-power laser phased-array. Two big questions coming up during the mission design are what material should and can be used for the sail, and whether the sail can be shaped, or controlled, to achieve dynamic stability as the sail assembly rides the driving laser beams. Due to the extremely high laser power densities, the candidate material must have high reflectivity, high temperature range, and high emissivity. Atwater and colleagues are suggesting the usage of ultra-thin dielectric materials, potentially layered to achieve desired mechanical and thermophysical properties. They then use a Finite-Element approach to simulate a thin membrane, with corresponding properties, and its interaction with the driving laser radiation. In the past they have investigated:

- regular reflecting/transmitting/absorbing materials,
- diffractive surfaces,
- surfaces with nanophotonic structuring,
- and spinning sails.

[1] The Breakthrough Starshot system model, Acta Astronautica, Vol 152, November 2018, Pages 370-384 arxiv.org/abs/1805.01306

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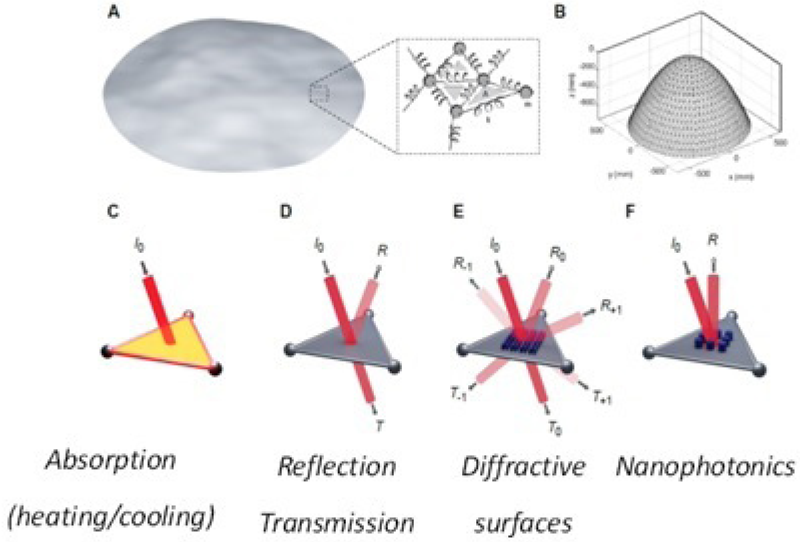

Figure 1: Image from the presentation, showing a schematic of the FEM thin sail membrane and different responses of the sail material to incident radiation.

In the present work they address whether a discrete payload would tear the sail or disrupt beam-riding stability. They conclude that round payloads integrated onto the sail significantly reduce stress concentrations, relative to square payloads, and that masses around 90 mg are possible with an acceleration of ~3,000 G, before the tensile limit of the considered material is reached. A mass of 900 mg is possible if the acceleration is kept below ~300 G. A local reinforcement of the sail structure could improve this situation further. The major take-away being that ``Payloads in the ~100-200 mg range appear compatible with 100 nm SiNx sails". Furthermore, stable beam-riding was observed by the authors in a tethered payload configuration, where the payload is attached to the sail at some distance.

The results of this research are highly relevant to the question of whether a laser sail can realistically be built with existing, or even physically possible, materials. The limitations on mass and payload shape are interesting for future studies and development, and the observation of stable beam-riding is encouraging to develop corresponding laser sail-payload configurations further.

Authors: Michael Kelzenberg (Caltech), Ramon Gao (Caltech), Harry Atwater (Caltech), James Schalkwyk (Breakthrough Initiatives)

IAF ref	title of talk/paper	presenter	institution	nation
A5,4-D2.8,2,x72880	NASA Envisioned Future Priorities for In-Space Transportation	Mr John Dankanich	NASA	USA

IAF abstract: iafastro.directory/iac/paper/id/72880/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A5/4-D2.8/manuscripts/IAC-22,A5,4-D2.8,2,x72880.pdf

IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A5/4-D2.8/presentations/IAC-22,A5,4-D2.8,2,x72880.show.pptx

Open paper: none found

Reported by: Dr Dan Fries

The paper by Dankanich and Lichtford outlines NASA's priorities with regard to propulsion technology enabling robust and affordable in-space logistics, for commercial development of near-Earth space, to create a sustained human presence on the moon and in cis-Lunar space, and to allow for the exploration of Mars and beyond. The new NASA strategic framework can be split into focus areas of 'Go', 'Land', 'Live', and 'Explore'. The overall goal is to provide rapid, accessible, and reliable in-space transportation for humans, goods, and probes. The 'Go' part heavily favours nuclear thermal and electric propulsion, as well as cryogenic propellant storage and refueling. The latter also involves In-Situ Resource Utilization (ISRU) to enable a human exploration. Resources of most interest are oxygen, methane and hydrogen, but also some noble gases.

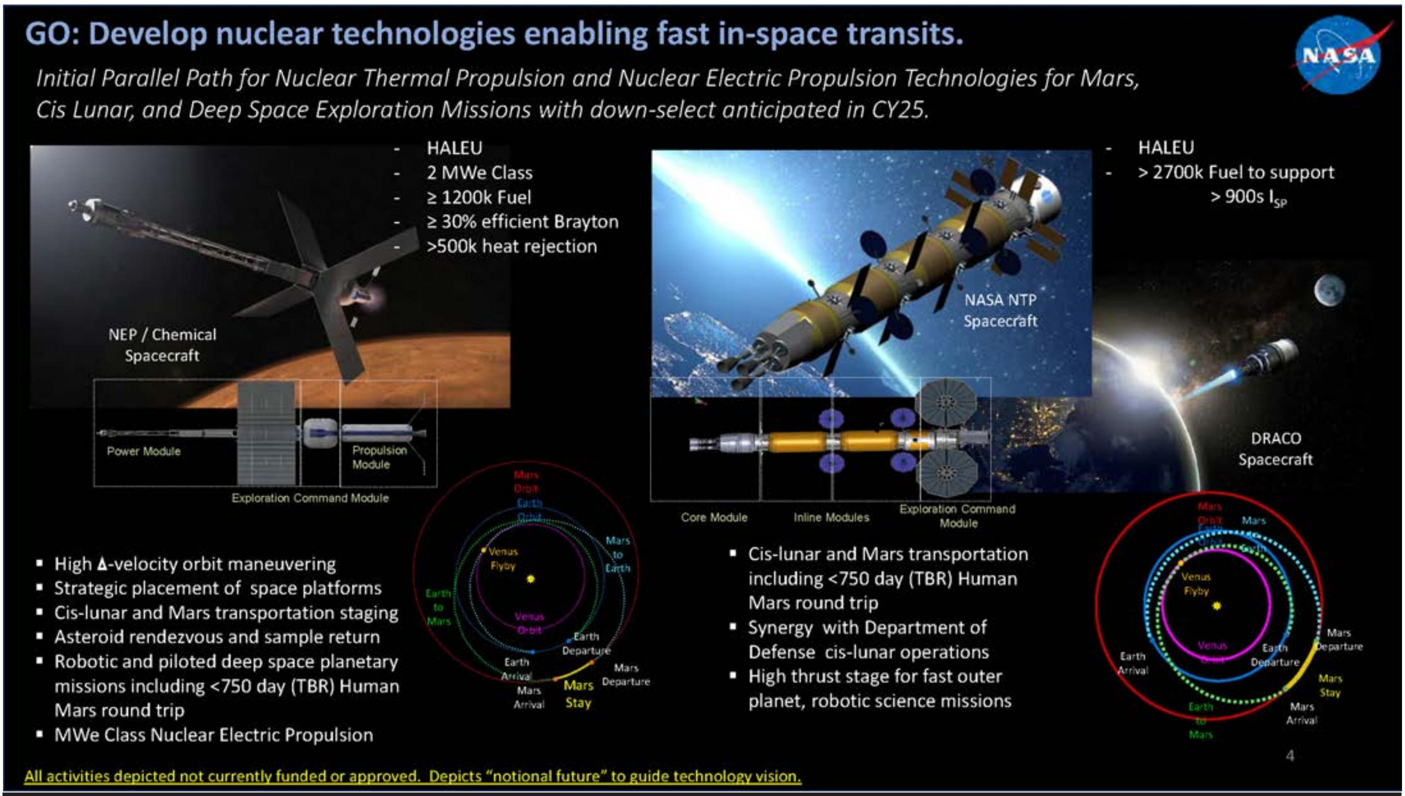

Figure 1: Example of a NASA nuclear electric/chemical spacecraft concept (left), and a nuclear thermal concept (right).

