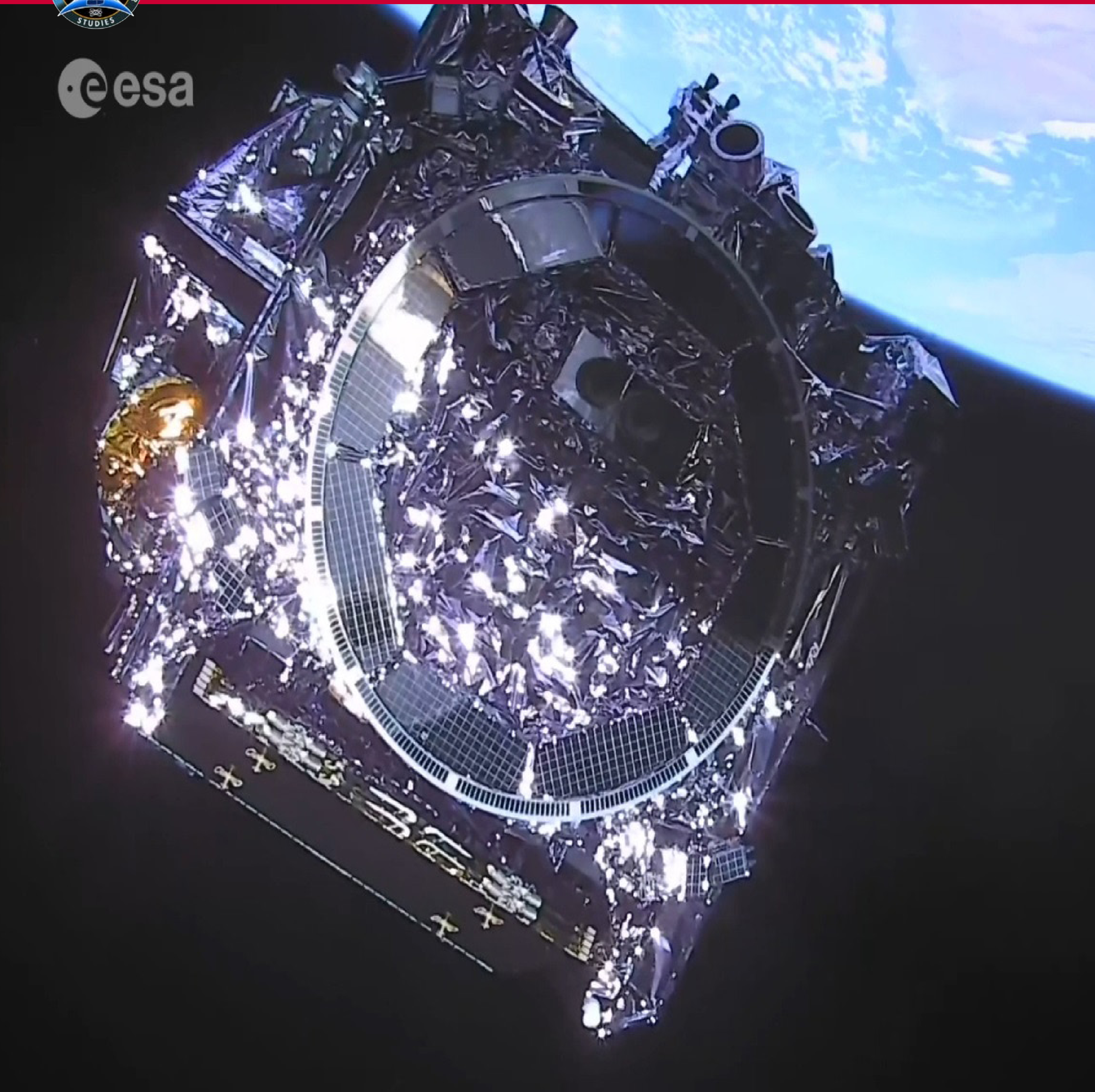
PRINCIPIUM

The Initiative and Institute for Interstellar Studies | Issue 38 | August 2022

SCIENTIA AD SIDERA | KNOWLEDGE TO THE STARS



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EDITORIAL

Welcome to issue 38 of Principium, the quarterly magazine of i4is, the Initiative and Institute for Interstellar Studies. Our lead feature this time is a book review, *Life in the Cosmos – From Biosignatures to Technosignatures*, by Dr Andreas Hein, i4is Technical Director [1]. Dr Manasvi Lingam and Professor Avi Loeb, an astrobiologist and an astronomer, discuss the range of topics from the basic properties of life to extraterrestrial biospheres and extraterrestrial technospheres.
We have 19 pages of Interstellar News and six pages of our regular summary of relevant peer-reviewed papers in *The Journal of the British Interplanetary Society* (JBIS) and *Acta Astronautica*.
The front cover image this time is the parting image of the James Webb Space Telescope (JWST) seen from the final stage of the Ariane 5 launcher. The rear cover image, of Jupiter and Europa, marks the first images from the deployed JWST. More about both in *Cover Images* inside the rear cover.
The concluding part of *Two Equations to the Stars, Part Two: The Photon Sail Equation*. In P37 we showed how the Tsiolkovsky rocket equation can be made understandable to school students who have yet to study either the integral calculus in mathematics or the concept of momentum. Again we aim to give teachers and advanced school students the tools to achieve this by explaining the basics of the photon sail equation used by Robert L Forward in his seminal 1984 paper advocating photon propulsion as a means of reaching the stars.

We survey *The Interstellar Papers* announced for International Astronautical Congress 2022. As always we have the i4is members' page and another regular feature, *Become an i4is member*.

The next issue, in November 2022, will include -
• a report on the summer 2021 and 2022 courses *Human Exploration of the Far Solar System and on to the Stars*, delivered by i4is for the Limitless Systems Institute (LSI)
• *Oumuamua - A Second Chance*: Adam Hibberd's personal account of his journey to and through his vital contribution to i4is Project Lyra
• *73rd International Astronautical Congress 2022 - The Interstellar Presentations*: First reports of the interstellar themes at the biggest world space conference of the year
• Book review: Interplanetary Liberty - Building Free Societies in the Cosmos, Charles S Cockell by Max Daniels
- all listed in *Next Issue* at the end of this one.

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

John I Davies, Editor, john.davies@i4is.org
Patrick Mahon, Deputy Editor, patrick.mahon@i4is.org

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

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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 on page53 of this issue and at i4is.org/membership.

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Please print and display our posters - one on page 52 and all our poster variants are available at i4is.org/i4is-membership-posters-and-video

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

[1] Associate Professor of Space Systems Engineering at SPASYS, Université du Luxembourg.

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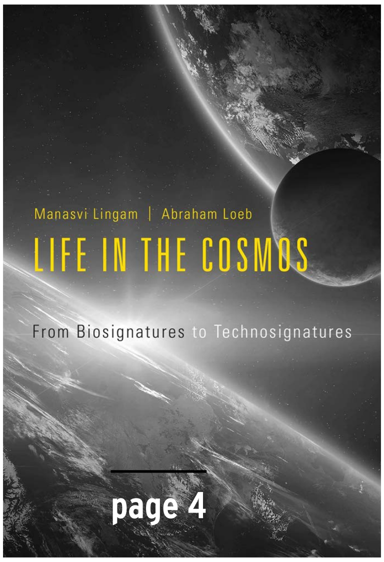

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IAC PARIS 2022

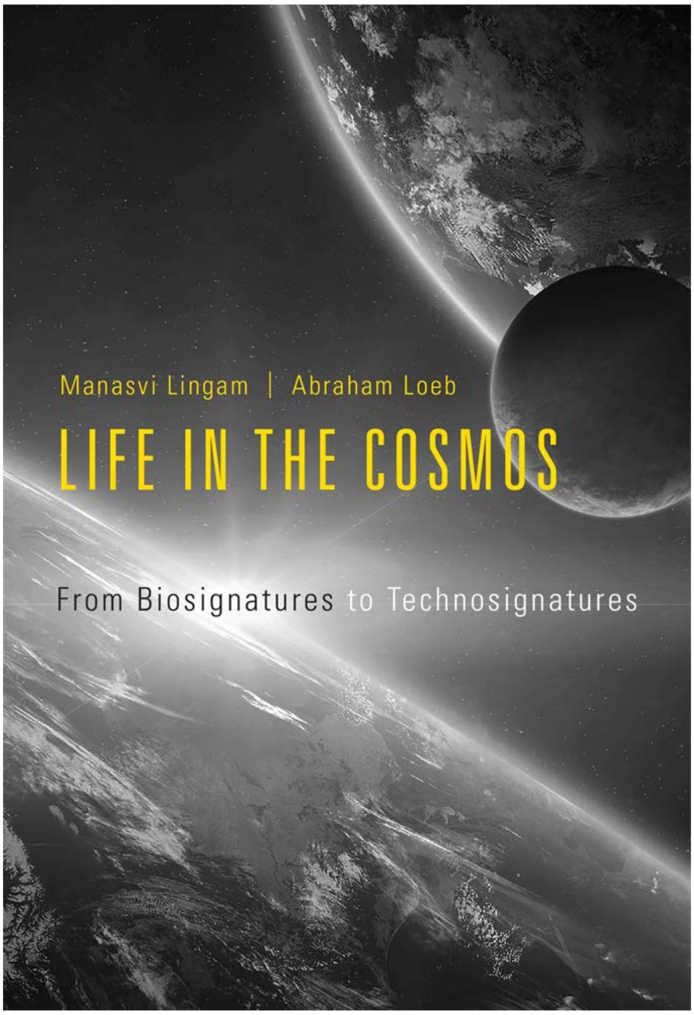
See us at both these events

Book Review: Life in the Cosmos

From Biosignatures to Technosignatures

Andreas Hein

Our lead feature this time is a review by Dr Andreas Hein, Associate Professor - Space Systems Engineering, Université du Luxembourg, and Technical Director, i4is, of the book, *Life in the Cosmos - From Biosignatures to Technosignatures*, Manasvi Lingam and Avi Loeb, 1088 pages, Harvard University Press 2021. (www.hup.harvard.edu/catalog.php?isbn=9780674987579).



Introduction

How can I write a review of a friend's book? Manasvi Lingam, who is the main author of the book "Life in the Cosmos" is a close collaborator and a friend of mine. This obviously makes my review not independent, which is the first point I want to disclose right at the beginning. The second point, which outweighs the first in my view, is that I have limited knowledge of astrobiology. Hence, consider this review written by an educated amateur.

Life in the Cosmos – From Biosignatures to Technosignatures, written by Manasvi Lingam and Avi Loeb, was published by Harvard University Press in 2021. Avi Loeb is a professor at Harvard University and a well-known figure in astrophysics and cosmology. While he has built his scientific reputation in these fields, he has made headlines in recent years for publications within the area of SETI (Search for Extraterrestrial Intelligence) and astrobiology. Today, he is known to a wider audience via his conjecture that the interstellar object 'Oumuamua could be artificial. Most recently, he has launched the Galileo project to investigate potential signs of extraterrestrial technological civilization. It is therefore safe to say that he is not afraid of controversy and to enter fields where he has limited experience.

Manasvi Lingam is a professor of astrobiology at the Florida Institute of Technology. While he is still a relatively junior researcher, he has already an impressive track record of publications in astrobiology but also other fields such as plasma physics. From my personal collaboration with him, I know about his exceptional breadth of knowledge in a variety of fields. Manasvi was a postdoc of Avi Loeb several years ago and they share a history of collaboration, which resulted in a number of journal papers but also this book.

While I do not have insights into the repartition of the work between the two authors, I suspect that Manasvi has probably done most of the writing, as his distinct writing style was recognizable throughout the book. I will come back to this point later. But let's get to the book itself.

When this book arrived at my place, I was immediately impressed by its size and weight. It has roughly the size and feel of a brick but its layout is delicate, starting from the font used on the cover and its main body, as is the thin paper on which it is printed, hinting at the enormous quantity of material on the over 1000 pages. I usually do not pay much attention to these aspects, but this book already stands out in that respect.

Now, let's get to the actual content of the book. The title of the book "Life in the Cosmos – From Biosignatures to Technosignatures" already indicates that we are not dealing with a book that focuses on a narrow sub-domain of astrobiology but a book that covers the whole spectrum from simple life to intelligent civilizations. Manasvi is known for a number of audacious papers on a variety of topics related to astrobiology. Avi Loeb, the second author, and much more senior colleague is similarly known for having published a number of audacious, sometimes contested, papers in this field. The general population might know him mostly from his publications related to 'Oumuamua. Both authors rather have a background in theoretical physics/astrobiology, meaning that their research is less on the experimental side of astrobiology.

The structure of the book follows a clear logic, coherent with the title, starting from the basic properties of life, which we know from Earth in terms of its origins and evolution, extraterrestrial biospheres, and extraterrestrial technospheres.

The Content

Chapter 1 provides an overview of definitions of life and its requirements. Readers familiar with astrobiology will know that defining life is notoriously difficult and no convincing all-encompassing definition has been provided yet. Lingam and Loeb are of course aware of this and they lay out some important definitions (NASA's astrobiology division's definition, Boltzmann and Schrödinger's definitions) and their limitations using examples. In about six pages, the authors provide a lucid summary of the current state of the scientific debate. Due to its nature, this chapter is the by far most philosophical one of the book. In 1.2, they continue with the requirements of life, such as carbon and water, potential alternatives. 1.3 introduces, in an almost poetic turn the Anna Karenina Principle ("Happy families are all alike; every unhappy family is unhappy in its own way."), which basically points at the multi-factor nature of life, where each condition needs to be satisfied. Only those who satisfy all criteria (the happy families) exist for this very reason (all alike in that aspect), all others (unhappy families) do not for a variety of reasons (failed in their own way). For life to exist, a set of necessary criteria need to be satisfied and one key research question is what these criteria are.

Chapter 2 describes how life might have emerged on Earth. The origin of life (abiogenesis) on Earth from inorganic matter is one of the big questions in science and the authors provide an overview of current hypotheses and theories. They go on in length regarding the specific conditions under which life emerged on Earth, ranging from atmospheric conditions, radioactivity, impacts,

[1] *What are the characteristics of life?* https://astrobiology.nasa.gov/education/alp/characteristics-of-life/
[2] en.wikipedia.org/wiki/What_Is_Life

hydrothermal conditions etc. DNA/RNA as basic building blocks of life are introduced. Section 2.8 provides an overview of mathematical models of the origin of life, introducing, for example, Jeremy England's non-equilibrium statistical mechanics model.

Chapter 3 provides an overview of the evolution of life on Earth with its different stages, ranging from single-cell organisms, sexual reproduction, multi-cellular organisms, and intelligence. While the main focus is on Earth, sub-sections are sprinkled in where the implications for extraterrestrial life are made, for example, regarding extraterrestrial technological intelligence.

Chapter 4 focuses on stellar habitability factors. This includes a discussion of the well-known habitable zone (traditional one for CO_2-H_2O as greenhouse gases and extensions CO_2-CH_4, and CO_2-H_2 atmospheres), stellar winds, stellar electromagnetic radiation, stellar flares and space weather.

Coming from the stellar habitability factors, **Chapter 5** now focuses on the habitability regulators of planets, covering multiple factors: temperature, plate tectonics, tidal locking, atmospheric composition, landmass vs ocean ratio. Temperature plays an important role in determining the metabolic rate of organisms, which has a significant impact on factors such as population growth, turnover of biomass in an ecosystem, and biodiversity. However, a sudden increase in temperature, for example, due to extremely large solar flares, may lead to a significant loss of biodiversity.

Chapter 6 deals with biosignatures, in other words, signs that hint at biological life. The focus is on biosignatures at the molecular level, which can be potentially detected by observing the spectrum of a planet. The presence of a certain molecule would appear as an absorption line. Different methods for detecting biosignatures are introduced such as during the transit of a planet in front of a star, which provides an opportunity for various types of spectroscopy. Subsequently, indirect methods for detecting signs of habitability are introduced such as the presence of a magnetic field, the architecture of the planetary system and its composition, atmospheric and ocean losses, and stellar parameters. The presence of certain gases in the atmosphere might also be biosignatures. The recent alleged discovery of phosphine in the Venusian atmosphere would fall into this category. The chapter continues with surface and temporal biosignatures and ends with how to assess the plausibility of life detection, using a Bayesian approach. The question is essentially, how different evidence can be combined to arrive at conclusions on the likelihood of life detection.

Chapter 7 treats life in subsurface oceans. Most readers have probably heard about potential life in the subsurface oceans of Europa or Enceladus in our solar system. However, much more potential worlds are considered such as Titan, Ganymede, Callisto, who also have oceans. Subsequently, specific environmental conditions in such oceans and their implications for life are discussed, including the existence of ecosystems and their evolution.

Part 3 of the book deals with technosignatures.

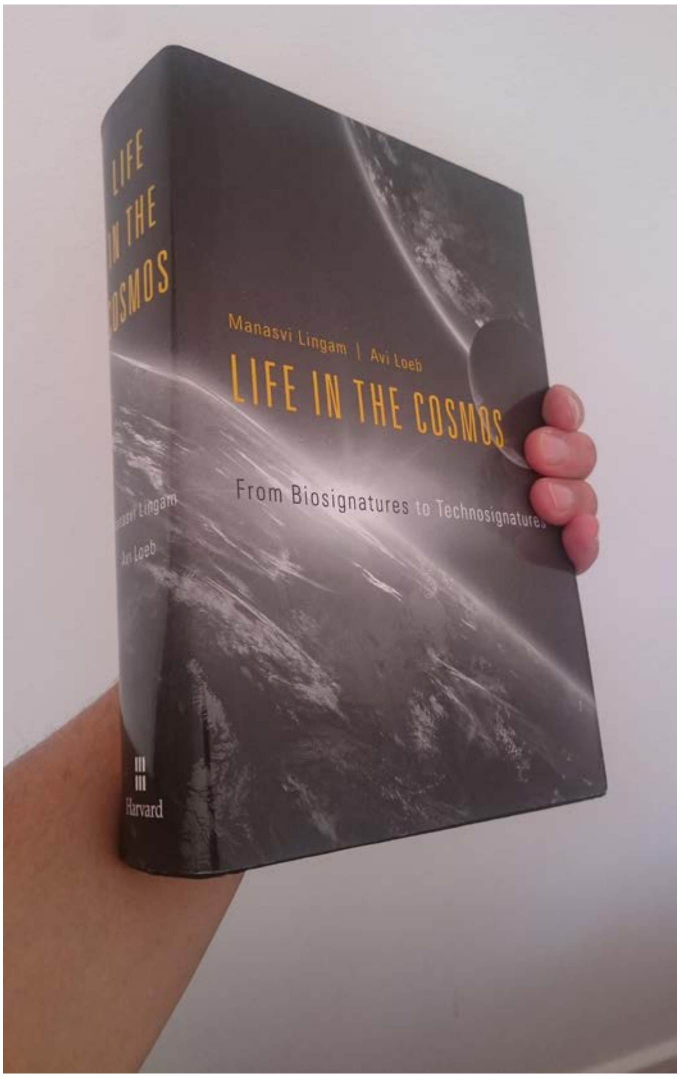
Chapter 8 introduces the famous Drake equation and Fermi's Paradox. Readers familiar with the discussions on extraterrestrial intelligence will likely be familiar with both concepts. The Drake equation in its original form was used to estimate the abundance of intelligent life in our galaxy. Some of its values can be empirically determined today such as the number of planets around stars. Others, such as the fraction of life-bearing planets is still unknown. The Drake equation, its implications and critique is discussed in detail and one gets an overview of the scientific discussion around this topic. Next comes Fermi's Paradox, another key concept concerning extraterrestrial intelligence. The famous question, allegedly asked by Fermi: "Where is everybody?" points at the apparent contradiction between the theoretical abundance of extraterrestrial intelligence and its observational absence. Various "solutions" to the Fermi Paradox are presented such as the Zoo hypothesis, underpinned by the respective equations and a discussion.

Chapter 9 deals with the search for technosignatures. This is a field which has recently received a lot of attention. The chapter aggregates the search for signals, which is part of "traditional" SETI and physical artifacts such as inscribed artifacts for transmitting messages to megastructures such as Dyson Spheres (called Stapledon-Dyson Spheres in the honour of Stapledon, who also proposed them in this novel "Last and First Men" and "Star Maker"). The Kardashev scale is introduced, which is equally well-known and classifies the level of energy consumption of a civilization (planetary, stellar, to galactic level). The artifacts treated in this chapter range from pollution in the atmosphere, energy leakage from propulsion systems such as light sails, antimatter, etc to global warming and its mitigation. Also, satellites and space debris are considered as potentially detectable. Finally, the implications of these technosignatures on the search strategy are discussed. The authors conclude that a minimum budget of $1 million per year would be merited, given the likelihood of detection and the potential impact of detecting ETI.

Chapter 10 deals with the propagation of life in the universe in the widest sense. Interstellar travel enthusiasts will find all relevant interstellar propulsion methods described in this chapter such as fusion, laser, interstellar ramjet, and light sail propulsion. Magnetic and electric sails are also treated. However, the authors begin the chapter with the rather controversial topic of panspermia. This is interesting, as panspermia is an essentially non-technological way of how life may propagate throughout the universe. The discovery of ʻOumuamua and (comet) Borisov has shown that panspermia might indeed be able to travel between the stars. A dedicated section deals with interstellar panspermia and its propagation mechanisms, which lead to its ejection out of a star system.

The book ends with an epilogue with recommendations on future research directions. Poetry is abundantly sprinkled in this book and it is no surprise that it concludes with a phrase from Virgil's Aeneid: "Blessings on your fresh courage, child; thus one journeys to the stars." What more could be said?

Target audience



In terms of accessibility, I would recommend the book to readers who have at least a basic foundation in the natural sciences, eg chemistry and mathematics, although high school level would be sufficient. To fully appreciate the book, I would rather recommend it to undergraduate students and upwards in natural sciences/engineering, although some of the chapters, for example, chapter 1 are accessible to a layperson as well. Nevertheless, this is definitely not a popular science book and it doesn't try to be one. The language used is sophisticated, similar to the one found in scientific publications. For my personal taste, it was sometimes a bit too much (e.g. the use of Latin expressions such as "sensu latu"), where I thought that non-native English (or non-Latin) speakers might need to check a dictionary ("variegated", "well-nigh", p.374). Fortunately, the use of such sophisticated vocabulary does not significantly alter the reading experience. It also becomes clear that the authors have done their share of reading the Classics ("we must navigate the waters carefully, between the Scylla of labyrinthine, tangled reality and the Charybdis of reductive oversimplification," p.375). Whether the reader appreciates such references is a matter of taste.

Hence, students and researchers who intend to work on an astrobiology-related topic will find this book fantastic as a starting point for further research, as it provides an up-to-date overview of the literature. The more generally interested reader will find a fantastic place for brief exposés on astrobiology topics that are rather self-contained and can be read independently of other chapters. A huge amount of references invites to dig deeper into each subtopic. I would say that this book is going to be the one-stop-shop for astrobiology for years to come. A must-have for those interested in astrobiology and bold enough to work through over 1000 pages of intellectual condensate.

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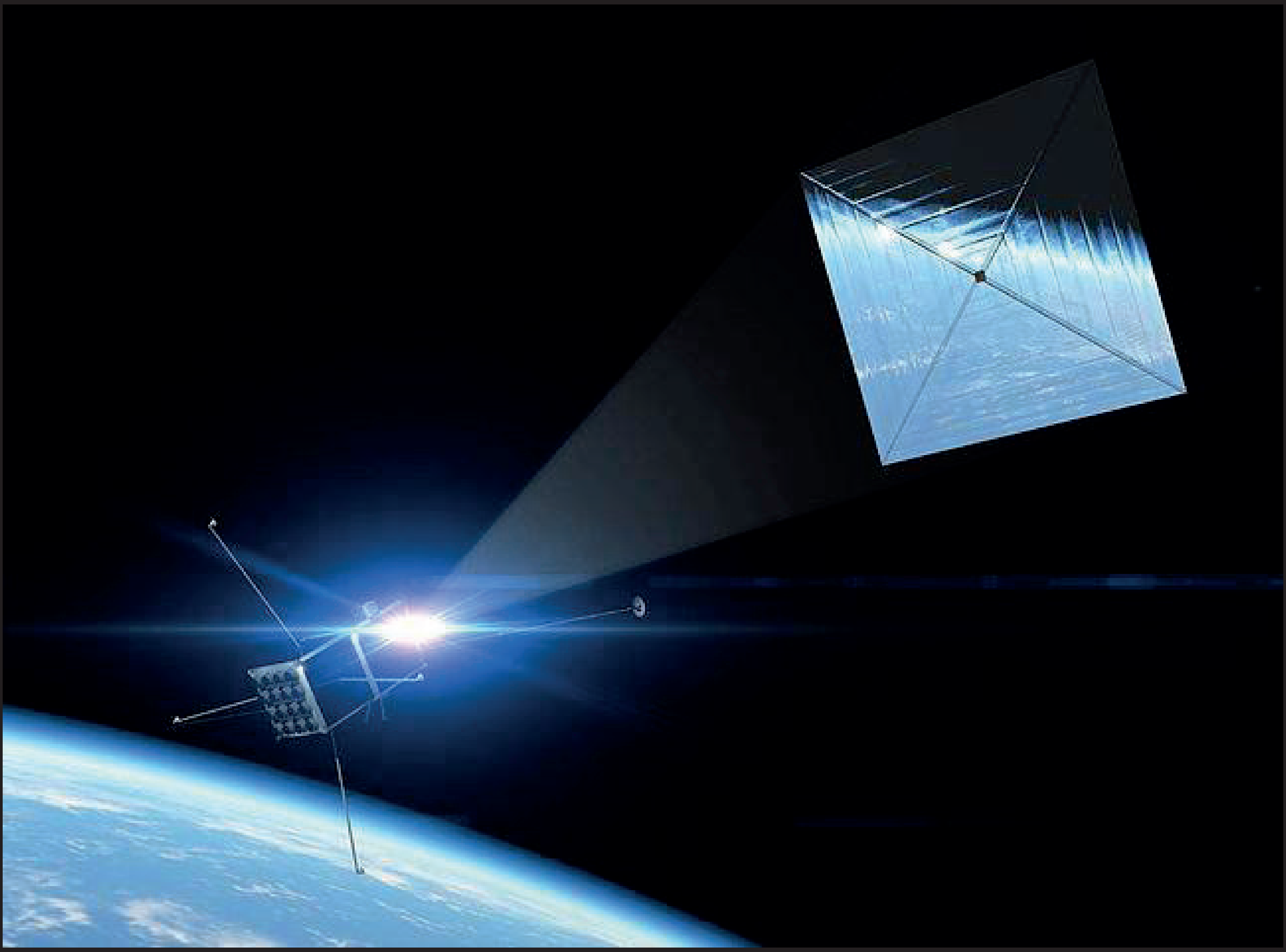
Do you think humanity should aim for the stars?

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



The Initiative for Interstellar Studies (i4is) has launched a membership scheme intended to build an active community of space 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.

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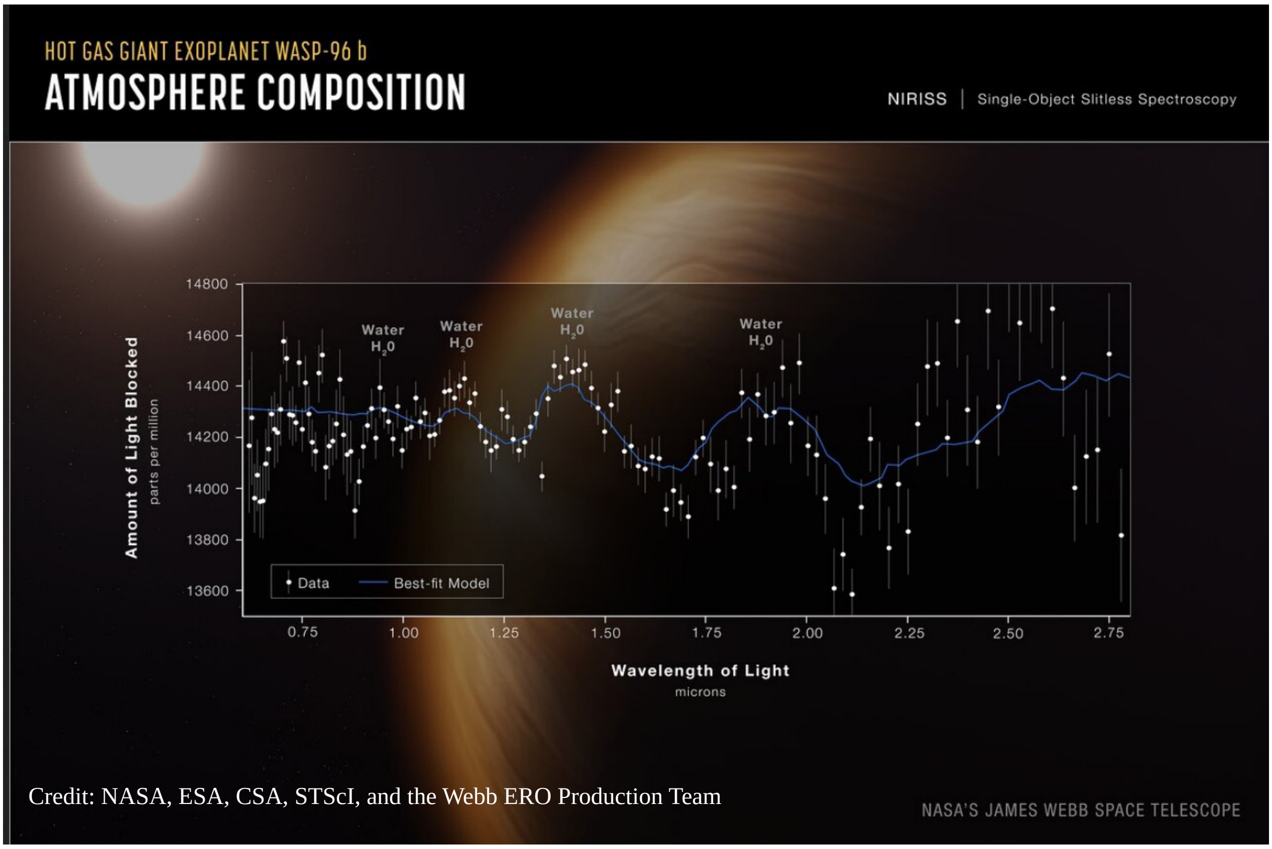
To find out more, see www.i4is.org/membership

John I Davies reports on recent developments in interstellar studies



Credit: NASA, ESA, CSA, STScI, and the Webb ERO Production Team

Webb telescope: early results

The James Webb telescope is a joint project by NASA, ESA and the Canadian Space Agency. ESA published lots of striking early images and results (esawebb.org/) but from the i4is point of view this exoplanet atmosphere result above is one of the most striking, *Webb Reveals Steamy Atmosphere of Distant Planet in Exquisite Detail* (esawebb.org/news/weic2206/).

As ESA notes "...Webb's Near-Infrared Imager and Slitless Spectrograph (NIRISS) measured light from the WASP-96 system for 6.4 hours as the planet moved across the star. The result is a light curve showing the overall dimming of starlight during the transit, and a transmission spectrum revealing the brightness change of individual wavelengths of infrared light between 0.6 and 2.8 microns." and "the transmission spectrum reveals previously hidden details of the atmosphere: the unambiguous signature of water, indications of haze, and evidence of clouds that were thought not to exist based on prior observations."

Not necessarily a happy home from home for our species but much detail that was not obtainable previously and this is a first indication of the ground breaking capabilities of this magnificent instrument.

Warp Drive Aerodynamics

Warp Drive Aerodynamics (arxiv.org/abs/2207.06458) [1] analyses the potential for a warp drive spacetime to develop instabilities due to the presence of quantum matter. They find that warp-drive bubbles in dimension 2+1 or higher are in fact likely to be stable and that certain instabilities in Alcubierre warp-drive spacetime can be diminished with particular, more “aerodynamic” shapes and trajectories for the drive. They conclude that while this work does not prove that warp drives are a completely viable option for faster-than-light travel, they strongly evidence that these instabilities do not, in principle, preclude “aerodynamic” configurations of the Alcubierre drive from being able to sustain a net superluminal speed and states that "The launchpad for our future superluminal journeys is thus left with one less obstruction".

[1] *Warp Drive Aerodynamics*, Carlos Barcel (Instituto de Astrofisica de Andalućıa (CSIC), Spain), Valentin Boyanov, Luis J Garay and Jose M Sanchez Velazquez (Universidad Complutense de Madrid), Eduardo Martın-Martınez (University of Waterloo)

Artist's illustration of interstellar asteroid 'Oumuamua.
Credit: Gemini Observatory/AURA/NSF/Joy Pollard

Traversable wormhole?

In *Traversable wormholes with like-Casimir complexity supported with arbitrarily small amount of exotic matter* [1] researchers from Universidad San Francisco de Quito, Ecuador, and Universidad Central de Venezuela provide the redshift function of a Casimir traversable wormhole which leads to a traversable wormhole with a minimum amount of exotic matter. They report "...we found that the solution connects two asymptotically flat regions through a tunnel with the size of the Earth-Moon distance and the time required to traverse the wormhole from a spatial station located in the asymptotically flat region it is on the order of a few hours".