Space nuclear propulsion now plays a major role in NASA's overall vision of space development and exploration, with significant technological progress and maturation still required. The TRL (Technology Readiness Level) of most nuclear propulsion (NP) options is very low, and especially large high temperature radiators and advanced thermal coatings require investment to push them into the mid-readiness levels.

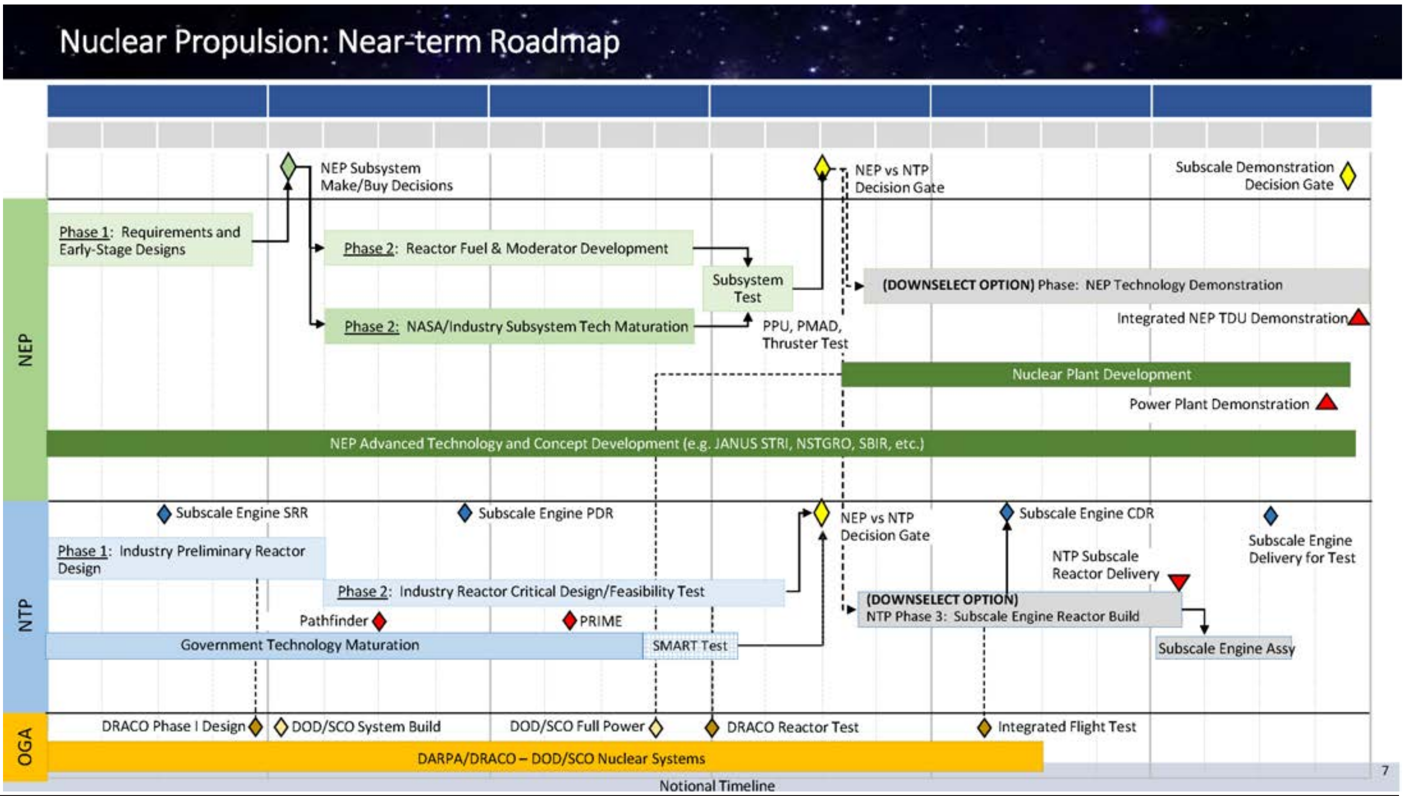

Figure 2: Roadmap for the near-term development of nuclear propulsion options.

While cryogenic technologies are more mature in general, there are still significant challenges when it comes to soft vacuum insulation, heat load reduction, active cooling, and modelling capabilities. Propellant boil-off needs to be minimized and controlled to avoid uncertainties and point-of-failure scenarios in NASA's logistic vision.

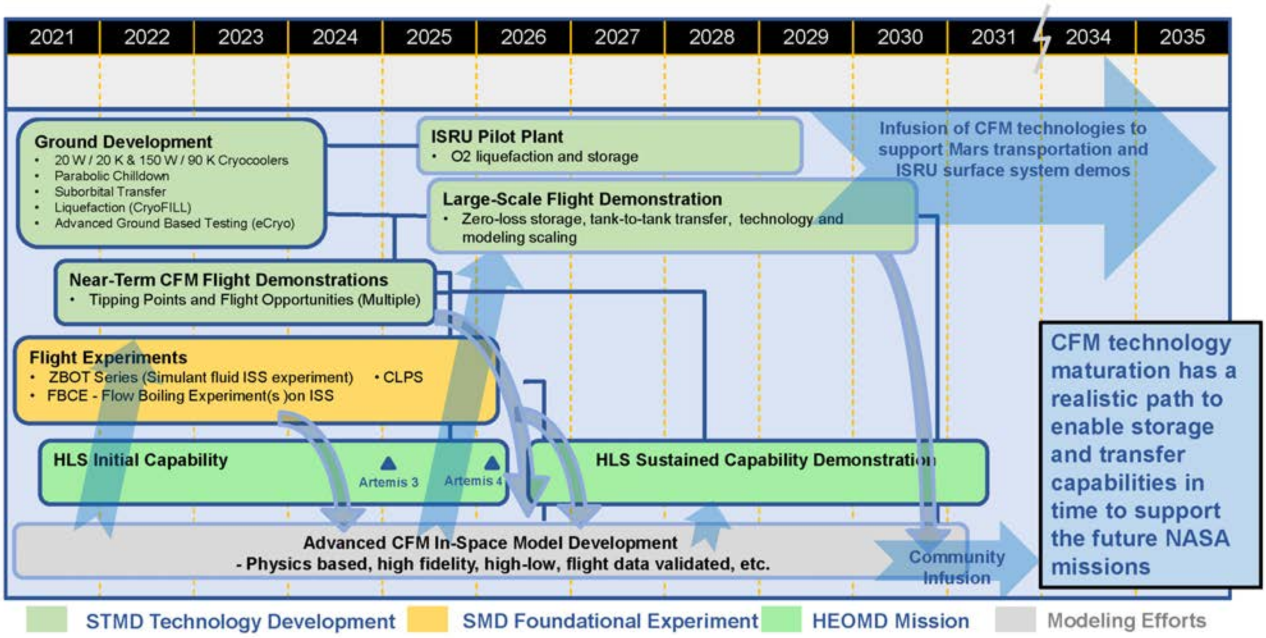

Figure 3: Roadmap for the near-term development of CFM capabilities.

Finally, advanced propulsion is identified as a critical 'Go' area. This includes Hall thrusters and gridded ion thrusters in the >10 kW class, and >100 kW propulsion systems such as HET, MPD and VASIMR, enabling MARS transportation architectures. Lower power, long lifetime systems are required for missions to the outer planets, and sail architectures or airbreathing electric propulsion systems are options for observational capabilities at Earth's and the Sun's poles. A roadmap out to 2030 for technology development is also given here. Particularly interesting is that NASA now explicitly names solar perihelion burn Oberth maneuver capabilities for interstellar missions and fusion propulsion concepts in their low TRL categories for further development.