They refer especially to a paper by a good friend of i4is, Remo Garattini of Bergamo University, Italy, *Casimir wormholes* (epjc.epj.org/articles/epjc/abs/2019/11/10052_2019_Article_7468/10052_2019_Article_7468.html). His lectures for i4is and others are reported in *Traversable Wormholes and the Casimir Energy in Modified Gravity* (Principium 10, August 2015), *Wormholes, Energy Conditions and Time Machines* (Principium 22, August 2018), *Foundations of Interstellar Studies Workshop 2019* (Principium 26, August 2019) and *Interstellar Workshop of the European Space Agency* (Principium 30, August 2020). All Principium issues are available at i4is.org/publications/principium/.

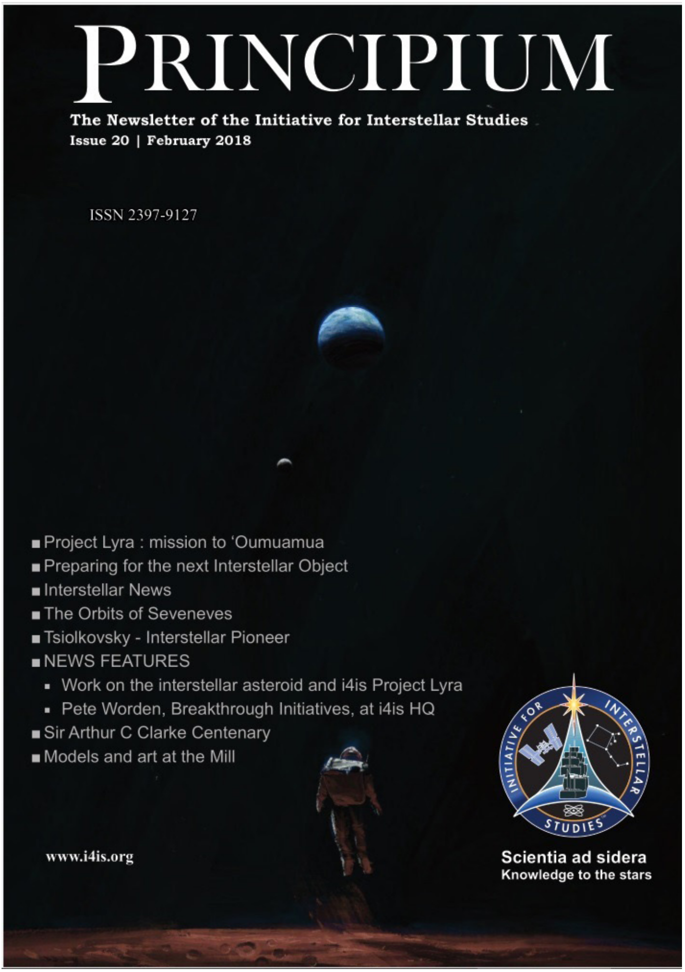
The view from 'Oumuamua's perspective

Adam Hibberd has produced a brilliant short piece - *1I/'Oumuamua's Orbit As It Encountered The Inner Solar System* (i4is.org/1i-oumuamuas-orbit-as-it-encountered-the-inner-solar-system/). Imagine being the astronaut on 1I/'Oumuamua visualised on our P20 (February 2018) cover - right.

Adam tells how the Earth's appearance would change as viewed by that astronaut as 1I/'Oumuamua zoomed past.

Here is a purely personal view of things from Principium editor, John Davies -

> The longer we go without finding a similar object the greater the urgency of a mission to what remains a unique ISO. As Popper[2] would put it, all conjectures about 'Oumuamua need to seek means of refuting them. A mission is feasible, as i4is Project Lyra has demonstrated many times, and such a mission is the only way we may support or refute conjectures about its nature.



[1] *Traversable wormholes with like-Casimir complexity supported with arbitrarily small amount of exotic matter*, R Avalos, E Fuenmayor, E Contreras, link.springer.com/content/pdf/10.1140/epjc/s10052-022-10389-8.pdf

[2] *Conjectures and Refutations: The Growth of Scientific Knowledge*, Karl Popper, Harper & Row, 1963

JWST Near-Infrared Spectrograph for exoplanets

In a recent paper *The Near-Infrared Spectrograph (NIRSpec) on the James Webb Space Telescope - IV. Capabilities and predicted performance for exoplanet characterization*, S M Birkmann (ESA) et al [1] discuss capabilities of the NIRSpec instrument on the James Webb Space Telescope for time-series observations and transit and eclipse spectroscopy of exoplanets (for an early example see *Webb telescope: early results* above).
Spectroscopic characterisation of exoplanet atmospheres has only been performed for a few dozen exoplanets so far. The JWST will open a new era in exoplanet atmosphere investigation.
Exoplanets are often detected by their transit across image of the host star and thus close-orbiting exoplanets are most easily found. Where they are well separated from their host star their resolved image may be obtainable by other JWST instruments and the NIRSpec will also be able to characterise these directly.
The NIRSpec was built by Astrium Germany (now part of Airbus Defence and Space) for ESA.

The NIRSpec logo. Credit: Space Telescope Science Institute, Baltimore, Maryland

The ET mission to search for Earth 2.0s

A team from Shanghai Astronomical Observatory (Chinese Academy of Sciences) and NASA Ames have published a proposal for an improved exoplanet finding space telescope to improve upon the results of the Kepler space telescope [2]. Called *ET (Earth 2.0)* it will carry seven 30 cm refracting telescopes, of which six are wide-field transit telescopes and one is a microlensing telescope. Contrast Kepler which has a single 95 cm reflector. The proposal states that ET will have a larger field of view (FOV), higher precision photometry than Kepler and improved CMOS detectors with much lower noise than Kepler. They aim to find the first Earth 2.0 - one with environmental conditions similar to those found on Earth - and determine planet density, internal structure, and atmospheric composition to assess their habitability.

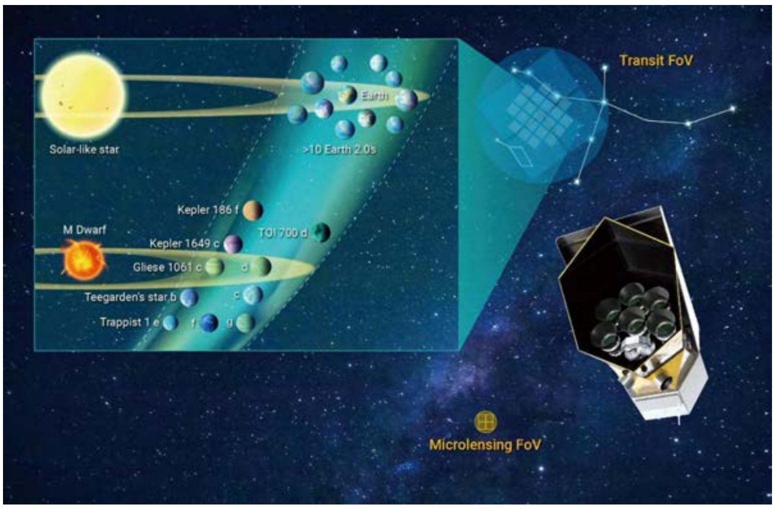
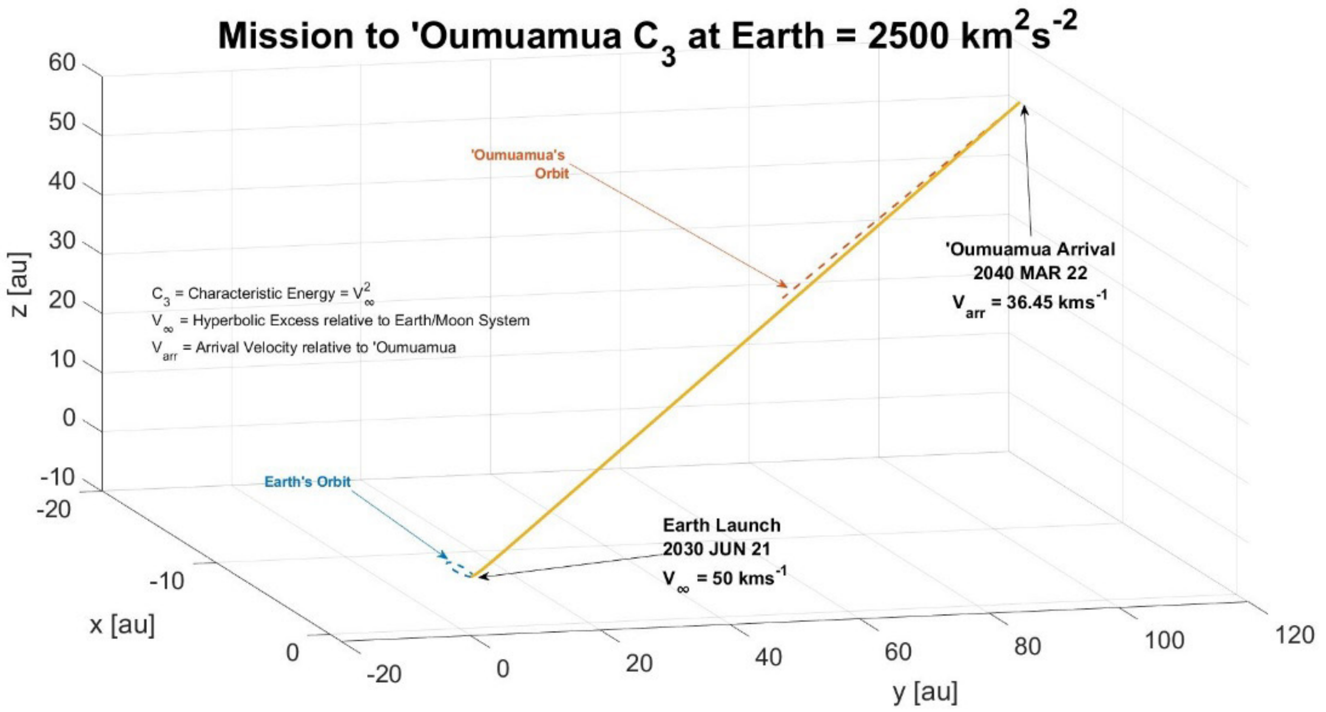


Figure 1. The design of the ET scientific payload which includes six 30 cm diameter transit telescopes and one 30 cm diameter microlensing telescope. ET's 500 square degrees of field of view (encompassing the original Kepler field) will be monitored continuously by the ET's transit telescopes over 4 years to search for transit signals from Earth 2.0s. To date, all the potentially habitable Earth-size planets were detected around M dwarfs. ET plans to find the first Earth 2.0 within the habitable zone of solar-type stars.
Credit (caption and image): The ET team

[1] *The Near-Infrared Spectrograph (NIRSpec) on the James Webb Space Telescope - IV. Capabilities and predicted performance for exoplanet characterization*, www.aanda.org/articles/aa/full_html/2022/05/aa42592-21/aa42592-21.html
[2] *The ET mission to search for Earth 2.0s.* https://www.sciencedirect.com/science/article/pii/S2666675822000674

SunDiver Workshop in Luxembourg

The SunDiver Workshop in Luxembourg, 17-18th of May, was a workshop on "Fast, Low-Cost, Interplanetary Sailcraft Science Missions". Project Lyra was presented, see *Project Lyra: Presentation at SunDiver Workshop in Luxembourg* (i4is.org/project-lyra-presentation-at-sundiver-workshop-in-luxembourg/) for a picture of Andreas and the team at the Neimenster Abbey in Luxembourg, organized by the University of Luxembourg (SnT), Breakthrough Initiatives, and NASA-JPL. i4is Executive Director Andreas Hein organized this meeting in his capacity as a professor of Space Systems Engineering at the University of Luxembourg.



Example mission to 1I/'Oumuamua. C3 is the departing velocity - which delivers a probe to 1I/'Oumuamua in 10 years. Credit: A Hibbert

The meeting featured some prominent researchers working on solar sails such as Slava Turyshev (NASA-JPL), Jan Thimo Grundmann (DLR), Bernd Dachwald (FH Aachen) with numerous space scientists such as Phil Mauskopf (Arizona State University), James Lloyd (Cornell) and Marshall Eubanks (Space Initiatives). Project Lyra was notably presented during Hein's presentation of potential SunDiver missions to interstellar objects. Another presentation suggested a planetary defence concept, see next item.

Sundiver Lightsail Technology - To The Kuiper Belt

To The Kuiper Belt! Solar System Precursor Missions with Solar and Laser-Driven Sailcraft [1] was a presentation to the *Breakthrough Initiatives/University of Luxembourg "Sundiver" workshop on Fast, Low-Cost, Interplanetary Sailcraft Science Missions*, a 2-day meeting of scientists and engineers to discuss possibilities for fast, low-cost planetary science missions into the solar system using smallsats with solar sails, May 17-18, 2022. Hosted at the Neimenster Abbey, a conference venuein Luxembourg, it included several members of the i4is technical team. This presentation offers a number of high speed probe missions including one to the still-mysterious interstellar object (ISO), 1I/'Oumuamua.

[1] *To The Kuiper Belt! Solar System Precursor Missions with Solar and Laser-Driven Sailcraft* tinyurl.com/ToTheKuiperBelt T M Eubanks - (wpb@space-initiatives.com), W P Blase, A Hibberd, R G Kennedy III, A M Hein - of Space Initiatives Inc, Initiative for Interstellar Studies (i4is) and Institute for Interstellar Studies US (i4is- US), *www.researchgate.net/publication/360937695*

Fast interception of threats to Earth

A recent presentation, *Sailing to Apophis* [1], by a team from i4is and Space Initiatives Inc, proposes laser-driven quick-reaction missions to intercept potentially hazardous objects (PHOs) approaching Earth. In order to maximize the time available for planning and carrying out actions, it would be useful to launch an intercept mission as soon as possible after initial detection of potentially PHOs approaching Earth. However, keeping a fuelled rocket with a conventional probe on standby would be logistically difficult and prohibitively expensive. This paper proposes using laser-driven light-sail probes to implement quick-reaction missions to intercept PHOs approaching Earth, with an initial test of this capability using the upcoming close approach of Asteroid 99942 Apophis. A major challenge for laser-driven probes is that, for several proposed geometries, the payload will be subjected to the full intensity of the drive beam. The paper therefore suggests a solid-sail approach in which the sail is a solid body, made from ultra-light materials, with the entire rear surface being the reflective sail element and the electronics mounted on the forward layer. The vehicle would be a shallow conical disk, 450 mm diameter and approximately 5 mm thick in the centre, with a taper of approximately 2 degrees so that the edges are approximately 2 mm thick. The first launch would use a humble sounding rocket rather than an orbit-capable launcher.

A drive beam of 17 MW would be required. A standard UK socket delivers a maximum of 13 amps at 240 volts RMS, a power of 3 kW, for example to an electric kettle. So 17 MW represents $17*10^3$ kW = 5,667 kettles turned on a once! That's about 5 typical UK villages with all needing a "nice cup of tea" at the same time [2] so not much by comparison with industrial furnaces and the like.

More about such missions in Interstellar News item *Proposed rendezvous missions to asteroid Apophis*, in Principium 34 August 2021 page 17 [3].

The paper concludes that laser-driven sail-craft launched by sounding rockets offer a relatively inexpensive, way to launch quick-reaction fly-by missions to PHOs and near-Earth asteroids. With some enlargement of the drive laser and the probe, low-cost missions to the Kuiper Belt, the Oort Cloud, and even passing free-flying interstellar visitors could be mounted.

Self-replicating probes and SETI

In *Self-replicating probes are imminent - implications for seti* [4], Alex Ellery argues that humans are developing self-replication technology today so an advanced ETI would have developed self-replication technology long ago and thus we would have noticed them. This supports the thesis that ETIs do not exist, we are alone in the universe and thus SETI is pointless. He backs this up with descriptions of nascent in-space self-replication, a wide range of terrestrial self reproduction work, a survey of available in-situ resources and the exponential nature of self replication. Even if there is only one advanced ETI in the Galaxy its self-replicating probes would have reached us long ago. It even applies between galaxies since with billions of years available probe velocities at small fractions of the speed of light would have populated the known universe by now. Even the "Great Filter", the idea that civilisations meet their end before spreading by self replication, will soon no longer apply to us and thus to older civilisations. All this tends to support the rare Earth hypothesis, that we are alone or near-alone in the universe.

Ellery touches on a number of related issues including the predator-prey ecology, genetic mutation, panspermia, first-mover advantage, interstellar propulsion and of course Kardashev. However, he wraps up by suggesting that SETI remains essential if we follow Popper's principle that science demands an endless search for evidence against our theories with full certainty

[1] *Sailing to Apophis*, W P Blase (wpb@space-initiatives.com) and T M Eubanks (both at Space Initiatives Inc), A Hibberd and A M Hein (both at Initiative for Interstellar Studies), R G Kennedy III (Institute for Interstellar Studies US (I4IS-US) presented at *Apophis T-7 Years: Knowledge Opportunities for the Science of Planetary Defense*, held virtually 11-12 May, 2022. LPI Contribution No. 2681, id.2016, https://www.hou.usra.edu/meetings/apophis2022/pdf/2016.pdf

[2] Average UK household 2021 = 2.42 people, 68 million people in UK so 68/2.42=28 million households, typical village Brinkworth, Wiltshire 2,400 people so about 1000 households.

[3] i4is.org/wp-content/uploads/2021/08/Interstellar-News-Principium34-print-2108231132opt-2-1.pdf

[4] *Self-replicating probes are imminent - implications for seti*, Alex Ellery (Carleton University, Ottawa) International Journal of Astrobiology (2022) https://www.cambridge.org/core/services/aop-cambridge-core/content/view/2CB214D26020D497D48AE489756BEE77/S1473550422000234a.pdf/self-replicating-probes-are-imminent-implications-for-seti.pdf.

approached but never quite achieved - at least from his philosophical point of view. And whatever the outcome of this "the self-replicating machine is the ultimate machine affording unchallenged cosmological power to the human species over the longest term".
This is a 31 page paper full of detailed exposition and argument - and with over 180 references, many of which will "ring bells" with those of us interested in interstellar studies in the broad sense.

Radiation hazards for interstellar probes

A new paper from UC Santa Barbara and UC Berkeley, *Radiation Effects from the Interstellar Medium and Cosmic Ray Particle Impacts on Relativistic Spacecraft* [1], considers relativistic spacecraft will have to survive radiation that is unique when compared to conventional spacecraft. At relativistic speeds, the interstellar medium (ISM) will appear as a nearly monoenergetic beam of charged particles impinging on the leading edge of the spacecraft. ISM protons and electrons will travel characteristic lengths through the spacecraft shield and come to a stop via electronic and nuclear stopping mechanisms producing,

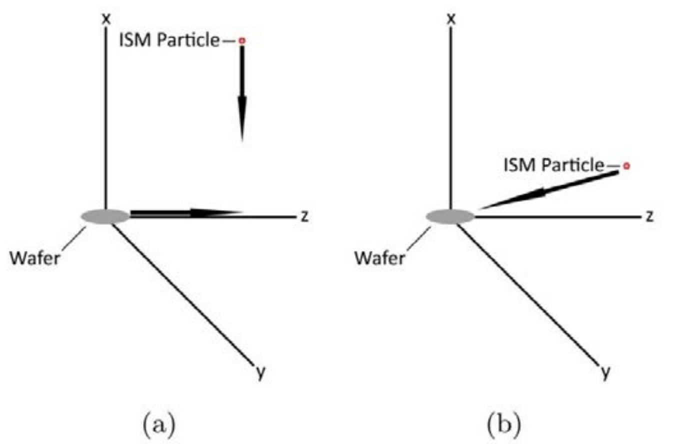


Figure 1. (a) Stationary ISM reference frame, with spacecraft shown as a thin gray wafer with the x-axis along its axis of symmetry and a velocity vector along the z-axis. An example ISM particle is shown with arbitrary velocity vector. (b) Spacecraft reference frame (primed frame), wherein the composite ISM particle velocity vector is shown. As will be shown in this section, the ISM particle distribution function becomes strongly peaked in the forward direction in the reference frame of a relativistic spacecraft. Credit(image and caption): Lubin et al

bremsstrahlung [2] photons within the shield. Here they discuss the implications of the interstellar environment for relativistic spacecraft.
They consider radiation damage and tolerance of onboard devices to expected radiation doses. They conclude -

> "While the bremsstrahlung production from incident electrons is small (less than a medical X-ray), incident protons have the ability to produce cascades of bremsstrahlung photons deeper below the surface. Material choice for the shield will be key in mitigating these damage mechanisms. In addition to incident ISM species, the spacecraft will also have to weather much higher energy, though much less frequent, cosmic ray impacts. Even in the frame of a relativistic spacecraft, GeV/nucleon cosmic rays will impact practically isotropically, and thus a raised-edge shield will do little to protect the spacecraft. However, due to their comparatively low flux, shielding schemes from cosmic rays for a relativistic spacecraft may not need to differ significantly from an ordinary spacecraft."

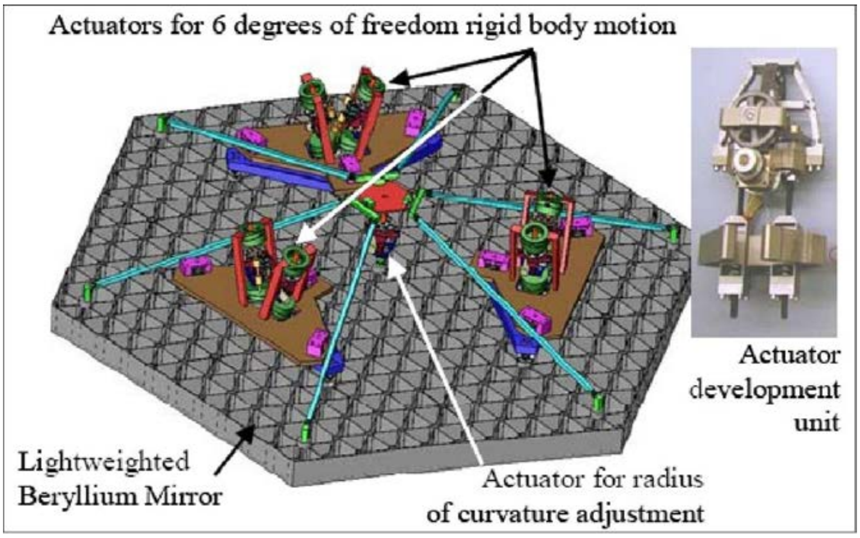
Trapped interstellar matter surrounding the solar system?

In a recent paper, Jorge Peñarrubia, of the Institute for Astronomy and Centre for Statistics at Edinburgh University, suggests that the solar system may be surrounded by a halo that contains the order of N^{ISO} 10^7 energetically-bound 'Oumuamua-like objects, and a dark matter mass of M^{DM} of approximately 10^{-13} solar masses, *A halo of trapped interstellar matter surrounding the solar system* [3]. He suggests that the presence of trapped interstellar matter in the solar system can affect current estimates on the size of the Oort Cloud, and leave a distinct signal in direct dark matter detection experiments.
If his conjecture is right, it seems likely that missions to this distance will have much to investigate.

[1] *Radiation Effects from the Interstellar Medium and Cosmic Ray Particle Impacts on Relativistic Spacecraft*, Philip Lubin and Alexander N Cohen (both UCSB) and Jacob Erlikhman (UC Berkeley), American Astronomical Society. The Astrophysical Journal, 20 June 2022, iopscience.iop.org/article/10.3847/1538-4357/ac6a50
[2] "braking radiation" produced when a charged particle is deflected by an electric field, typically an atomic nucleus, faculty.wcas.northwestern.edu/yoram/teaching/23astron441CP2013/00web/01papers/rlChap5.pdf
[3] A halo of trapped interstellar matter surrounding the solar system, https://arxiv.org/abs/2206.08535

A peek at the JWST technology

There's a lot of rather superficial material about how the marvellous James Webb telescope works. Looking a bit more deeply we found the ESA Earth Observation Portal (eoPortal) has - *JWST (James Webb Space Telescope)*, (directory.eoportal.org/web/eoportal/satellite-missions/content/-/article/jwst-content).
A good example is the adjustment of the 18 primary mirror segments. Popular accounts mention six actuators plus one central actuator for each segment. They don't mention that this gives 6 degrees of freedom (in aircraft/spacecraft terms - three translations - up-down, left-right, forward-back and three rotations - pitch, roll and yaw) and how this is done - by three bipod actuator pairs. Here's the picture of them from the ESA eoPortal.



An approximation to determine the source of the WOW! Signal

Alberto Caballero has a paper, *An approximation to determine the source of the WOW! Signal*, in the International Journal of Astrobiology, Cambridge University Press: 06 May 2022 [1].
The WOW! Signal remains a live issue in SETI research. Seth Shostak of the SETI Institute surveyed the subject in 2017 [2].
Caballero has developed a number of theories in recent years with varying degrees of attention in the professional press and a lot of notice in the UK popular press. This recent paper in the International Journal of Astrobiology identifies the source, 2MASS 19281982-2640123, as the best possibility amongst the small number of potential sources of the signal [3].
Caballero is an accomplished amateur astronomer and the professionals often rely on the serious amateurs in this field. His methodology reflects this. He uses the massive amount of data from the Gaia space telescope system, which has been mapping the universe for nearly s years and has produced positions, motions and spectra for thousands of stars [4]. The paper filters Gaia data for a number of star characteristics likely to support life - radius, luminosity, spectral type, temperature - and arrives at a short list of 38. Caballero notes that Claudio Maccone predicted that the nearest ETI must be at least 500 light years away [5] and that his shortlist conforms to this assumed limit.

Direct Imaging and Spectroscopy of Extrasolar Planets

In *Direct Imaging and Spectroscopy of Extrasolar Planets* [6] researchers suggest that direct imaging and spectroscopy is the likely means by which we will someday identify, confirm, and characterize an Earth-like planet around a nearby Sun-like star. They set out the current state of knowledge regarding discovering and characterizing exoplanets by direct imaging and spectroscopy.

[1] www.cambridge.org/core/journals/international-journal-of-astrobiology/article/an-approximation-to-determine-the-source-of-the-wow-signal/4C58B6292C73FE8BF04A06C67BAA5B1A

[2] *Was it ET on the line? Or just a comet?* www.seti.org/was-it-et-line-or-just-comet

[3] Wow!_signal#Celestial_location, en.wikipedia.org/wiki/Wow!_signal#Celestial_location

[4] for an interactive visualisation of Gaia results, see Gaia Sky zah.uni-heidelberg.de/gaia/outreach/gaiasky

[5] Maccone, C (2010) *The statistical Drake equation*. Acta Astronautica. No public source found.

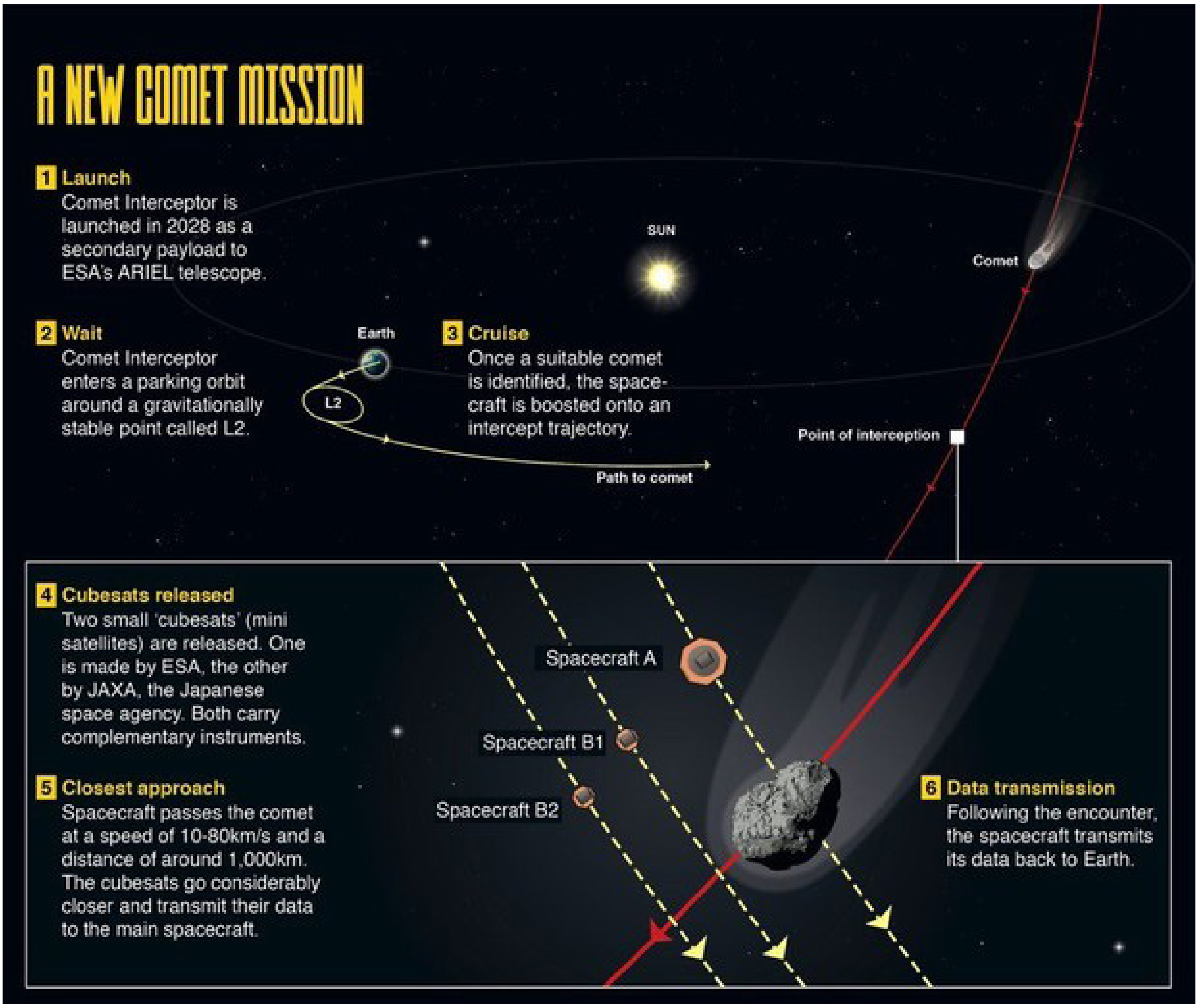
[6] *Direct Imaging and Spectroscopy of Extrasolar Planets*, Thayne Currie & Olivier Guyon (National Astronomical Observatory of Japan), Beth Biller (University of Edinburgh), Anne-Marie Lagrange (Observatoire de Paris), Christian Marois (Herzberg Astronomy & Astrophysics, Canada), Eric L Nielsen (New Mexico State University), Mickael Bonnefoy (Univ. Grenoble Alpes, France) and Robert J De Rosa (European Southern Observatory) arxiv.org/pdf/2205.05696.pdf

Comet Interceptor approved for construction

ESA and JAXA have given the go ahead for the Comet Interceptor (www.esa.int/Science_Exploration/Space_Science/Comet_Interceptor_approved_for_construction). The Comet Interceptor website is www.cometinterceptor.space/ [1].

More at *Comet Interceptor Could Snag an Interstellar Object* [2] - from the ever watchful Paul Gilster and see IAC21 report in Principium 35 (i4is.org/wp-content/uploads/2021/11/International-Astronautical-Congress-2021-The-Interstellar-Papers-Principium35-print-2111260906-opt-2.pdf).

With its "linger" at Lagrange 2 (alongside Gaia and JWST), launching from there when the target appears and its probe plus two sub-probes architecture, this is a unique piece of spacecraft mission planning and engineering. Fingers crossed for an ISO like 1I/'Oumuamua!



Mission plan and architecture. Credit BBC Science Focus Magazine

[1] Executive Summary to ESA at www.cometinterceptor.space/uploads/1/2/3/7/123778284/comet_interceptor_executive_summary.pdf
[2] www.centauri-dreams.org/2022/06/14/comet-interceptor-could-snag-an-interstellar-object/

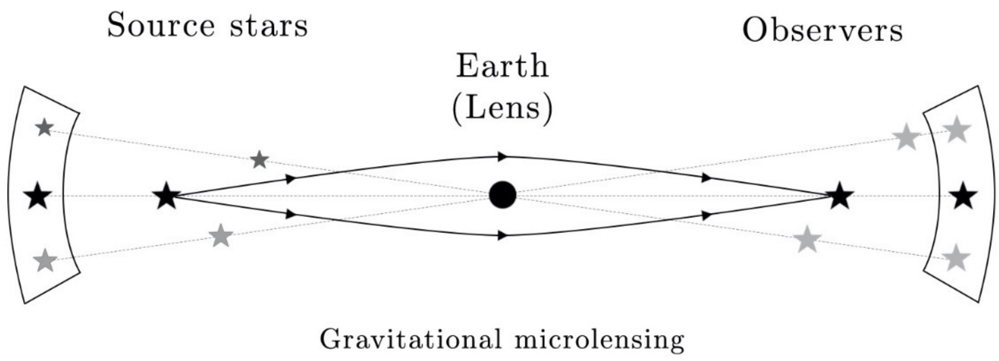


Figure 3. An illustration of a gravitational microlensing event and observer source pairings for this study. In order to calculate microlensing properties of each observer an observer is selected from stars within HEALpix area (hierarchical equal area isolatitude pixilation) area [1] and paired with every star in its antipode HEALpix area.
Credit (image and caption): Suphapolthaworn et al

Earth through the looking glass

In *Earth through the looking glass: how frequently are we detected by other civilisations through photometric microlensing?* [2], a team from Japan (Hokkaido University), Thailand (National Astronomical Research Institute, Chiang Mai University - 3 contributors), UK (Jodrell Bank Centre for Astrophysics) and France (Observatoire de Besançon) propose we should aim, as Robert Burns advises, to "To see oursels as others see us!". Microlensing using the Sun is technically tough (focus at about 300 AU - well beyond the Kuiper belt) but we would expect ETIs to acquire that capability. The team postulate an "Earth microlensing zone" from which we may be observed.
They have used the *Gaia DR2 catalogue magnitudes <20* to generate earth microlensing probability and detection rate maps for these external observers [3]. They expect photometric microlensing signatures from Earth to be observable on average only tens per year by any of these candidate "snoopers".