Authors: John W. Dankanich (NASA), Ron J. Litchford (NASA)

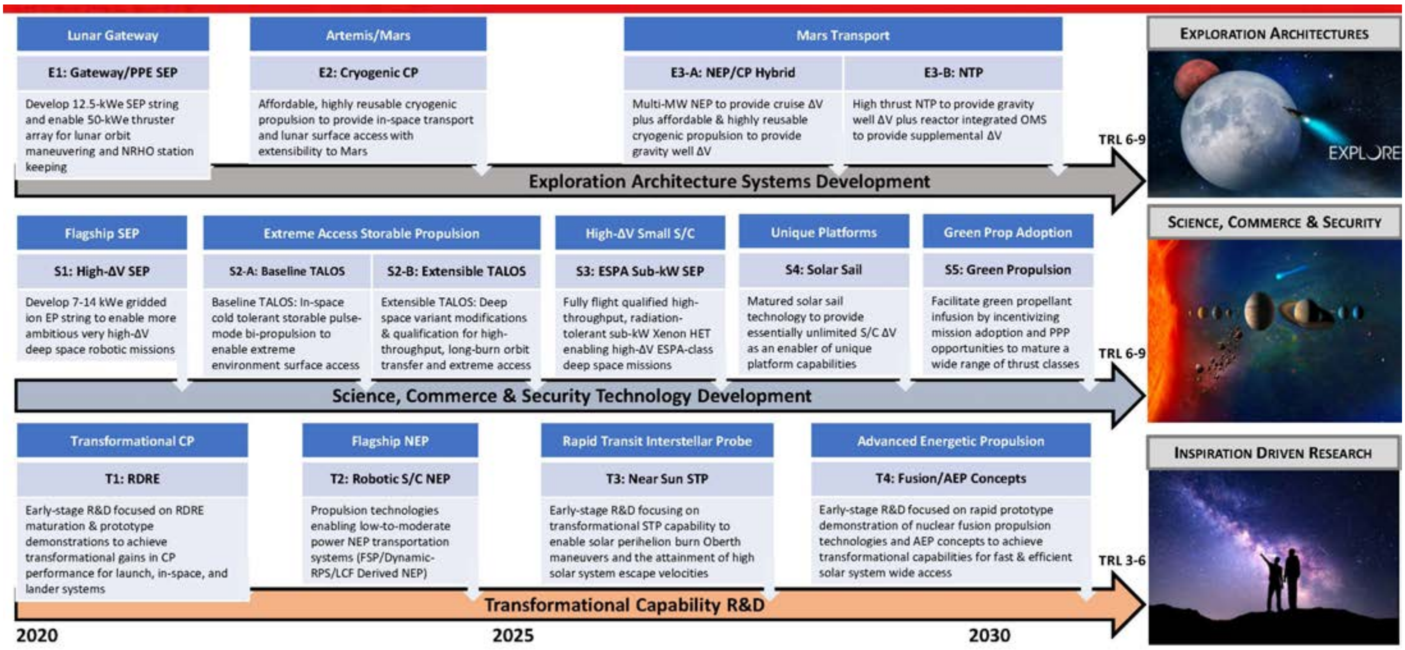

Figure 4: Roadmap for the near-term development of advanced propulsion concepts

IAF ref	title of talk/paper	presenter	institution	nation
D4,4,10,x73530	Stella science for interstellar probe	Prof Dr Robert F Wimmer-Schweingruber	University of Kiel	Germany

IAF abstract: iafastro.directory/iac/paper/id/73530/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/4/manuscripts/IAC-22,D4,4,10,x73530.pdf

IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/4/presentations/IAC-22,D4,4,10,x73530.show.pptx

Open paper: none found

Reported by: John I Davies

Stella is a proposed ESA contribution to NASA's Interstellar Probe (ISP) aiming to answer the questions -

• What is the composition of the local interstellar medium?

• How is our dynamical heliosphere upheld and how does it change from the Sun to the local interstellar medium?

• What is the origin and role of galactic cosmic rays in the solar system and beyond?

• How does the local interstellar medium become structured when it meets the heliosphere?

• Are there any deviations from the 1/r gravity law on the interstellar scale?

The ISP mission will propel an ~860 kg spacecraft out of the heliosphere at a speed of 7.0 au/year using a heavy-lift launch vehicle such as the Space Launch System and a Jupiter Gravity Assist Manoeuvre (JGAM). to reach 350 au in a 50 year nominal design lifetime, but with system resources to reach beyond to, at least, 525 au.

The Stella proposal will be assessed in the heliophysics decadal survey by the US National Research Council to be published around the end of 2023 or in early 2024.

It builds on the results from the Interstellar Boundary Explorer IBEX, a low Earth orbit satellite observing energetic neutral atoms to image the interaction region between the Solar System and interstellar space.

IAF ref	title of talk/paper	presenter	institution	nation
D4,4,4,x69452	Stella: Europe's contribution to a NASA interstellar probe	Prof Stanislav Barabash	Swedish Institute of Space Physics	Sweden

IAF abstract: iafastro.directory/iac/paper/id/69452/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/4/manuscripts/IAC-22,D4,4,4,x69452.pdf

IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/4/presentations/IAC-22,D4,4,4,x69452.show.pptx

Open paper: none found

Reported by: John I Davies

Stella includes two core and two optional elements for the full complement:

• Core: Provision of European scientific instruments;

• Core: Provision of the European interstellar probe (ISP) communication system including the spacecraft's 5-m high gain antenna;

• Full complement: ESA deep space communication facility: an extension of ESA's DSA with a new antenna array;

• Full complement: Contribution to ISP operations to increase drastically the ISP and European payloads science return.

The proposed instruments are -

Neutral gas mass spectrometer (NGMS): University of Bern, Switzerland - asking: What is the composition of the VLISM (Very Local Interstellar Medium) gas?

Plasma Science System (PSS): IRAP, Toulouse, France; IRF, Kiruna, Sweden - asking: How is our dynamical heliosphere upheld and how does it change from the Sun to the VLISM?

Cosmic Ray Spectrometer (CRS): University of Kiel, Germany - asking: What is the origin and role of galactic cosmic rays in the solar system and beyond?

Lyman-a spectrometer (LyS): Laboratoire Atmosphère Milieux, France - asking: How does the local interstellar medium become structured when it meets the heliosphere?

Radio Science (RS): Universita' La Sapienza, Italy - asking: Are there any deviations from the gravity law on the scale of VLISM?

The instruments proposed are -

Stella instrument resource budgets. Credit: Barabash et al, Tab 3.1.2.

Instr.	**Mass (kg) / Allocation [1]**	**Power (W) / Allocation [1]**
NGMS	9.8 / 10.0	11 / 11
PSS-A	6.2 / n/a, partial contribution	10 /
PSS-F	3.0 / n/a, partial contribution	5 /
CRS	7.5 / 8.0	7 / 7
LyS	12.5 / 12.5	12 / 12

PSS-A: Plasma Analyzer; PSS-F: Faraday cup

The paper concludes that all will be at TRL 6, having "a fully functional prototype or representational model" [2] by 2026, each with a significant heritage from previous probes.

They also propose two optional contributions, in addition to the European deep space communication facility to serve as a dedicated link for ISP. Saying "NASA's Deep Space Network (DSN) is aging and oversubscribed" and "the new European facility would increase drastically the ISP and European payload science return". With a baseline -

ESA-provided ISP communication system. Credit: Barabash et al, Tab. 3.2.1.

Parameter	NASA ISP Value [1]
Frequency	8.4 GHz (X-band)
Range	350 au (50-years mission)
TR antenna, ø	5 m
Transmit power	52 W
Min data rate	200 bps (to 4x35-m @ 350 au)

- and options for 18 m and 35 m antennas. The study includes a substantial section on Management of both science and mission/technology planning.