Gravitational Microlensing and the Solar Gravitational Lens

Einstein's General Theory of Relativity (1907-1915) was experimentally supported by Eddington's observation of deflection of light by the Sun during the 1919 solar eclipse. The fact that the path of light is deflected by gravitational fields leads to both microlensing - most practically when a distant object happens to fall into the line of sight of an even more distant object - and to the potential usefulness of our own Sun as such a primitive but powerful lens if we can place a telescope somewhere far enough from it to achieve the effect, the Solar Gravitational Lens.
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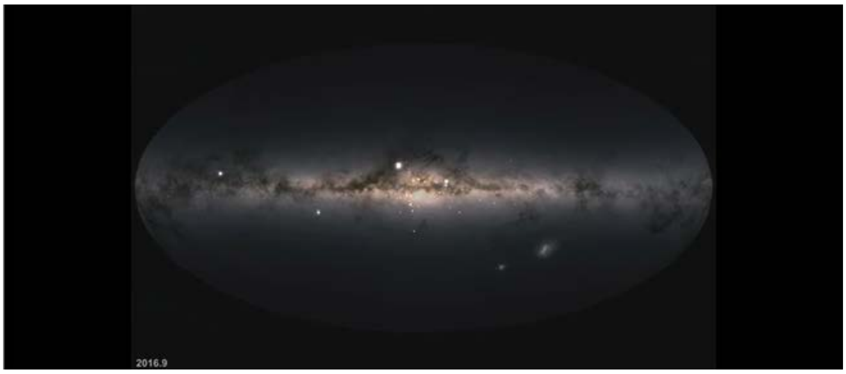


Microlensing events in Gaia's Data Release 3 captured in 30 seconds (video)
https://www.cosmos.esa.int/web/gaia/dr3-do-they-go-boom

[1] HEALPix is a Hierarchical, Equal Area, and iso-Latitude Pixelisation of the sphere designed to support efficiently - local operations on the pixel set, see *The HEALPix Primer*, Gorski et al arxiv.org/abs/astro-ph/9905275
[2] S Suphapolthaworn et al, arxiv.org/abs/2206.09820, publication expected in Monthly Notices of the Royal Astronomical Society
[3] Recall that magnitudes work backwards, magnitudes <20 means brighter than magnitude 20. The ISS is typically -3 to -4, very bright!

Exoplanets with Chinese characteristics

A recent proposal by Jianghui Ji et al, *CHES: a space-borne astrometric mission for the detection of habitable planets of the nearby solar-type stars* [1] suggests a Close-by Habitable Exoplanet Survey (CHES) mission to discover habitable-zone Earth-like planets of the nearby solar-type stars via micro-arc-second relative astrometry. This will survey systems at distances up to 10 parsecs, about 33 light-years (ly) - many of these are distinguishable by normal unaided vision [2]. The telescope would be a fairly modest 1.2 metre aperture three-mirror instrument [3] with the important capability of "ultra-high-precision relative astrometry" of 0.3 micro-arc-seconds [4] using the radial velocity method [5]. The paper suggests that "habitable-zone Earth-like planets orbiting the nearby solar-type stars are rarely found" illustrating this with a striking graphic of the distribution of known habitable-zone planets showing stellar temperature versus effective flux incident on the planet (see diagram on the right).

The paper states that exoplanet detection by astrometry will produce unbiased observations - for example in not requiring that the orbital plane of the planet intersect our line of sight as in the transit method. The paper includes an interesting "Decomposition of detection requirements" looking at positioning accuracy, telescope parameters (aperture, focal length, field of view) and interstellar distance measurement accuracy. The telescope has 1.2 m aperture, 36 m focal length and a camera pixel size of 6.5 µm yielding a single pixel field of view of 0.037 arc-seconds. To achieve the required micro-arc-second relative astrometric precision.

This means -

- near diffraction-limited imaging from the telescope and thus on-orbit optical calibration, precise detector pixel positioning
- ultra-high attitude stability - note attitude control is entirely by gas thrusters so system lifetime will be less than if momentum exchange methods (reaction wheels or control moment gyros) were used
- excellent telescope thermal control
- heterodyne laser interferometry [6] to deliver accurate inter-pixel calibration

Like the James Webb and Gaia instruments the spacecraft will be placed near the Earth-Sun Lagrange 2 point. So far operators seem to be keeping L2 tidy by moving defunct ones to less popular destinations [7].

China is beginning to contribute substantially to SETI activities. SETI is already an explicit objective of the Five-hundred-metre Aperture Spherical radio Telescope (FAST) - the biggest dish on Earth.

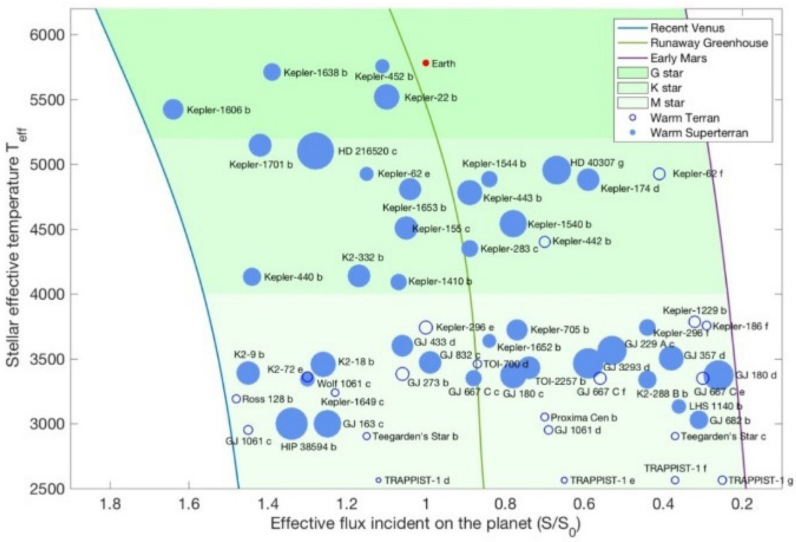


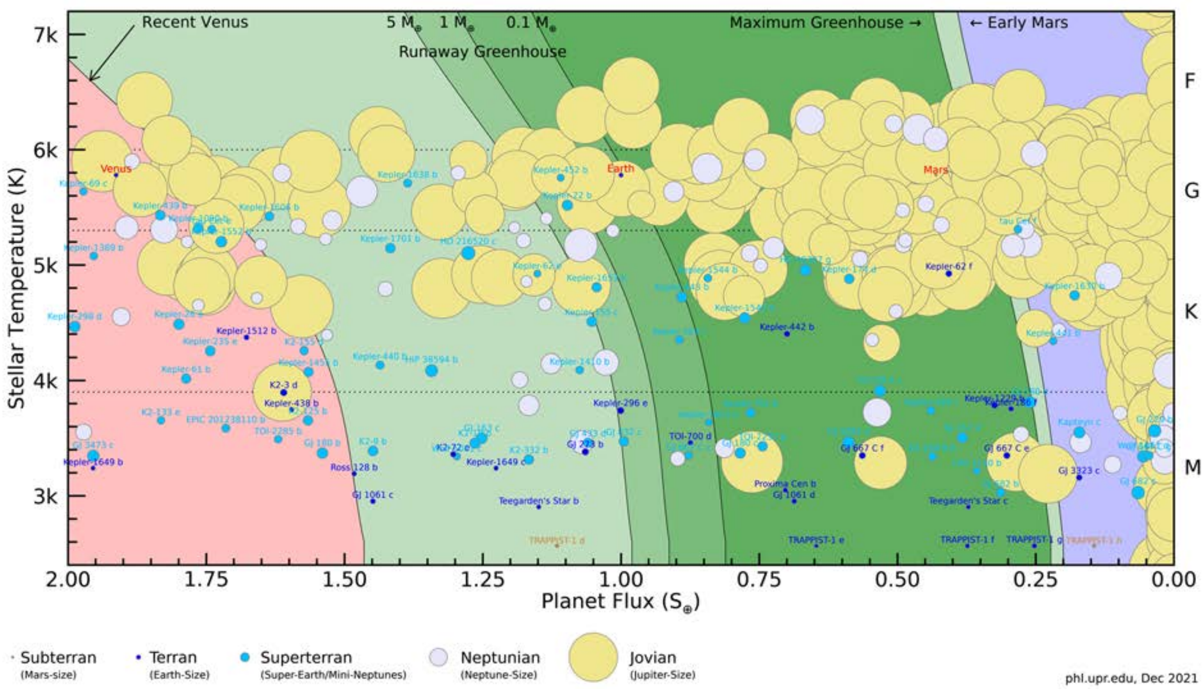
Fig. 2: Distribution of known habitable-zone planets.

Distribution of known habitable-zone planets. "Earth is indicated by red dot whereas the blue circles stand for warm terrestrial planets and super Earths, and the three separated curves, respectively, indicate the habitable border of the Recent Venus, Runaway Greenhouse and Early Mars [scenarios]" [8]
Credit (image and caption): Jianghui Ji et al

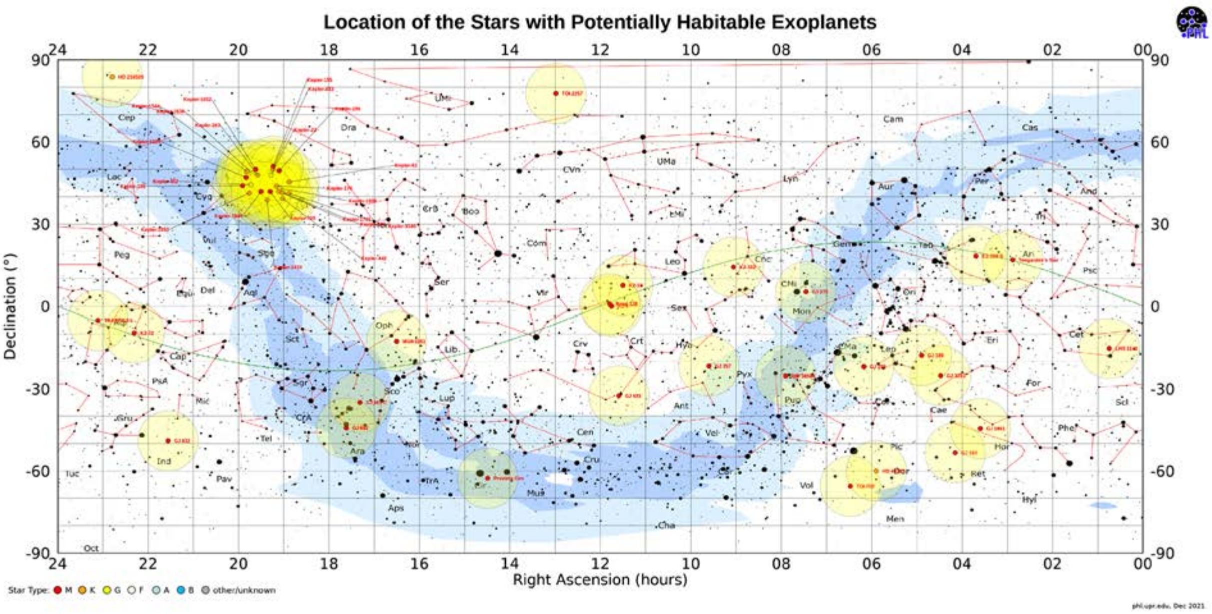
[1] *CHES: a space-borne astrometric mission for the detection of habitable planets of the nearby solar-type stars.* Jianghui Ji, Haitao Li, Junbo Zhang, Liang Fang, Dong Li, Su Wang, Yang Cao, Lei Deng, Baoquan Li, Hao Xian, Xiaodong Gao, Ang Zhang, Fei Li, Jiacheng Liu, Zhaoxiang Qi, Sheng Jin, Yaning Liu, Guo Chen, Mingtao Li, Yao Dong, Zi Zhu, CHES consortium; [v3] Thu, 9 Jun 2022 arxiv.org/abs/2205.05645 with publication expected in the Institute of Physics journal, *Research in Astronomy and Astrophysics (RAA)*
[2] en.wikipedia.org/wiki/List_of_nearest_bright_stars#Stars_within_10_parsecs
[3] Cassegrain plus a plane mirror to fold the optical path to the focal plane
[4] Compare the Gaia astrometry mission www.cosmos.esa.int/web/gaia/science-performance - though not primarily looking for exoplanets
[5] The slight wobble produced in a star's position by the gravity from its planets, en.wikipedia.org/wiki/Methods_of_detecting_exoplanets#Radial_velocity
[6] There are two types of laser interferometers: homodyne and heterodyne. A homodyne interferometer uses a single-frequency laser source, whereas a heterodyne interferometer uses a laser source with two close frequencies. spie.org/publications/tt61_541_laser_interferometer
[7] en.wikipedia.org/wiki/List_of_objects_at_Lagrange_points#L2
[8] *Habitable Zones Around Main-Sequence Stars: New Estimates*, Kopparapu et al, 2013, The Astrophysical Journal, https://iopscience.iop.org/article/10.1088/0004-637X/765/2/131/pdf

Habitable Exoplanets Catalogue

The Planetary Habitability Laboratory (PHL), University of Puerto Rico at Arecibo, maintains a Habitable Exoplanets Catalog (HEC) using the NASA Exoplanet Archive (exoplanetarchive.ipac.caltech.edu/index.html). The PHL catalogue (phl.upr.edu/projects/habitable-exoplanets-catalog) tabulates relevant exoplanets and includes some helpful graphics. Just two of them here -



Habitable Zone Plot. The figure above shows all planets near the habitable zone (darker green shade is the conservative habitable zone and the lighter green shade is the optimistic habitable zone). Only those planets less than 10 Earth masses or 2.5 Earth radii are labeled. The different limits of the habitable zone are described in Kopparapu et al (2014). Size of the circles corresponds to the radius of the planets (estimated from a mass-radius relationship when not available).
Credit (image and caption): PHL @ UPR Arecibo.

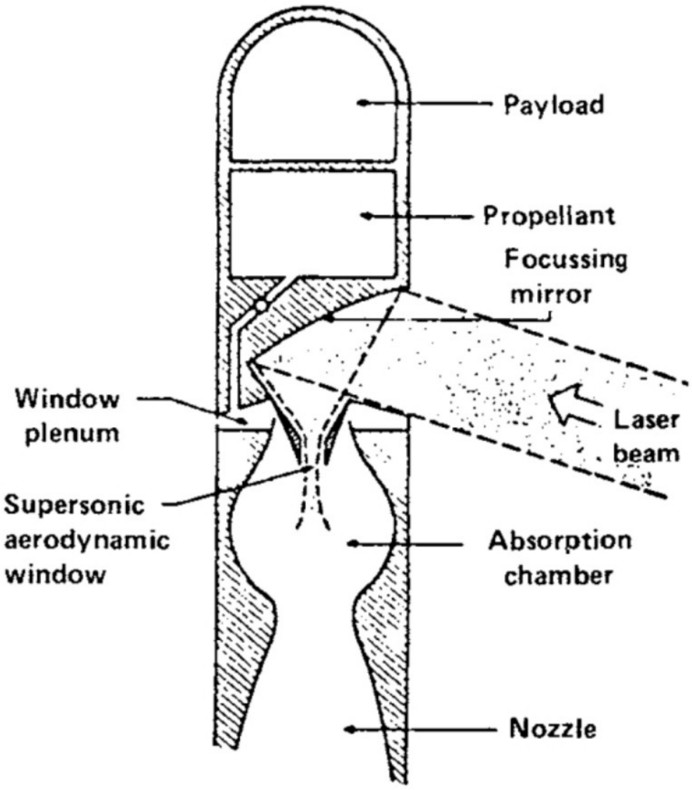


Stellar Map. Location in the night sky of all the known stellar systems with potentially habitable worlds (some systems have more than one planet). There is also a "click to enlarge" version www.hpcf.upr.edu/~abel/phl/hec2/images/hec_starmap.png

Credit: PHL @ UPR Arecibo, Jim Cornmell.

Have Starship Will Travel & IRG 2023

The 26th edition of *Have Starship, Will Travel* (HSWT) is now available. It's good to see the Interstellar Research Group (IRG) is still using that playful name despite their recent name change from Tennessee Valley Interstellar Workshop (TVIW). Fans of old TV westerns will recognise the reference!
Find it at - irg.space/wp-content/uploads/2022/07/IRG_Newsletter_N26_v2.pdf
It's got the usual good mixture of topics including -
Laser Thermal Propulsion tor Rapid Transit to Mars, Andrew Higgins.
Andrew is a prof of mechanical engineering at McGill University, Montreal. He is an old friend of i4is and next year he's hosting the IRG 8th Interstellar Symposium, 10 – 13 July, 2023 (irg.space/irg-2023/).
His paper is about the McGill work on laser-thermal rocketry designs. In this case as applied to fast missions to Mars. Based on the work of Philip Lubin's group at UC Santa Barbara on laser sailing, this looks at how we might make an intermediate step using less powerful laser banks. Andrew describes himself as "an old-time gasdynamicist" (pause while those of us who never got thermodynamics through their heads at college to tip the hat). He therefore thought about heating propellant that is expanded out of a traditional nozzle, ie a giant steam kettle in space. There's a lot more about the background to this in his piece but the basic ideas come from the emergence of inexpensive fibre-optic lasers and gas-core nuclear thermal rockets (see the News Feature on IAC 2022 elsewhere in this issue [1]). For a one ton payload (based on a NASA requirement) a 100 MW laser would point at the vehicle for about an hour. They aim to use a large inflatable reflector at the target spacecraft to accelerate it to about 14 km/s.
They have a paper published in Acta Astronautica Volume 192, March 2022, pp. 143-156 *Design of a rapid transit to Mars mission using laser-thermal propulsion*, (arxiv.org/abs/2201.00244).
How Will Aliens Land Their Spacecraft? Probably Using Magnetohydrodynamics, Colin Warn.
Maybe curious ETIs will find atmospheric braking in their attempt to visit earth would be thermodynamically challenging?



Concept for a laser-thermal rocket from the early 1980s, using a 10-micron-wavelength CO_2 laser.
Credit: Kemp, Physical Sciences Incorporated (1982)

Magnetohydrodynamic (MHD) Braking is what they need! Colin Warn reviews *Magnetohydrodynamic Enhanced Entry System for Space Transportation (MEESST) as a Key Building Block for Low-Cost Interplanetary Missions*, Manuel La Rosa Betancourt et al JBIS 74 #12, December 2021. This suggests use of electromagnetic fields to exploit Magnetohydrodynamic (MHD) principles to displace the ionised gas away from the spacecraft, reducing the thermal loads and even opening a magnetic window for radio waves, mitigating the blackout phenomenon you may have observed so unnerving if you watch a returning spacecraft live and especially challenging for the Apollo astronauts on a Moon-Earth transit trajectory. High Temperature Superconductors (HTS) have now reached industrial maturity offering the necessary low weight and compactness required for space applications. The work has the support of a grant from the EU Horizon 2020 programme. For non-UK readers it's worth noting that UK researchers are no longer eligible for EU Horizon funding - as a result of the UK Brexit decision.

[1] Joint Session on Advanced and Nuclear Power and Propulsion Systems IAC-22,C3-4

Internet of Spacecraft

Internet of Spacecraft for Multi-planetary Defense and Prosperity, Yiming Huo, University of Victoria, British Columbia, in *Signals*, Vol 3 #3 2022 (arxiv.org/abs/2205.08567) is a substantial review of the necessity of a network infrastructure for space including a revisit to the K-Pg extinction event, the Chelyabinsk event, extra-terrestrialisation, terraforming, planetary defence, including the emerging near-Earth object (NEO) observation and NEO impact avoidance technologies and strategies and a consequent prediction. Topics include the proposed framework of a novel Solar Communication and Defense Networks (SCADN) using advanced algorithms and high efficacy to enable an internet of distributed deep-space sensing, communications, and defence to cope with disastrous incidents such as asteroid/ comet impacts with perspectives on legislation, management, and supervision of founding the proposed SCADN.

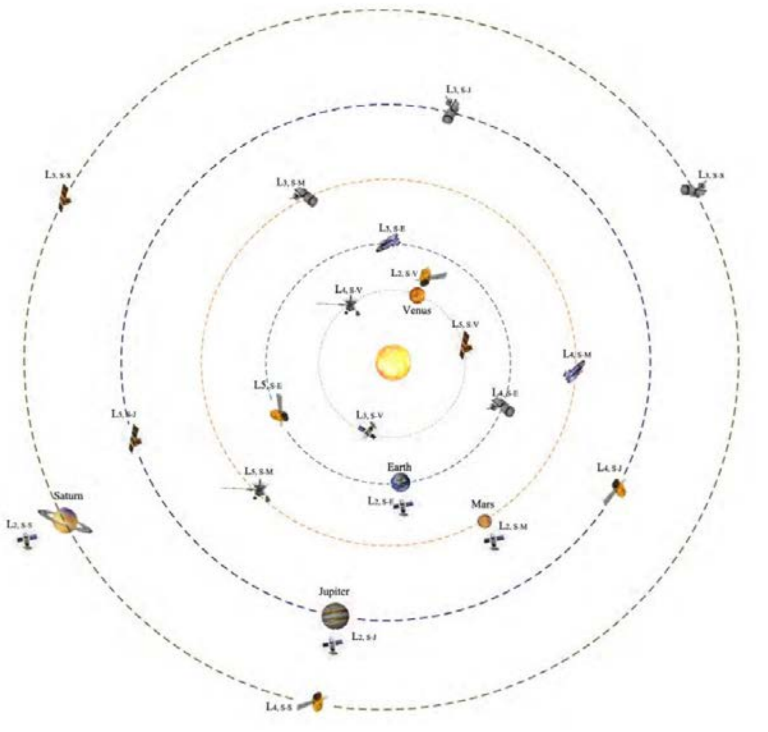


Fig. 17. An exemplary illustration of survey stations and spacecraft deployed under the SCADN framework, in particular, where survey stations/spacecraft are deployed at Lagrange points of the solar planets
Credit: Yiming Huo

The paper considers the challenges of wireless communications over extremely long propagation, particularly the very large latency, using Earth as the only routing point to store, exchange, and process data and telemetry commands from survey stations/spacecraft with resulting very long latency and low efficiency. Potential solutions include artificial intelligence (AI) and edge computing on the survey stations/spacecraft so that they could process the image and data extracted from the space and determine if a detection is of interest. Communication interruption due to interference could be mitigated and eventually, such an AI and edge computing assisted architecture can improve the overall system efficiency of wireless communications in deep space and identify the objects of interest.

It's striking that this otherwise wide-ranging paper makes no reference to the work on Vinton G Cerf, the grandfather of the interplanetary internet (and much else in the internet), for example in *Delay-Tolerant Networking Architecture*, 2007 [1].

In i4is work there was some dialogue back in 2018 on the possibilities for machine learning for chipsat data reduction between Pete Warden (then Google Brain) and Andreas Hein (then and now Technical Director of i4is). Mainly about edge computing for intelligent data filtering on very small Earth observation satellites on the Google side and of obvious interest to the twin i4is projects, Glowworm [2] and Pinpoint [3].

[1] *IETF RFC 4838 Delay-Tolerant Networking Architecture*, Cerf et al www.rfc-editor.org/rfc/rfc4838. This draft standard has gathered 1732 citations according to Google Scholar

[2] *News Feature: i4is Project Glowworm update*, Dan Fries and John Davies, in Principium 31, November 2020 (i4is.org/wp-content/uploads/2021/08/News-Feature-i4is-Project-Glowworm-update-Principium31-print-201129123l-opt-5.pdf)

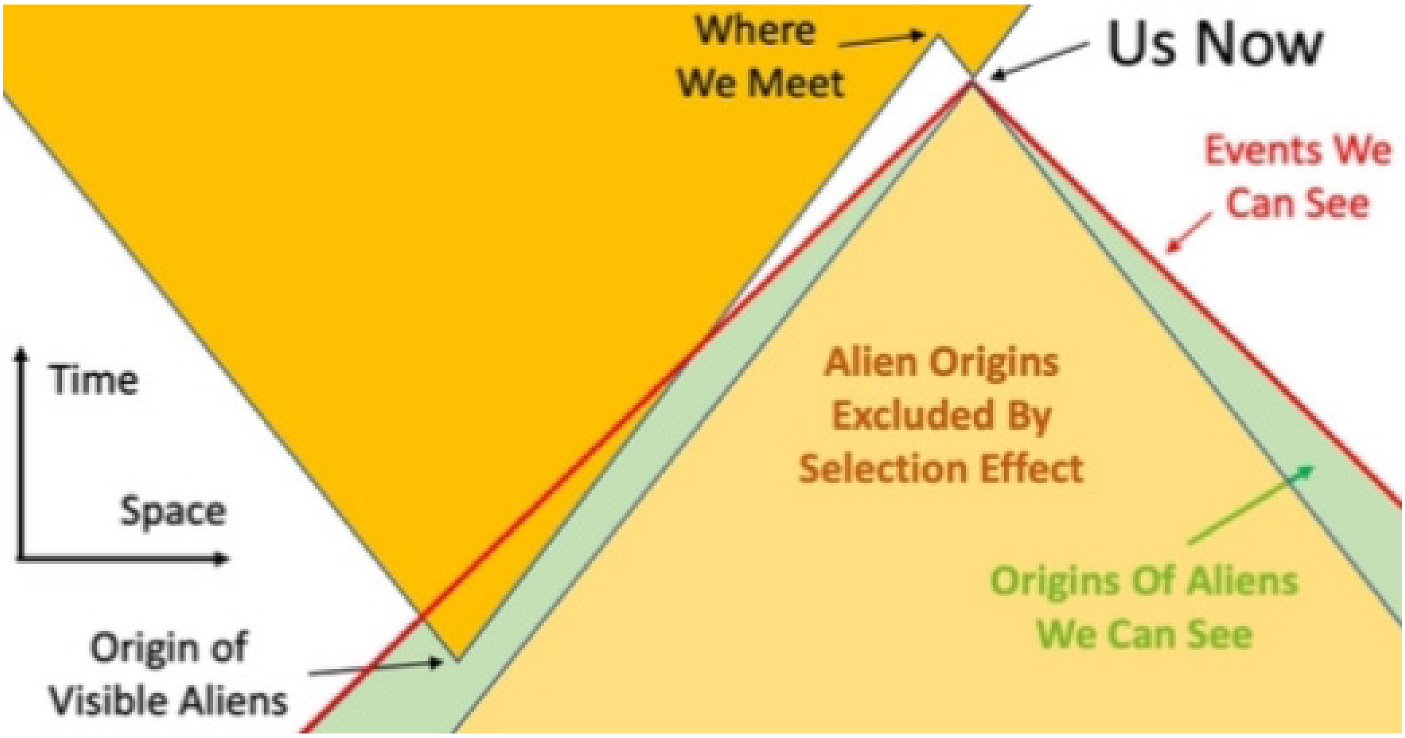
[3] *Project Pinpoint: Pushing the Limits of Miniaturization*, Andrew Broeker, in Principium 33, May 2021 (i4is.org/wp-content/uploads/2021/05/Project-Pinpoint-Pushing-the-Limits-of-Miniaturization-Principium33-print-2105280923.pdf)

Loud and quiet aliens

Paul Gilster's Centauri Dreams (www.centauri-dreams.org) is probably the most fruitful single source on interstellar technology and SETI. This is a particularly relevant posting, *If Loud Aliens Explain Human Earliness, Quiet Aliens Are Also Rare: A review* [1]. This reports a recent paper on the perennial "where are they" question. Gilster analyses it in some detail. It refers back to some of Gilster's own work and explains the Hard Steps Power Law, which argues that each evolutionary "hard step" multiplies the difficulty of achieving the anticipated outcome. The recent paper divides exosolar technological civilizations (ETCs) into loud and quiet categories and reports simulations based on loudness and number of hard steps required. It concludes -

- We have appeared very early in the history of civilizations arising in the universe.
- For SETI to be successful, there needs to be a loud ETC close by, and for one to be close by, the conversion rate of quiet civilizations to expansive, loud ones must be in the order of one per billion.
- Speed of expansion of ETCs, see diagram.

Gilster comments that the pessimistic conclusion (we are one of the first) leads to the probability that "there should be lots of places (planets, moons) with life at some step in their evolution, so while SETI searches don't look promising from the conclusions of this paper, the search for signs of exosolar life may be productive." He believes that this paper gives us a new framework for SETI and is part of a process which will eventually see the Drake equation supplanted.



The orange portion of the diagram shows the origin and expansion of an ETC at a significant proportion of the speed of light. We—by looking out into space are also looking back in time—can only see what is in our light cone (that which is below the red line), so we see the origin of our aliens (say one billion years ago) and their initial spread up to about half that age. After which, the emissions from their spreading civilization have not yet had time to reach us.
The tan triangle represents the area in space from which an ETC spreading at the same rate as the orange aliens would already have arrived at our planet (in which case we would either not exist or we would know about it), so we can assume that there were no expansive aliens having originated in this portion of time and space.
If we make the spread rate a smaller proportion of the speed of light, then this has the effect of making both the orange and tan triangles narrower along the space axis. The size of the tan exclusion area becomes smaller, and the green area, which is the area that can contain observable alien civilizations that haven't reached us yet, becomes bigger.
You'll also notice that the narrower orange triangle of the expansive ETC crosses out of our light cone at an earlier age, so we'd only see evidence of their civilization from an earlier time.
Credit (image and caption): Gilster

[1] *If Loud Aliens Explain Human Earliness, Quiet Aliens Are Also Rare*. A review (www.centauri-dreams.org/2022/05/20/if-loud-aliens-explain-human-earliness-quiet-aliens-are-also-rare-a-review/, Robin Hanson et al

Interstellar quantum communication

In *Viability of quantum communication across interstellar distances* [1] (arxiv.org/abs/2205.11816), Arjun Berera and Jaime Calderon-Figueroa of the University of Edinburgh, investigate the possibility of quantum communication using photons across interstellar distance. Factors that could induce decoherence of photons include the gravitational field of astrophysical bodies, the particle content in the interstellar medium, and the more local environment of the Solar System. They concentrate on the potential factors that could prevent us from detecting quantum signals (or establishing quantum communication channels) at interstellar scales.

They explain this potential communication mechanism as "quantum teleportation". Note that the no-communication theorem (en.wikipedia.org/wiki/No-communication_theorem) excludes super-luminal communications so this is not an "ansible" mechanism as envisaged by SF writer Ursula K Le Guin (sf-encyclopedia.com/entry/ansible).

Berera and Calderon-Figueroa go into detail about the interaction between the basic quantum mechanics and those external factors such as gravitation. They discuss communication with an unknown distant ETI through quantum teleportation. They assert that quantum computation would be required at both ends to achieve the bandwidth benefits theoretically available and that our current quantum computation technology is not yet sufficiently capable - there is a lot of "it has been shown that..." theory here. They also mention astronomical observation through this mechanism although it's not clear how this could be so since they also state that a quantum teleportation signal received would be an indication of ETI so outside the realm of astronomy.

Migrating ETI

A new paper, *Migrating Extraterrestrial Civilizations and Interstellar Colonization: Implications For SETI And SETA* [2] considers SETI and the search for extraterrestrial artefacts (SETA). Within this context, Irina K Romanovskaya considers searching for migrating extraterrestrial intelligence (SMETI), contrasting interstellar spacecraft versus free-floating planets as interstellar transport. Scenarios include using free-floating planets that pass by home worlds of extraterrestrial civilizations, using free-floating planets steered towards extraterrestrial civilizations' home worlds by means of astronomical engineering, using free-floating planets ejected from planetary systems by means of astronomical engineering and using cosmic objects ejected from extraterrestrial civilisations' home worlds by their host post-main-sequence stars. An example local flyby was the star GJ 433, which experienced a close flyby of the solar system a few thousand years ago. However, are interstellar spacecraft more likely than free-floating planets as interstellar transport? The paper sees the advantages a SMETI search for free-floating planets to be -

- Plentiful space for habitation, technologies and resources for in-situ resource utilization
- Availability of liquid water for space radiation shielding
- Constant surface gravity
- Possibility of applying astronomical engineering

We would need to search for technosignatures produced by extraterrestrial civilizations using free-floating planets including unexplained electromagnetic radiation and astrophysical phenomena. Similar technosignatures produced in more than one planetary system would be another strong clue.