The team involved includes contributors from the Swedish Institute of Space Physics, Kiel University, IRAP (Toulouse), JHU-APL, Università la Sapienza (Rome), LATMOS (Guyancourt, France), Nortumbria University (UK) and University of Bern (Switzerland)

[1] Interstellar Probe: NASA Solar and Space Physics Mission Concept Study, 2021 interstellarprobe.jhuapl.edu/
[2] Technology Readiness Level https://www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level

i4is 10th anniversary

The Initiative for Interstellar Studies founded 2012

Andreas M Hein

i4is 10 year anniversary – Major achievements

i4is has celebrated its 10-year anniversary in 2022. This is a good point in time to reflect on our achievements towards the interstellar vision. The list is long and a short article like this will not do justice to what the team has achieved. Our benchmark is ambitious: In the long-run, i4is' success will be judged on how far it contributed to create an interstellar-capable civilization. How far did we contribute to this ambition over the last 10 years? I would like to structure our achievements in terms of community-building, education and technical achievements.

Community-building

What have we done that contributed to entertaining an interstellar community? There are a number of contributions such as Principium (past editor Keith Cooper, now John Davies), which has remained for now 40 issues the main regular outlet, focusing uniquely on interstellar travel. Contributions to the Foundations of Interstellar Studies Workshop, to the Tennessee Valley Interstellar Workshop (now the Interstellar Research Group, irg.space), ESA Interstellar Workshop, Breakthrough Discuss and numerous other events. Community-building also means bringing people together longer term to work on projects. I will come back to this point later, in the section on technical achievements.

Education

Over the last decade our educational program has evolved from an initial interstellar summer school to a fully fledged week-long interstellar curriculum in collaboration with the Limitless Space Institute, under the leadership of Rob Swinney (Director of Education Committee). In addition, we have given two-week modules and individual lectures for several years at the International Space University (ISU, www.isunet.edu/). Notable interstellar modules were the World Ship module (three times) and the ChipSat module (the first ever on these gram-sized spacecraft). These two-week modules combine teaching and group activities which result in a final presentation and a research article. In addition, our team co-supervised a handful of Individual Projects (IPs) of ISU MSc students, which in their majority have led to papers and presentations at the International Astronautical Congress (IAC) and a few even to peer-reviewed journal papers. Our educational activities are, however, not limited to university students. We have been contributing regularly to the Royal Institution in the UK via the "Skateboards to Starships" programmme, targeting high school students. Hundreds of students have been introduced to interstellar travel via our courses and supervision and many of them now working in the space industry.

Technical

Looking at the last 10 years, some technical achievements stand out. In the following, I would like to focus on two, as they have historical implications for the field of interstellar travel.

First, Project Lyra, an ongoing research project to investigate missions to interstellar objects. This has probably been the most prominent technical project of i4is in terms of media appearances but also in terms of number of publications. It is the more remarkable that this project was purely serendipitous with the unforeseen discovery of 1I/'Oumuamua in October 2017. Just weeks after its discovery, a team formed and released a first paper on a mission to 1I on arXiv, refuting the current view that a mission was infeasible. In the months and years afterwards a team of international researchers from multiple institutions [1] formed, publishing papers on this topic since then. The set of targets has expanded from 1I to 2I/Borisov to different (hypothetical) classes of interstellar objects, Planet 9, and nomadic worlds (aka rogue planets). Project Lyra has thereby expanded the scope of what interstellar travel is by looking at the space between the stars: Interstellar objects and nomadic worlds allow us to explore other star systems without flying to them. Besides nine peer-reviewed journal papers, Project Lyra has been featured in hundreds of articles (National Geographic, Forbes, NBC, etc) and videos (~6 million views).

[1] Florida Institute of Technology, Paris Observatory, Technical University of Munich, Aachen University of Applied Sciences, Space Initiatives Inc etc.

A second and another to a certain extent serendipitous achievement is Project Dragonfly, a project focusing on small, laser-driven interstellar probes. The idea evolved from conversations with Greg Matloff in early 2013 to internal discussions, preliminary works, and a workshop at the British Interplanetary Society (BIS) towards the organization of a competition in 2014-2015 where 4 international student teams participated (www.centauri-dreams.org/2015/07/17/small-interstellar-probes-riding-laser-beams-the-project-dragonfly-design-competition-workshop/). Accompanied by a Kickstarter campaign to financially support the travel expenses of the students, a final workshop was organized in the premises of the BIS in July 2015, where the teams presented their designs.

While the winning team was from the Technical University of Munich, the 3rd placed team was from the University of California, Santa Barbara (UCSB), under the supervision of Phil Lubin. It turned out that the design of that particular team then evolved into the baseline architecture for Breakthrough Starshot, which was announced in April 2016.

According to later accounts (www.centauri-dreams.org/2018/10/05/de-star-and-breakthrough-starshot-a-short-history/) of Phil Lubin, his ideas on small laser-driven interstellar probes emerged around the same time as ours, which is a remarkable coincidence. Why did the UCSB team not win? In hindsight, our competition requirements did not necessarily reward teams which would go to extremes in terms of miniaturization, as science instrument mass was to be maximized, given a fixed 100 GW of beaming power. This explains to a certain extent the outcome of the competition, where teams with larger probes were at an advantage. If we would have gone for simultaneously minimizing the cost of the mission and maximizing science output, some teams might have taken a similar route of extreme miniaturization, trading a lower science output against lower cost. Although we were pondering ideas of miniaturizing interstellar sailcraft, we were rather thinking about CubeSat-scale spacecraft (www.centauri-dreams.org/2014/09/05/project-dragonfly-the-case-for-small-laser-propelled-distributed-probes/) with a mass of a few kg. Our assumption back then was that it would not be possible to transmit a meaningful amount of data back and we would not be able to acquire meaningful science data with a smaller spacecraft.

We do not want to forget about other achievements during the last 10 years and will continue to report on some of them in later Principium issues.

The Journals

John I Davies

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

JBIS

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

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

JBIS VOLUME 75 NO.10 OCTOBER 2022 Interstellar Issue		
Intermediate Points for Missions to Interstellar Objects Using Optimum Interplanetary Trajectory Software	Adam Hibberd	Initiative for Interstellar Studies (i4is)
This paper explicates the concept of an 'Intermediate Point' (IP), its incorporation as a node along an interplanetary trajectory, and how it permits the determination and optimization of trajectories to Interstellar Objects (ISOs). IPs can be used to model Solar Oberth Manoeuvres (SOM) as well as V∞ Leveraging Manoeuvres (VLM). The SOM has been established theoretically as an important mechanism by which rapid exit from the solar system and intercept of ISOs can both be achieved; the VLM has been demonstrated practically as a method of reducing overall mission ΔV as well as the Characteristic Energy, C3, at launch. Thus via these two applications, the feasibility of missions to interstellar objects such as 1I/'Oumuamua can be analysed. The interplanetary trajectory optimizer tool exploited for this analysis, Optimum Interplanetary Trajectory Software (OITS), permits IP selection as an encounter option along the interplanetary trajectory in question. OITS adopts the assumption of impulsive thrust at discrete points along the trajectory, an assumption which is generally valid for high thrust propulsion scenarios, like chemical or nuclear thermal for instance.		

Probability or Determinism: How Rare is ETI?	Barton Paul Levenson	-
Snyder-Beattie et al (2021) propose based on Bayesian inference and the random timing of evolutionary transitions that the probability of a habitable planet hosting an intelligent species (Pin) is < 10-24. This would make Earth the only planet in the observable universe with a native intelligent species. A different approach is proposed here in which each evolutionary transition is treated based on what is known of planetary and biological conditions at the times of occurrence. In this light, Pin may be many orders of magnitude higher than the Snyder-Beattie et al estimate. Until such factors are better known, speculation on the value of Pin may be premature.		

Algorithms for Decoding Interstellar Messages	Michael Matessa	METI International
How would we determine the meaning of an interstellar message from a distant civilization? This paper describes algorithms for assigning meaning to symbols found in such a message. It is assumed the message is pre-parsed, resulting in symbols grouped into expressions. Algorithms assign meanings to symbols within an expression and meta-algorithms maintain a list of symbol meanings across expressions. The algorithms described in this paper are Equality-check, Counting-check, Function-check, Base-check, Approximation-check, Constant-check, and Planck-check. The meta-algorithms are Intersect, Prune, and Substitute. These algorithms have been implemented in software, and results from a sample message are given that assign meanings ranging from numbers to the concepts of mass and length. By developing algorithms, it is hoped that message decoding can grow from an art done by individuals to a science done with algorithms.		

Other Messages for Other Senses	Michael Matessa et al	METI International
For interstellar messages that we have sent so far, the underlying assumption in schemes for encoding/decoding is that the recipients are fundamentally similar to ourselves. But there have been criticisms of this assumption of equivalence approach because intelligence even on our own planet takes many different forms, and these forms are influenced by the senses of the individual. Jonas and Jonas (1976) describe hypothetical extraterrestrial species with alternate senses inspired by Earth animals. This current work further expands on the capability of these extraterrestrial species to understand messages that we would send. A continuum of similarity to humans is proposed, from species whose senses do not allow them to develop radio technology, to species who do but whose senses do not allow them to understand 2D images, to species with senses only slightly different than our own. Implications for message construction are considered, and recommendations for future message content are given. These recommendations include redundant sections with questions that require different senses (similar to how a person can see a number in a colorblind Probability or Determinism: How Rare is ETI? test only if they are not colorblind). Replies would tell us the sensory modalities we should be addressing with this particular extraterrestrial intelligence. Another recommendation would be to use information about a targeted planet to determine the most probable sense of inhabitants, and tailor messages to that sense.		

VOLUME 75 NO.11 NOVEMBER 2022		
Assessment of the Applicability of Small Modular Reactors (SMRs) as a Start-up/Restart Reactor for Nuclear Fusion Rocket Propulsion Engines (NFRPEs)	Clésio Ismério de Oliveira	-
Nuclear fusion as a power source is becoming a reality and the next step is its use as propulsion for interplanetary spacecraft. Once solved, fusion will have the highest specific power (kW/kg) of any other type of power production. Spacecraft propelled by Nuclear Fusion Rocket Propulsion Engines (NFRPE) will need a power source both to start and to sustain the reaction. An assessment was performed of 78 Small Modular Reactors (SMRs), analyzing and quantifying their ability to be adapted for use in this application. It was shown that UK SMR had the best potential with 92% applicability, the Stable S. R. Wasteburner SMR with 89%, eight SMRs (ACP100, CAP150, CANDU SMR™, NUWARD™, RITM-200M, GTHTR300, MHR-T, and SVBR- 100) with 86%. Further research is required to determine the exact requirements for a Start-up/Re-Start Reactor.		

Orbital Nuclear Power System (ONPS): The Foundation of an Interplanetary Civilization	Donald Wilkins	-
Two seemingly unrelated problems could be resolved with the same solution and, as a pleasant side-effect, propel humanity into the Solar System. The first is the need for low-pollution power serving 21st century populations. Unreliable electrical energy cripples growth of many regions. Second, a thriving interplanetary society needs a surplus-generating industry, something equivalent to the tobacco or fur trade which funded initial colonization of North America. Without revenues from a thriving industry, space exploration relies upon fickle whims of political systems beset with other priorities. An Orbital Nuclear Power System (ONPS) offers advantages over other off-planet energy sources. A constellation of orbital nuclear reactors is cheaper to erect and provides more reliable power than an orbital solar power system (OSPS), and has a lesser impact on terrestrial ecology than any other energy solution. In addition, ONPS provides cheap power and broad bandwidth communications links necessary to exploit the Solar System's wealth and install thriving colonies throughout the inner Solar System.		

Acta Astronautica

Title	Number+date	Author	Affiliation
Abstract/Précis/Highlights			
Dyson sphere building: On the design of the GTOC11 problem and summary of the results	Volume 202, January 2023, Pages 889-898	Hong-Xin Shen et al	Xi'an Satellite Control Center, China
The National University of Defense Technology and the Xi'an Satellite Control Center organized the 11th edition of the Global Trajectory Optimization Competition (GTOC11) in 2021. The GTOC11 problem was created as a link between the ninth and tenth editions of the Global Trajectory Optimization Competition to bridge the gap between the planetary and galactic civilizations by introducing an intermediate stellar civilization scenario. The problem involves the construction of a Dyson sphere, a theoretical mega-structure that encircles a star with platforms orbiting in a tight formation to capture the maximum energy from it. Challenges in astrodynamics including the construction-orbit selection, combinatorial flyby of multiple asteroids, and mass distribution among stations were considered in the Dyson sphere design. A total of 94 teams registered for the competition, of which 25 teams provided solutions and passed automatic verification on the website. In this article, we describe the selection of the problem and its design process. In addition, an overview of the entire competition and an analysis of its results are presented. Full text available via: www.sciencedirect.com/science/article/pii/S0094576522004532			
Solar sail with inflatable toroidal shell	Volume 202, January 2023, Pages 17-25	V Ya Kezerashvili, R Ya Kezerashvili, O L Starinova	City University of New York / Samara National Research University, Russia
In the framework of a strict mathematical approach based on classical theory of elasticity we present an idea of the deployment and stretching of the circular solar sail attached to the inflatable toroidal shell. It is predicted that by introducing the gas into the inflatable toroidal shell one can deploy and stretch a large size circular solar sail membrane. The formulas for the toroidal shell and sail membrane stresses and strains caused by the gas pressure in the shell are derived. The analytical expressions can be applied to a wide range of solar sail sizes. Numerical calculations for the sail of radii up to 100 m made of CP1 membrane and attached to the toroidal shell with the varied cross-section radius are presented. The normal transverse vibration modes of the sail membrane under tension caused by gas pressure in the shell are calculated. The feasibility of deployment and stretching of a solar sail with a large size circular membrane attached to the inflatable toroidal shell is demonstrated. Full text available via: www.sciencedirect.com/science/article/pii/S0094576522005045			

Development of the HeliosX mission analysis code for advanced ICF space propulsion	Volume 202, January 2023, Pages 157-173	Kelvin Long	Interstellar Research Centre
This work presents some of the first results from a recently developed fusion propulsion code which calculates the performance of an advanced spacecraft design. HeliosX is a system integrated programming design tool written in Fortran 95 for the purpose of calculating spacecraft mission profile and propulsion performance for inertial confinement fusion driven designs. This code uses the vehicle configuration input and then calculates the likely mission profile for a given destination target. The key capability under development is the inclusion of the fusion propulsion system and an adequate modelling of its likely energy outputs and how this integrates into the mission profile. The results of a comparison to a concept from the literature are firstly presented for an interstellar flyby probe and then perturbations of this design to include updates and revisions to its input parameters and expected performance. Although the code is still being developed the early results show good potential to enabling a numerical tool for conducting spacecraft performance assessment of fusion based propulsion systems. The preliminary results of modelling different missions are shown for an interstellar target in 37–100 years trip times and 0.05–0.12c cruise speeds in flyby and rendezvous modes for orbital insertion to a distance 4.3–5.9 *ly*. A description is given for how the baseline concepts are being evolved since the code has been developed in parallel with the design process which aims to design improved vehicle concepts. Ultimately the calculations shown in this paper are working towards the development of a design tool which can facilitate the proper analysis of a range of different spacecraft designs and place them on a consistent modelling basis so that feasibility assessments can be made. Full text available via: www.sciencedirect.com/science/article/pii/S0094576522005598			