Where should we search for technosignatures and artefacts (SETA) produced by ETIs using free-floating planets - In Oort clouds? In neighbourhoods of what stellar types?

The paper cites 81 references.

We looked at moving solar systems using their stars as propulsion (Shkadov thrusters) in articles by Dmitry Novoseltsev, *Engineering New Worlds: Creating the Future* in Principium 17, May 2017 (i4is.org/principium-17/), and Principium 18, August 2017 (i4is.org/principium-18/), but this sort of engineering is well up the Kardashev scale from ourselves and even moving planets is tough until we invent the spindizzy! [3].

[1] Physical Review D, Volume 105, Issue 12, article id.123033, June 2022

[2] International Journal of Astrobiology Vol 21 # 3, April 2022, https://www.cambridge.org/core/services/aop-cambridge-core/content/view/BFFC1BB63FED869C85172BB3CC88DBBB/S1473550422000143a.pdf/migrating-extraterrestrial-civilizations-and-interstellar-colonization-implications-for-seti-and-seta.pdf

[3] *Earthman come home*, James Blish, Putnam 1955 (en.wikipedia.org/wiki/Cities_in_Flight and en.wikipedia.org/wiki/Spindizzy) and sf-encyclopedia.com/entry/spindizzy.

Mission architecture to the solar gravitational lens

In *A mission architecture to reach and operate at the focal region of the solar gravitational lens* [1], Henry Helvajian et al suggest using a metre-class telescope to produce images of an exoplanet with a surface resolution tens of kilometres to identify signs of habitability. The data would be acquired pixel-by-pixel while moving an imaging spacecraft within the image plane. Given the long duration of the mission, decades to reach 900 AU, they aim for the fastest possible transit time while reducing mission risk and overall cost using solar sailing and in-space aggregation of modules to form mission capable spacecraft. They identify and characterise major challenges in propulsion (a direct ascent cannot deliver the required vehicle), long-life nuclear power sources (since the Sun is too weak to help at this distance) and communication (need for LAN between multiple spacecraft and long distance laser downlink).

They conclude that this is a challenging mission but nevertheless feasible with technologies that are either extant or in active development. They suggest small satellites (10-20 kg), sail technology with articulated vanes, Brayton cycle power generation to deliver better efficiency than the radioisotope thermoelectric generators (RTGs) currently used and mass production of the satellite components.

Optimal mass and speed for interstellar flyby

In *Optimal mass and speed for interstellar flyby with directed-energy propulsion*, Messerschmitt, Lubin & Morrison [2] address the design of mission scenarios for the flyby investigation of nearby star systems by probes launched using directed energy. This work is supported by grants from NASA, the Limitless Space Institute [3], Breakthrough Initiatives and the Emmett and Gladys W Technology Fund.

Multiple probes are sent from a single launch infrastructure. They assume the primary goal is to reliably recover the largest volume of scientific data with the least data latency (elapsed time from launch to complete recovery of the data). They show that there is an efficient frontier where volume cannot be increased for a given latency and latency cannot be reduced for a given volume. For each probe launch, increasing the volume by increasing the probe mass results in a reduced probe speed (thus adding to latency). They determine that aiming for the highest feasible probe speed does not necessarily achieve a good tradeoff of volume versus latency. They conclude that the download time duration approximates to a fixed fraction of the launch-to-target transit time. Longer propulsion duration when probe mass is increased to increase data volume adds to a cost via the additional launch energy expended, though there are economies of scale. Thus an important characteristic of any probe technology is an efficiency scaling law that relates probe mass to transmit data rate.

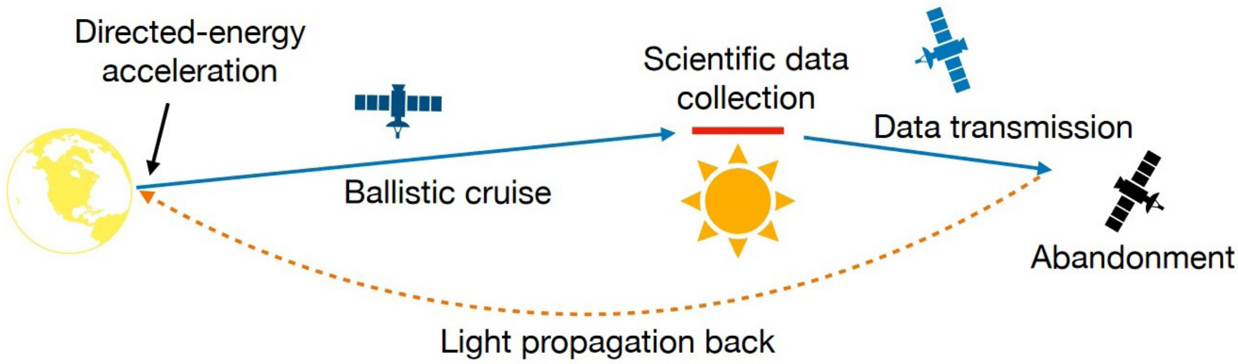


Figure 1: Illustration of the phases of a flyby mission for a probe propelled by directed energy from the launch site. The goal is to reliably recover the collected scientific data at the launch site. Credit(image and caption): Messerschmitt et al

[1] *A mission architecture to reach and operate at the focal region of the solar gravitational lens*, Henry Helvajian et al at The Aerospace Corporation, California and NASA's JPL, 2022, arxiv.org/abs/2207.03005
[2] *Optimal mass and speed for interstellar flyby with directed-energy propulsion*, David G Messerschmitt (UC Berkeley), Philip Lubin (UC Santa Barbara) and Ian Morrison (Curtin University, Australia) https://arxiv.org/abs/2206.13929
[3] LSI funds i4is courses *Human Exploration of the Far Solar System and on to the Stars* i4is.org/summer-course-25-29th-july-2022/

So Messerschmitt et al observe that despite the minimum cost versus minimum journey time calculation which governs much investigation of the feasibility of interstellar probes "...the ultimate purpose of a mission is an important consideration in the development of new propulsion technologies as well as in mission design". They muse that, for a ballistic flyby mission as envisaged by Starshot, there is a preference for slower speeds to maximise the time for information gathering at the target system. They offer two tables to summarise the dilemma -

Table 1: Flyby mission scientific performance metrics

Variable	Definition
V_{data}	Total received volume of scientific data reliably recovered at Earth
$T_{latency}$	Data latency = time elapsed from launch to reception of scientific data in its entirety

Table 2: Flyby mission parameters

Variable	Definition
t	Classical coordinate time at launch site and at probe
T_{down}	Time duration of transmission in coordinate time
m_P	Mass of probe, including sail, instrumentation, and communications
ξ_P	Mass ratio, equal to mP /m0 , where m0 is a baseline value for mass (ξ_P = 1 for some baseline case)
u_P	Ballistic probe coordinate speed, with value u0 for $\xi_P = 1$
D_{star}	Distance from launch to target star, and from probe transmitter to receiver at the start of downlink operation
R_{start}	Initial data rate at start of transmission, with value R0 for $\xi_P = 1$
k	Mass ratio to data-rate scaling exponent, so the data rate R scales by $\xi_P^{\ k}$

Credits: Messerschmitt et al

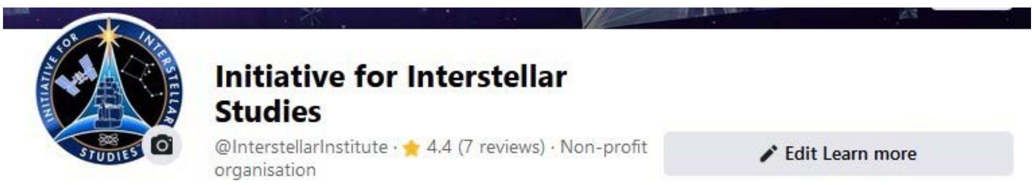
- where the mission performance metrics V_{data} and $T_{latency}$ should be jointly optimised to achieve the most favourable tradeoff between them.

Downlink data is an essential requirement of course and they suggest that the performance in this respect can be wrapped into a single parameter: a baseline data rate R_0.

They assume a launch system ("laser farm") that is shared between probes with different instrumentation, data volume, and latency parameters. Their analysis leads to consequences for launch energy cost and resultant economies of scale.

KEEP AN EYE ON OUR FACEBOOK PAGE

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

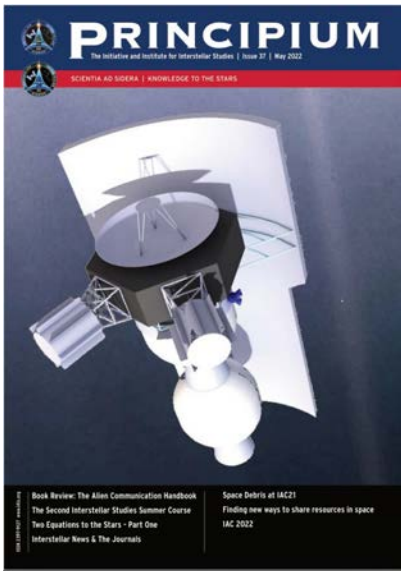


Project Lyra: Another way to 1I/'Oumuamua

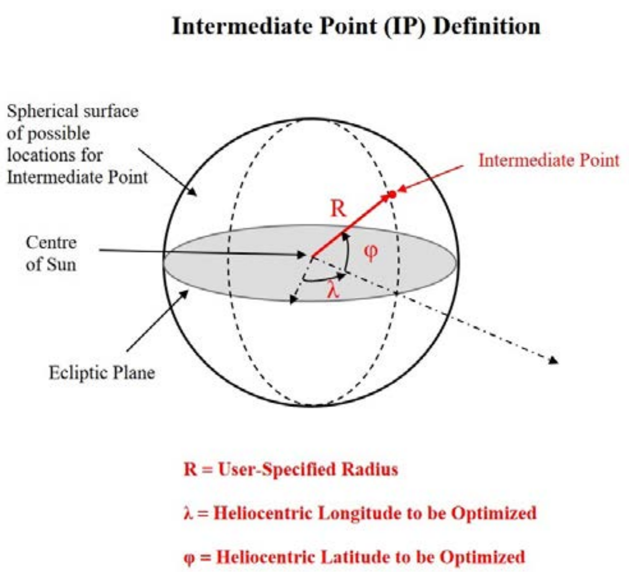
Adam Hibberd of the i4is Project Lyra team has published *Project Lyra: Another Possible Trajectory to 1I/'Oumuamua* (https://arxiv.org/abs/2205.04693). Adam suggests a mission to the interstellar object (ISO), 1I/'Oumuamua, using an Oberth manoeuvre at Jupiter (JOM) to accelerate the spacecraft towards its target. This route requires little or no deltaV (ΔV) en route to Jupiter and thus need not carry a liquid propellant stage. The cost is higher ΔV needed at Jupiter, requiring either 2 or 3 staged solid rocket motors. Adam's animation (www.youtube.com/shorts/MfWXpwuiEbo) shows how this also avoids the solar Oberth manoeuvre which can deliver maximum ΔV but at the cost of substantial heat shielding, as in our P37 front cover image.

Adam also has a more general paper, *Intermediate Points for Missions to Interstellar Objects Using Optimum Interplanetary Trajectory Software* (arxiv.org/abs/2205.10220) explaining the concept of an Intermediate Point (IP), its incorporation as a node along an interplanetary trajectory, and how it permits the determination and optimisation of trajectories to interstellar objects (ISOs). For example this is used to include the impulse at perihelion for a solar Oberth manoeuvre or modelling of V∞ Leveraging Manoeuvres (VLM) to reduce the total ΔV needed to achieve the asymptotic velocity - Vinfinity (V∞) - to reach ISOs or other distant objects. The paper covers the theory applied by Adam's Optimum Interplanetary Trajectory Software (OITS) and gives some example solutions.

Animation, https://www.youtube.com/shorts/MfWXpwuiEbo
Credit: Adam Hibberd



Principium 37 front cover visualisation of a probe using a solar Oberth manoeuvre showing the shielding required.The image depicts such a craft as it heads outwards to intercept the ISO 1I/'Oumuamua with Sagan's Pale Blue Dot of the Earth in the middle of the misty band to the right. The mass penalty of the shield is avoided in Adam's latest proposal.



Intermediate Point (IP) Definition from - *Intermediate Points for Missions to Interstellar Objects Using Optimum Interplanetary Trajectory Software.*

The stages of development of extraterrestrial civilizations (cultural evolution), and increment their requirement for mineral and energy resources. Credit(image and caption): Veysil

ETI evolution

The IRG database (irg.space/database/) draws attention to three recent papers -

Technological Evolution of Extraterrestrial Civilizations: Dyson Spheres, Warp Drives, Energy Capturing Conquerors, Hadi Veysi, Shahid Beheshti University, Tehran, Iran - in Journal of Astrobiology.
journalofastrobiology.com/Extraterrestrial1.pdf
Veysi surveys the range of possible ET civilisations adding zero to Kardashev's classic I, II and III categories (I guess we rate about 0.5?) and speculating mainly about post-biological civilisations. A diagram illustrates this. The paper includes about 75 references.

Extraterrestrial Intelligence: A Cognitive Evolutionary Perspective
Gordon Gallup and Hesper E Faliveno, University at Albany, The State University of New York
Journal of Astrobiology 2022
www.researchgate.net/publication/358629839_Extraterrestrial_Intelligence_A_Cognitive_Evolutionary_Perspective (open access)
The paper evaluates claims for extraterrestrial intelligence based on the logic behind assertions such as the absence of evidence is not evidence of absence via "two of the principle scientific claims for intelligence on Earth" (I think they mean "principal" here). Gallup and Faliveno are psychologists. Asking what distinguishes intelligent life from other life they cite Richard Dawkins "intelligent life comes of age when it works out the reasons for its own existence" and contrast Falk (see below) on brain size, cognition and intelligence pointing out that despite their large brains cetaceans lack the ability to create tools and technology, whereas a subset of primates developed tool technology and grammatical language and became the intellectually dominant species on this planet. They discuss self-awareness, are sceptical about intellectual parsimony "God, metaphorically speaking, does not always shave with Occam's Razor" and extinction events, something close to Liu Cixin's Dark Forest thesis (in his novels in that sequence) "Maybe Intelligent Extraterrestrial Life Does Not Want to be Found".

Implications of Brain Evolution in Cetaceans and Primates for Highly Intelligent Extraterrestrial Life, Dean Falk, Florida State University, Journal of Astrobiology 2022
diginole.lib.fsu.edu/islandora/object/fsu:791448.
Falk suggests that the evolution of cetaceans (whales, dolphins, etc) and primates on Earth may provide some clues as to how intelligent life may have evolved on other planets. He asserts that "If intelligent cetacean-like beings evolved convergently in other worlds in response to aquatic habitats similar to Earth's, they would not be expected to have complex tools and technologies". He is sceptical about relative brain size (RBS) as a correlate. His essential thesis seems to be incorporated in -
"on planet Earth only the human primate has evolved full-blown symbolic, grammatical language that may be used to generate and receive an endless stream of ideas. Put that ability with two (or more) manipulative extremities in an environment that has "stuff" and the sky's, literally, the limit."
So whales don't have hands and that makes the difference. He does not consider cephalopods, who do have similarly useful appendages, tentacles.

IAC 2022

72nd International Astronautical Congress 2022
The Interstellar Papers

edited by John I Davies

This year the International Astronautical Federation is holding the 2022 International Astronautical Congress in Paris 18-22 September. Here we 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.

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

We will have the first of two reports on the Congress in our next issue, Principium 39, in November. Our congress reports will not necessarily be restricted to this selection.