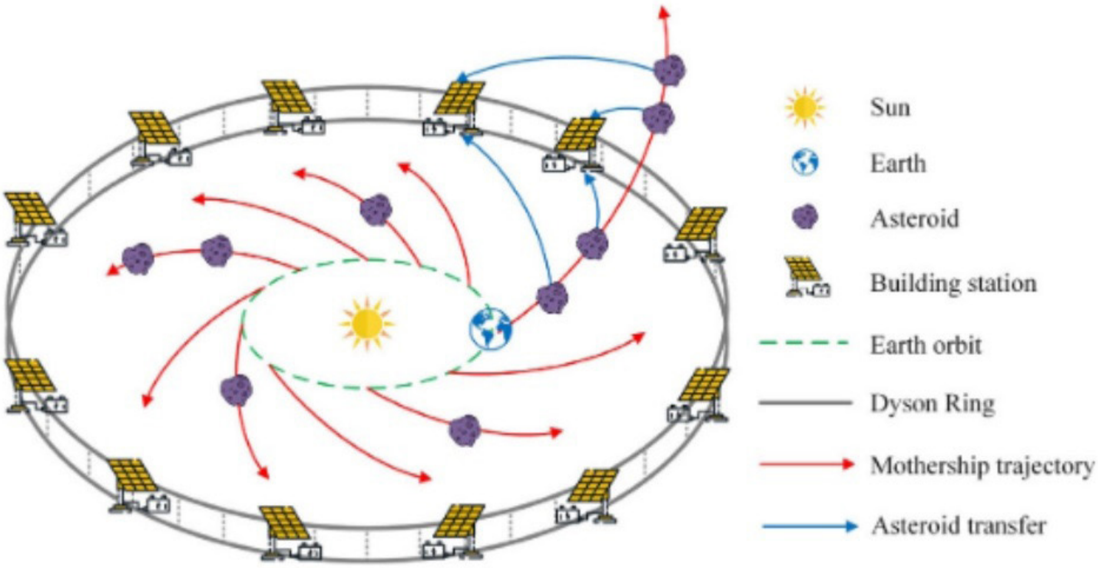

Illustration of the construction of the "Dyson ring" from *Dyson sphere building: On the design of the GTOC11 problem and summary of the results,* Fig. 1.

Credit: Hong-Xin Shen et al

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K E Tsiolkovsky

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• corporate publications, including our annual report.

Our latest member Newsletter included lots of Interstellar News ahead of this issue of Principium.

The members' area of our website now includes all the videos from last year's summer course on 'Human Exploration of the Far Solar System and on to the Stars' on behalf of the Limitless Space Institute.

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The Mariner 2 model

Terry Regan

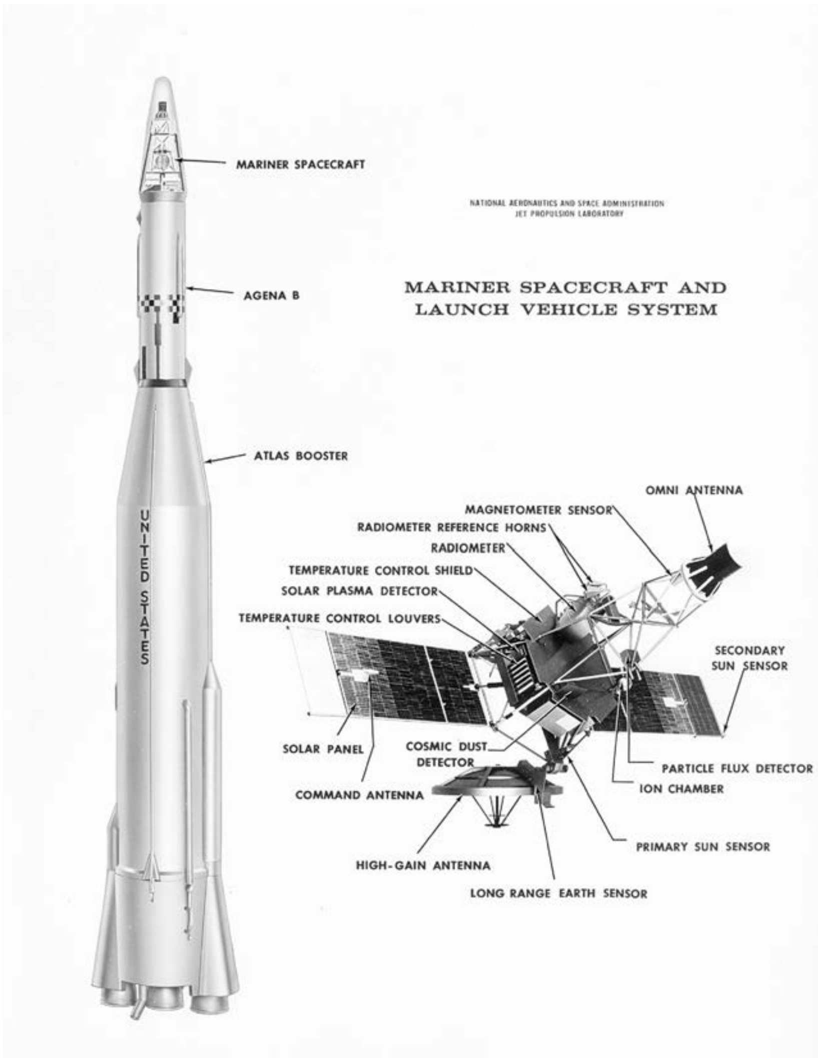
The i4is star model maker, Terry Regan, has celebrated another pioneering spacecraft by producing one of his brilliant scratch-built models. Here he recounts the original spacecraft and his motivation to build a model of Mariner 2. He'll be recording the rest of his creative process in later articles for Principium.

Introduction

Mariner 2 became the first successful mission to another planet when it flew by Venus on December 14, 1962. But it wasn't the first attempt to get a spacecraft to Venus. The Russians sent Venera 1 on 12 February 1961 but it lost communication on the way to Venus, incidentally Venera is Russian for Venus.

Brief History

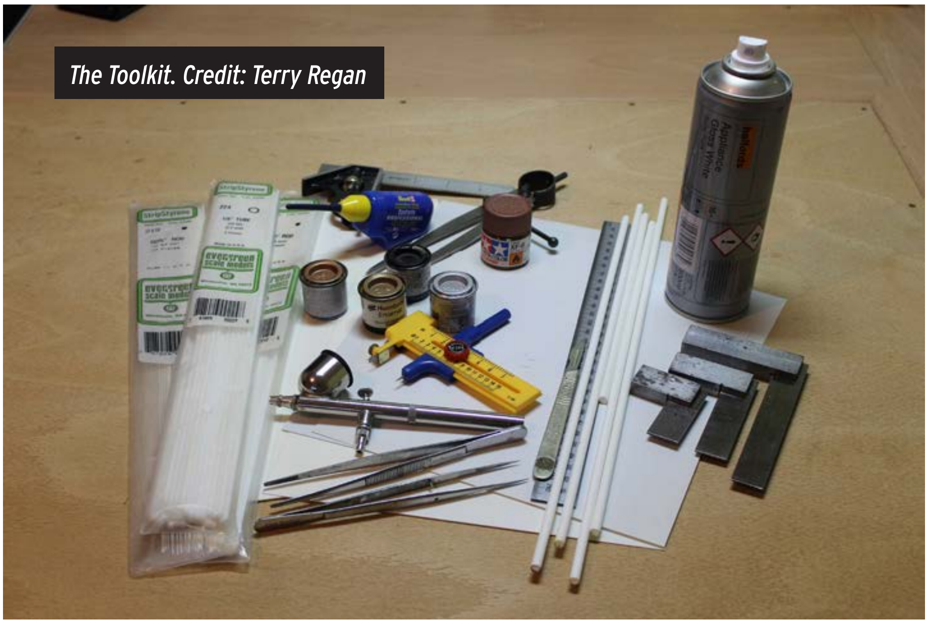
Mariner 2 was launched on 27th August 1962 and it would be a flyby , so what happened to Mariner 1 spacecraft ? It was launched on 22 July 1962 but around 5 minutes into flight it went off course so it was blown up by the range safety officer. Mariner 1 and 2 were simplified version of the block 1 spacecraft of the Ranger programme. Mariner 2 is now in orbit around the Sun, and this is the start of space exploration - beginning by sending more probes to the inner planets then getting more ambitious by sending probes to the outer planets in the solar system, like Pioneers 10 and 11, Voyagers 1 and 2 and New Horizon. The team at i4is build on this legacy by looking at possibilities for getting probes to other stars. And this all started with Mariner 2.



A diagram of the Mariner series of spacecraft and launch vehicle.
Mariner spacecraft explored Mercury, Venus and Mars.
Credit (caption and image): NASA/JPL-Caltech

Mariner 2 Model

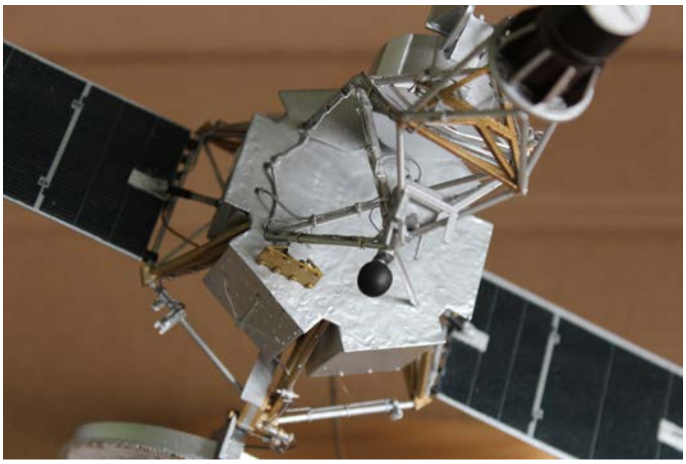
I have always liked the look of Mariner 1 and 2 and its down to it's unusual shape and the challenge it would be for me to build. I won't go into great depths on how I build it as this will be a later series for the Principium magazine. I used, as with all the other models I have built, sheets of plastic card - the same material that railway modellers use. For plans I would normally use plans designed for a paper model but in this case I found a set of hand drawn plans with the measurement in imperial units which I drew out and scaled down but at this stage I didn't know what scale it was going to be. However a couple of years later I did find a set of plans for a paper model and just by luck what I scaled down turned out to be almost exactly the same size as the plans so we have a 1/20th scale model.



The Toolkit. Credit: Terry Regan

Next step is the research starting at the British Interplanetary Society, emailing NASA archive department and the Science Museum London who were just so helpful and finally going onto the Smithsonian Air and Space museum web site where they have a replica Mariner 2 hanging from the roof plus around 30 odd close-up photos of the spacecraft which came very useful with detail that I could add to the model. In later editions of Principium I will be doing articles on how I made the Mariner 2 model and also the history of the mission. As a taster, here are a couple of images of the model.

The finished model on its stand. Credit: Terry Regan

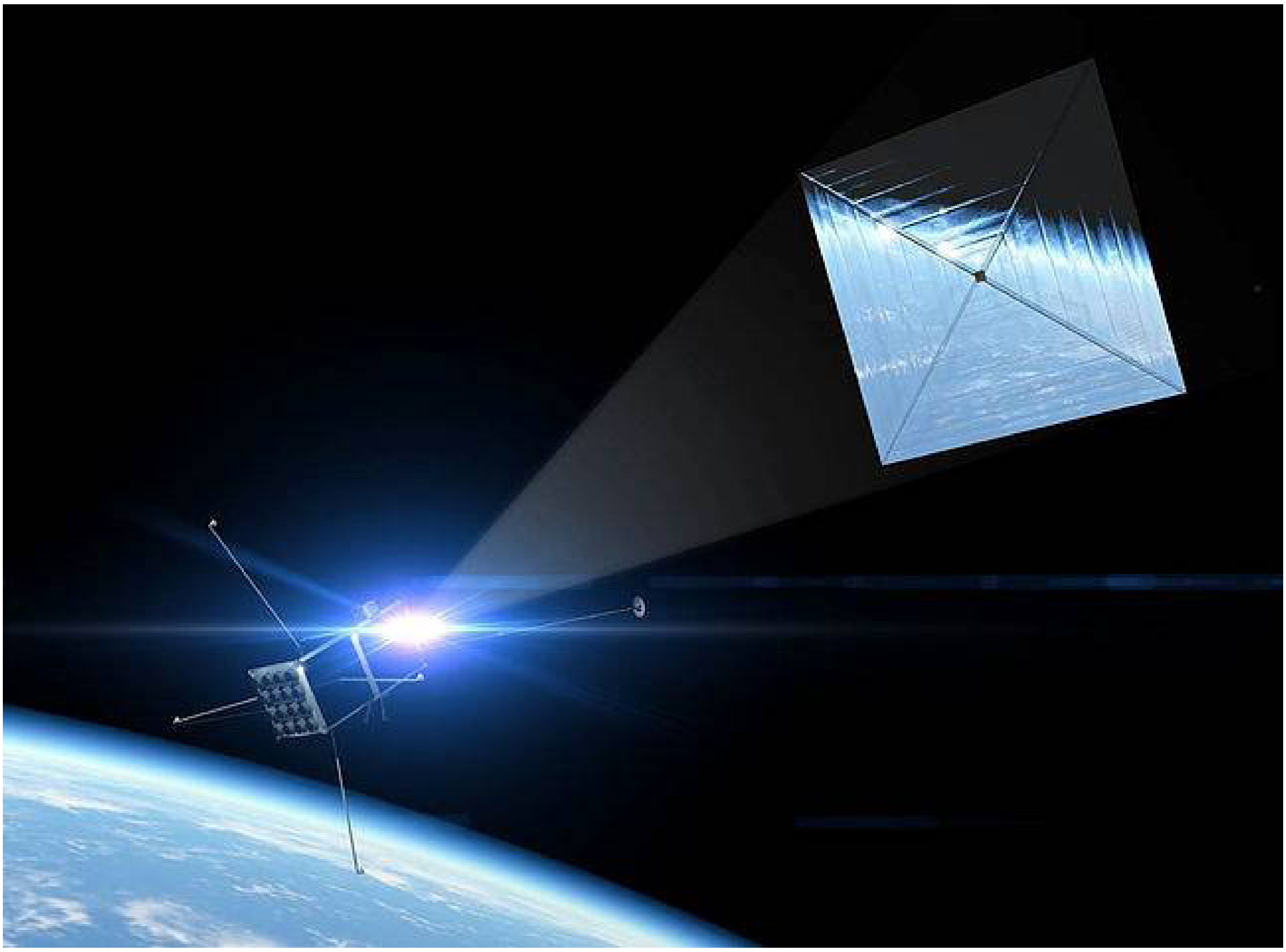


Main body and RTG generator arm Credit: Terry Regan

JOIN I4IS ON A JOURNEY TO THE STARS!

Do you think humanity should aim for the stars?

Would you like to help drive the research needed for an interstellar future...
... and get the interstellar message to all humanity?



The membership scheme of the Initiative & Institute for Interstellar Studies (i4is) is building an active community of enthusiasts whose sights are set firmly on the stars.
We are an interstellar advocacy organisation which:

- conducts theoretical and experimental research and development projects; and
- supports interstellar education and research in schools and universities.

Join us to support our work and also get:

- members newsletters throughout the year
- member exclusive posts, videos and advice;
- advanced booking for special events; and
- opportunities to contribute directly to our work.

To find out more, see www.i4is.org/membership
Discounts for BIS members, seniors & full time students!

THE i4iS MEMBERS' PAGE

Patrick Mahon

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

Recent members' newsletters and preprints

We have issued two newsletters to our members since Principium 39. The first, dated 19 December, included coverage of several recent developments of interstellar relevance, including:

- Advance notice of the Interstellar Research Group's 8th Interstellar Symposium, which will take place from 10-13 July at McGill University in Montreal, Canada;

- Information about our plans to exhibit at the next UK-based Science Fiction Worldcon, which will take place in Glasgow in August 2024;
- A list of our most frequently cited papers in the academic literature;
- A summary of a recent paper written by Andreas Hein and two of i4is's frequent collaborators, Manasvi Lingam and T Marshall Eubanks, considering the possibilities for missions to nomadic or rogue planets (those which aren't gravitationally bound to a star); and
- A call for a volunteer to become the new editor of the members' newsletter.

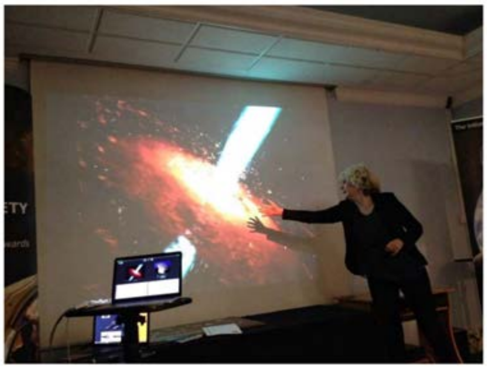
The second newsletter, issued on 22 January, covered:

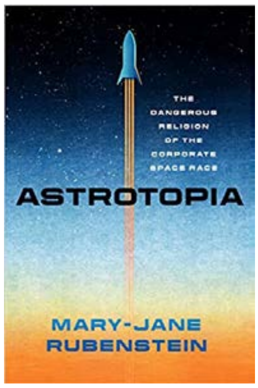
- A summary of a recent paper by a team at the University of Rochester in New York, which advocates that if you want to construct an O'Neill-type orbiting habitat, you might start with a so-called 'rubble-pile asteroid' (one where the asteroidal material is only loosely bound by gravity), then bind the rocks together with high tensile strength materials, before spinning it up to create artificial gravity;
- Publication by the 100 Year Starship organisation of the shortlists for its annual Canopus Awards, which celebrate excellent in interstellar writing, whether in fiction or non-fiction. We were delighted to see that the 2018 JBIS paper Artificial Intelligence for Interstellar Travel, co-written by our very own Andreas Hein and renowned British science fiction author Stephen Baxter, was shortlisted in the short-form non-fiction category;
- A paper from a team at Northeastern University, Boston, suggesting that conical or parabolic sails, constructed from metamaterials, would be better suited for use in laser sailcraft, rather than flat sails, which they say are likely to be dynamically unstable; and
- A summary of the diverse views in the space community and the media, in response to news in August that the US National Ignition Facility had achieved the long-sought result of net production of energy from an experimental fusion reactor.

Getting more actively involved

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

NEXT ISSUE





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

RIGHT: Astrotopia - The Dangerous Religion of the Corporate Space Race
Patrick Mahon will review.

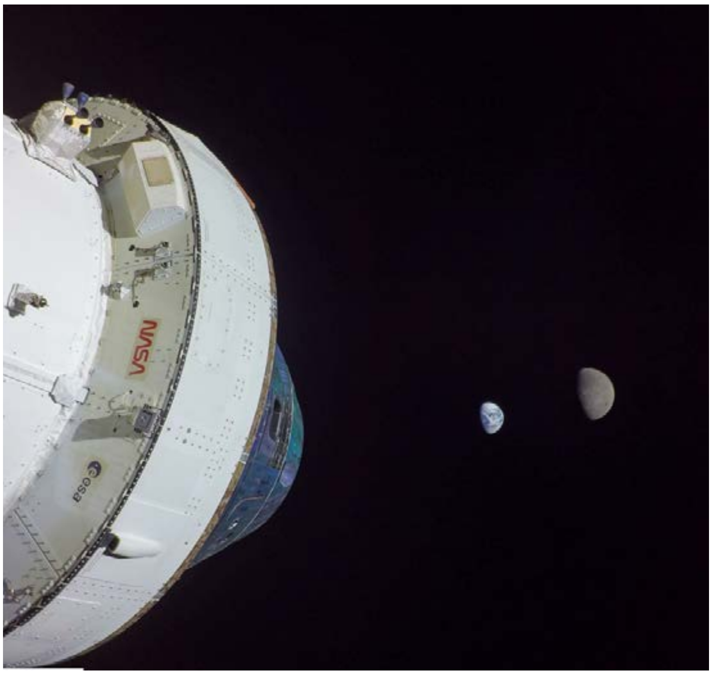
- **Current FTL thinking:** Faster than light (FTL) travel has been the subject of much serious thinking and it still engages the brains of some of the brightest on the planet but are we any nearer to achieving it other than in fiction? Dr Dan Fries, deputy head of the i4is Technical Team, will review where things stand.
- **Book Review** - in the new book **Astrotopia:** subtitled "The Dangerous Religion of the Corporate Space Race" Mary-Jane Rubenstein, Professor of Religion and Science in Society at Wesleyan University, examines the corporate space race and its implications for our future. Do we want to "colonise the Solar System"? Can we put cosmic caretaking ahead of imperialism and profiteering? Patrick Mahon will review.
- **A new way of finding out what's happening in interstellar studies:** We hope to be able to announce this ahead of our next issue - and explain what it can achieve.
- - **plus** *Interstellar News* and interstellar papers in *The Journals*.

There was a young lady named White
With velocity greater than light;
She went off one day
In a relative way
And returned on the previous night.

COVER IMAGES

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

FRONT COVER



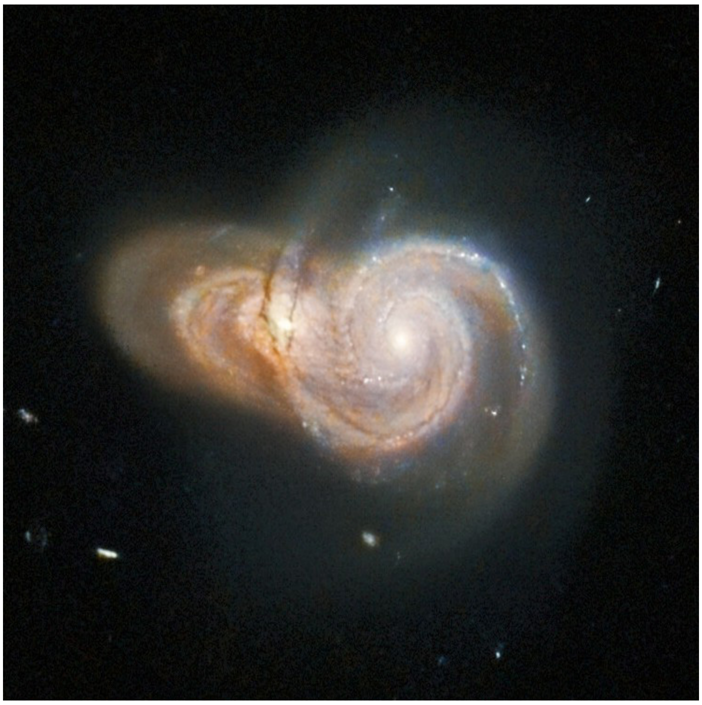
Artemis 1 went further...

... than any other crew-rated vehicle on the first flight of the Space Launch Stem (SLS - or Senate Launch System to its critics). A virtually flawless flight for both launcher and craft and a view astronauts will see in a few months time if all continues to go well. blogs.nasa.gov/artemis/2022/11/28/artemis-i-flight-day-13-orion-goes-the-max-distance/

Like Bobby Darin we will go beyond the Moon. But it might take a bit longer to go beyond the stars! I prefer the Charles Trenet version - but his objective was more terrestrial.

Credit: NASA.

BACK COVER



Hubble shows Galactic Overlap

Still not fully upstaged by the mighty JWST. Here's something happening way out there. Two galaxies SDSS J115331 and LEDA 2073461 more than a billion light-years from Earth. (We would need FTL or wormholes to get there - so maybe never?) esahubble.org/images/potw2236a/

But they are still a long way from each other - just overlapping from our point of view. The coincidence was found by the Galaxy Zoo project (www.zooniverse.org/) a citizen science project to find galactic oddities and, if of interest, flag them to the Hubble team.

Credit: NASA

The Initiative for Interstellar Studies is a pending institute, established in the UK in 2012 and incorporated in 2014 as a not-for-profit company limited by guarantee. The Institute for Interstellar Studies was incorporated in 2014 as a non-profit corporation in the State of Tennessee, USA.

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SCIENTIA AD SIDERA
KNOWLEDGE TO THE STARS

Front cover: Artemis 1, the Moon and the Earth.
Credit: NASA
Back cover: Hubble shows Galactic Overlap.
Credit: NASA

I4IS.ORG

MISSION

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

VISION

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

VALUES

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