The overall contents of the technical congress is at iafastro.directory/iac/browse/IAC-22/

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

Below is how they fit into the week Sunday 18th to Thursday 22nd -

Date	18/09/2022	19/09/2022	19/09/2022	20/09/2022	20/09/2022	21/09/2022	21/09/2022	22/09/2022	22/09/2022
Time / Room Number	15:15-17:45	10:15-12:45	15:00-17:30	10:15-12:45	15:00-17:30	10:15-12:45	15:00-17:30	10:15-12:45	13:45-16:15
N04	A3.1	A3.2A	A3.2B	A3.3A	A3.3B	A3.4A	A3.5	A3.2C	A3.4B
S06	D2.1	D2.3	D2.2	D2.4	D2.5	D2.6	D2.7	D2.8/A5.4	D2.9/D6.2
S05	C1.1	C1.2	C1.3	C1.4	C1.5	C1.6	C1.7	C1.8	C1.9
S04	A6.7	A6.9	A6.4	A6.3	A6.2	A6.5	A6.6	A6.8/E9.1	A6.1
S03	B3.1	B3.2	B3.3	B3.4/B6.4	B3.5	B3.6/A5.3	B3.7	B3.8	A6.10/E10.2
S02	B4.1	B4.2	B4.3	B4.4	B4.5	B4.6B	B4.7	B4.8	B4.6A
S01	E7.1	E7.2	E7.3	E7.4		E7.6/E3.5	E10.1	E7.5	E7.7
W07	C4.1	C4.3	C4.5	C4.2	C4.6	C4.7	C4.8/B4.5A	C4.9	C4.10/C3.5
W06	C2.1	C2.2	C2.3	C2.4	C2.5	C2.6	C2.7	C2.8	C2.9
W05	A1.1	A1.2	A1.3	C4.4	A1.4	A1.5	A1.6	A1.7	A1.8
W04	A2.1	A4.1	A4.2	A2.2	A2.3	A2.4	A2.5	A2.6	A2.7
W03	D1.1	D1.2	D1.3	A5.1	A5.2	D1.4A	D1.4B	D1.5	D1.6
W02	B1.1	C3.1	C3.2	B1.2	B1.3	B1.4	B1.5	B1.6	C3.4
E04B	E9.2	E3.1	E3.2	E3.3	E3.4	A7.1	E3.6	A7.2	E8.1
W01	E5.1	D5.1	E5.2	D5.2	E5.3	D5.3	E5.4	E5.5	E5.6
731/732	B5.1	B2.1	B2.2	B2.3	B2.4	B2.5	B2.6	B2.7	A7.3
E08B	E1.1	E1.2	E1.3	E1.4	E1.5	E1.6	E1.7		E1.9
E06B	D4.1	D4.2	D4.3	D3.1	D3.2A	D4.4	D4.5	D3.2B	D3.3
E03B	E2.1	E2.2	B6.3	E2.4	B5.2	B5.3	B6.1	B6.2	B6.5
W08	B2.8/GTS.3	D6.1	E2.3/GTS.4	D6.3	E6.5/GTS.1	C3.3	B4.9/GTS.5	D5.4	B3.9/GTS.2
733/734		E6.4	E6.3	E6.2	E4.1	E4.2	E6.1	E4.3	
ISZ								E1.8	

Category A: Science & Exploration	A1--> A7	Category C: Technology	C1--> C4	Category E: Space & Society	E1--> E9
Category B: Applications & Operations	B1--> B6	Category D: Infrastructure	D1--> D6		

Rooms versus dates and times

Credit: IAF

- followed by links to Index pages including room, company and author.

The Papers

The Code and link gives the IAF refererence for each paper (prefix "IAC-22," if you want to quote the full reference) and a link to the IAF summary page which includes an onward link to the PDF of the abstract.

Our summary is in the box below each table.

◀ A1. IAF/IAA SPACE LIFE SCIENCES SYMPOSIUM
iafastro.directory/iac/browse/IAC-22/A1/

Astrobiology and Exploration IAC-22,A1,6 iafastro.directory/iac/browse/IAC-22/A1/6/

Code and link	title of talk/paper	presenter	institution	nation
A1,6,2,x68198 iafastro.directory/iac/paper/id/68198/summary/	Salinisphaera Shabanensis - A New Astrobiological Model Organism	Dr Petra Rettberg	DLR [1]	Germany

Having tested the response of a variety of (facultative) anaerobic microorganisms to conditions on current day or on early Mars, Rettberg et al report that Salinisphaera shabanensis, previously isolated from a deep-sea brine, is also radiation tolerant and can survive long periods of desiccation making it a promising new model organism for astrobiology.

The image shows the results of research in survivability of microorganisms in a simulated Mars environment.

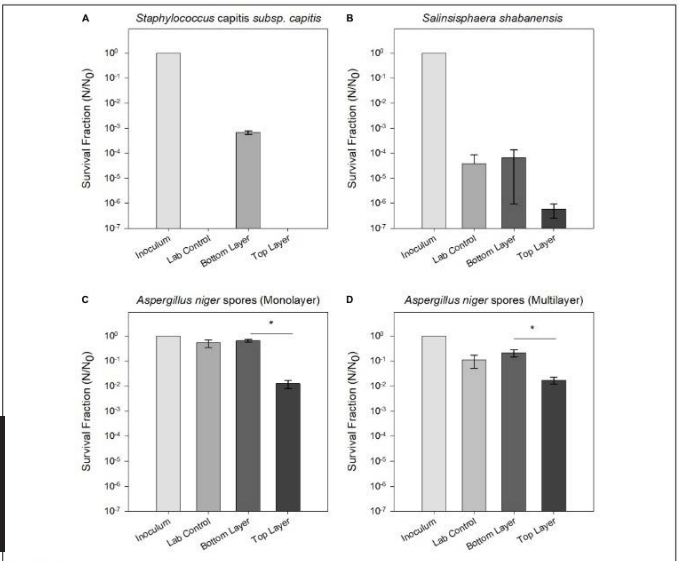


FIGURE 6 | Survival fraction (N/N0) of tested strains after exposure to Mars simulated conditions aboard the MARSBOx payload. (A) *S. shabanensis* (B) *S. capitis* subsp. *capitis*. (C,D) *A. niger* spores in monolayer (C) and in multilayer (D). Data for *Buttiauxella* sp. MASE-IM-9 are not shown, since no surviving cells were recovered after exposure.

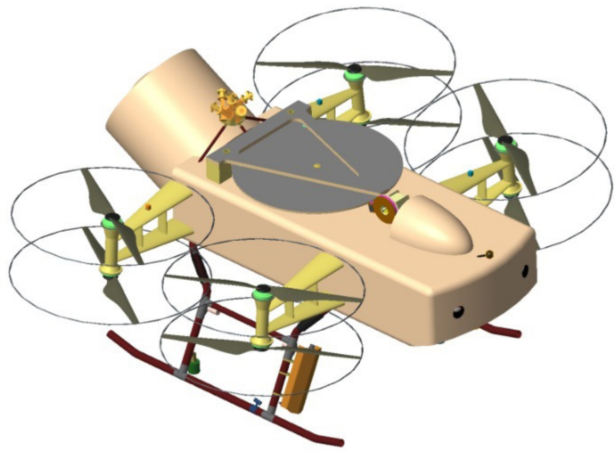
Survival fraction (N/N0) of tested strains after exposure to Mars simulated conditions aboard the MARSBOx payload [2]

Credit(image and caption): Cortesão et al

A1,6,4,x73104 iafastro.directory/iac/paper/id/73104/summary/	Space exploration of icy moons to determine their astrobiological potential	Dr Athena Coustenis	LESIA - Observatoire de Paris	France

Jupiter's Europa and Ganymede show indications of harbouring liquid water oceans under their icy crusts, which, in the case of Europa, may be in direct contact with a silicate mantle floor and kept warm through time by tidally generated heat. Around Saturn, Titan and Enceladus, were found to possess organic chemistries with seasonal variations, unique geological features and internal liquid water oceans. They provide a conceptual basis within which new theories for understanding habitability can be constructed. This talk will focus on the new scientific insights that will be offered by ESA's JUICE mission and NASA's recently selected Dragonfly mission.

The Dragonfly configuration for atmospheric flight (with the gray circular HGA stowed flat). Note the aerodynamic fairing in front of the HGA gimbal. The cylinder at rear is the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG). A sampling drill mechanism is visible in the nearside skid leg, and forward-looking cameras are recessed into the tan insulating foam forming the rounded nose of the vehicle. The rotor wing section and planform are designed for the Titan atmosphere.
Credit (image and caption): Figure 3, Lorenz et al, *Dragonfly: A Rotorcraft Lander Concept for Scientific Exploration at Titan*, 2018
www.jhuapl.edu/content/techdigest/pdf/V34-N03/34-03-Lorenz.pdf



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[1] DLR - Deutsches Zentrum für Luft- und Raumfahrt e.V.
[2] *MARSBOx: Fungal and Bacterial Endurance From a Balloon-Flown Analog Mission in the Stratosphere*, Cortesão et al, DLR, https://www.researchgate.net/profile/David-Smith-251/publication/349495107_MARSBOx_Fungal_and_Bacterial_Endurance_From_a_Balloon-Flown_Analog_Mission_in_the_Stratosphere/links/6033c00a4585158939c130a1/MARSBOx-Fungal-and-Bacterial-Endurance-From-a-Balloon-Flown-Analog-Mission-in-the-Stratosphere.pdf

A1,6,8,x68072 iafastro.directory/iac/paper/id/68072/summary/	Cubesat lunar cycler platform to measure darwinian evolution beyond low earth orbit	Ms Yana Charoenboonvivat	School of Aerospace Engineering, Georgia Institute of Technology	USA

Life can be defined as a "self-sustaining chemical system capable of Darwinian evolution." Biological Exploration Payload 2 (BioX2) is targeted for launch to the International Space Station (ISS) to grow and evolve Bacillus subtilis under selective pressure provided by ultraviolet (UV) radiation. This paper suggests that a subsequent BioX3 cislunar CubeSat mission integrates BioX2's core astrobiology experiment into a lunar cycler to characterize the effects of deep-space radiation on microbial evolution beyond the radiation shielding provided by Earth's magnetosphere.

A3. IAF SPACE EXPLORATION SYMPOSIUM

/iafastro.directory/iac/browse/IAC-22/A3/

Small Bodies Missions and Technologies (Part 2) IAC-22, A3, 4B

iafastro.directory/iac/browse/IAC-22/A3/4B/

A3,4B,10,x70801 iafastro.directory/iac/paper/id/70801/summary/	Mission architecture and spacecraft design for long-term contact studies of the interstellar asteroid 1I/Oumuamua	Dr Olga Bannova	University of Houston	USA

This paper presents an explorative study conducted by a team of more than 100 undergraduate and graduate students and young scientists from Russia, USA, France, Switzerland, Italy and UK who participated in the International Youth Scientific School "Space Development: Theory and Practice - 2021", held at Bauman Moscow State Technical University which developed a technical proposal for a complex of spacecraft for long-term contact study of the interstellar asteroid 1I/Oumuamua. The proposal included braking to rendezvous, detailed surface examination usung a spider robot and guidance to target using a Hubble-class telescope. The paper includes a computational analysis of options for mission architecture and new technology suggestions for small body studies.

The paper has two further co-authors from the Bauman Moscow State Technical University.

Solar System Exploration including Ocean Worlds IAC-22,A3, 5

iafastro.directory/iac/browse/IAC-22/A3/5/

A3,5,2,x71874 iafastro.directory/iac/paper/id/71874/summary/	Exploration of Venus Using Bioinspired Flier, BREEZE	Mr Nicholas Noviasky	University at Buffalo	USA

BREEZE is the Bioinspired Ray for Extreme Environments and Zonal Exploration developed by the CRASHLAB team from the University at Buffalo-The State University of New York combining an inflatable structure with bioinspired propulsion to create a buoyant flyer that could efficiently scan the surface of Venus, map the magnetic field, and analyze the atmospheric composition for signs of life. The concept combines the benefits of both lift and buoyancy-based aircraft. BREEZE can flap to overcome the winds of Venus and traverse a range of altitudes by actively controlling its volume and has the ability to survive without the Sun's power on the dark side of the planet. The team has explored thrust production capabilities of the bioinspired motion, advanced structural analysis techniques of the flexible structure, and proof of concept actuation methods with string actuators.

visualisation of BREEZE. Credit: NASA [1]

[1] www.nasa.gov/directorates/spacetech/niac/2019_Phase_I_Phase_II/breeze/

Note that Venus rotates about twice during each orbit around the Sun - it has a synodic day length of 117 Earth days and a sidereal rotation period (about the Sun) of 243 Earth days.

The apparent detection of phosphine, a potential biosignature, led to several studies of Venus atmospheric vehicles including from a team centred on i4is [1].

A3,5,4,x70283 iafastro.directory/iac/paper/id/70283/summary/	Feasibility study of a robotic space mission for searching trace of life on Europa	Mr Mario Rizzi	Politecnico di Torino	Italy

Europa is the smallest of the four Galilean moons orbiting Jupiter. However it is only slightly smaller than Earth's Moon and has smooth icy surface making it probable that a water ocean exists beneath the surface. Oceans are good at supporting "life as we know it" so missions to explore beneath that surface are very attractive - while remaining highly technically challenging.

This paper describes work performed during the 2nd Level Specializing Master Programme SEEDS (SpacE Exploration and Development Systems), now in its fourteenth edition, to develop a feasibility study for a future space mission to Europa yielding the detailed design of a lander capable of drilling, moving, and employing ice probes with the involvement of three Universities (Politecnico di Torino, ISAE-SUPAERO and University of Leicester), space agencies and industries (ASI, Thales Alenia Space, CNES and ESA) and a team of forty-five students hosted in the cities of Turin, Toulouse, and Leicester during a five-month period.

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

SETI 1: SETI Science and Technology IAC-22, A4, 1

iafastro.directory/iac/browse/IAC-22/A4/1/

A4,1,1,x73848 iafastro.directory/iac/paper/id/73848/summary/	KEYNOTE (Pesek Lecture): Breakthrough Listen Search for Intelligent Life in the Galactic Plane with the Parkes Telescope	Ms Karen Perez	Columbia University	USA

The Breakthrough Listen (BL) programme is a 10-year effort to conduct the most sensitive, comprehensive, and intensive search for advanced intelligent life on other worlds ever performed. This will be an update on the programme.

A4,1,3,x72363 iafastro.directory/iac/paper/id/72363/summary/	Automation and target selection for commensal SETI observing	Dr Daniel Czech	University of California, Berkeley	USA

Radio telescope arrays offer exciting opportunities for commensal SETI surveys. Ethernet-based architectural approaches adopted by MeerKAT, the VLA[2] and the Allen Telescope Array allow multiple observers to receive data simultaneously. This paper describes the automation of Breakthrough Listen's commensal observing at MeerKAT including the optimal automated response of the observing system to different scenarios, along with the associated processing, target selection and survey figures of merit. Practical implementation details are discussed, including the software (in development) [3] written to automate observations - with an evaluation observing performance under different scenarios.

UC Berkeley SETI Program logo

[1] *Precursor Balloon Mission for Venusian Astrobiology*, The Astrophysical Journal Letters, Volume 903, Number 2, April 2020 https://iopscience.iop.org/article/10.3847/2041-8213/abc347/pdf
[2] Hickish et al *Commensal, Multi-user Observations with an Ethernet-based Jansky Very Large Array*, 2019. arxiv.org/abs/1907.05263
[3] github.com/UCBerkeleySETI/commensal-automator

A4,1,8,x73676 iafastro.directory/iac/paper/id/73676/summary/	SETI India: A search for techno-signatures from extraterrestrial life using uGMRT.	Mr Arun Muraleedharan	Amity University Mumbai	India

Despite the large scale radio SETI activities at numerous observing facilities, there exists a dearth of continuous frequency coverage between 300 MHz and 1 GHz. Upgraded Giant Metrewave Radio

A panoramic view of the GMRT telescope, located near Pune, India.
Credit(image and caption): The SKA Project https://www.skatelescope.org

Telescope's (uGMRT) [1] operation capability at these frequencies makes it a desired and complementary instrument with ongoing SETI activities. The GMRT also provides unique opportunities to capture phased array beam voltages parallel with interferometric imaging visibilities. This papers present ongoing efforts in SETI, the first of their kind in India, to capture the raw stream of data products from the uGMRT and conduct searches for novel signals likely to be produced by the activities of advanced ETIs.

A4,1,10,x72939 -iafastro.directory/iac/paper/id/72939/summary/	Extragalactic SETI	Prof Mike Garrett	University of Manchester	UK

Even the largest radio telescopes observing at 1-2 GHz have a field-of-view that spans several arcminutes, and the Breakthrough Listen (BL) surveys therefore often encompass many distant background sources. To appreciate and exploit the presence of extragalactic objects in the field of view, the Aladin sky atlas (aladin.u-strasbg.fr/) and NED (NASA/IPAC Extragalactic Database) were employed to make a rudimentary census of extragalactic objects that were serendipitously observed as part of one of the initial Breakthrough Listen observing campaigns. Using the 100-m Greenbank telescope observing at 1.1-1.9 GHz, 692 fields were originally targeted, each selected to contain a nearby star of known distance. This work examines 469 of these fields. Several nearby galaxies, galaxy groups and galaxy clusters are identified, permitting the parameter space probed by SETI surveys to be significantly extended. It is demonstrated that the recent Breakthrough Listen Initiative, and indeed many previous SETI radio surveys, place stronger limits on the prevalence of extraterrestrial intelligence in the distant Universe than is often fully appreciated.

Mike Garret and the Manchester Mark 1 (aka Lovell telescope)
Credit: @Mike_Garrett/Twitter

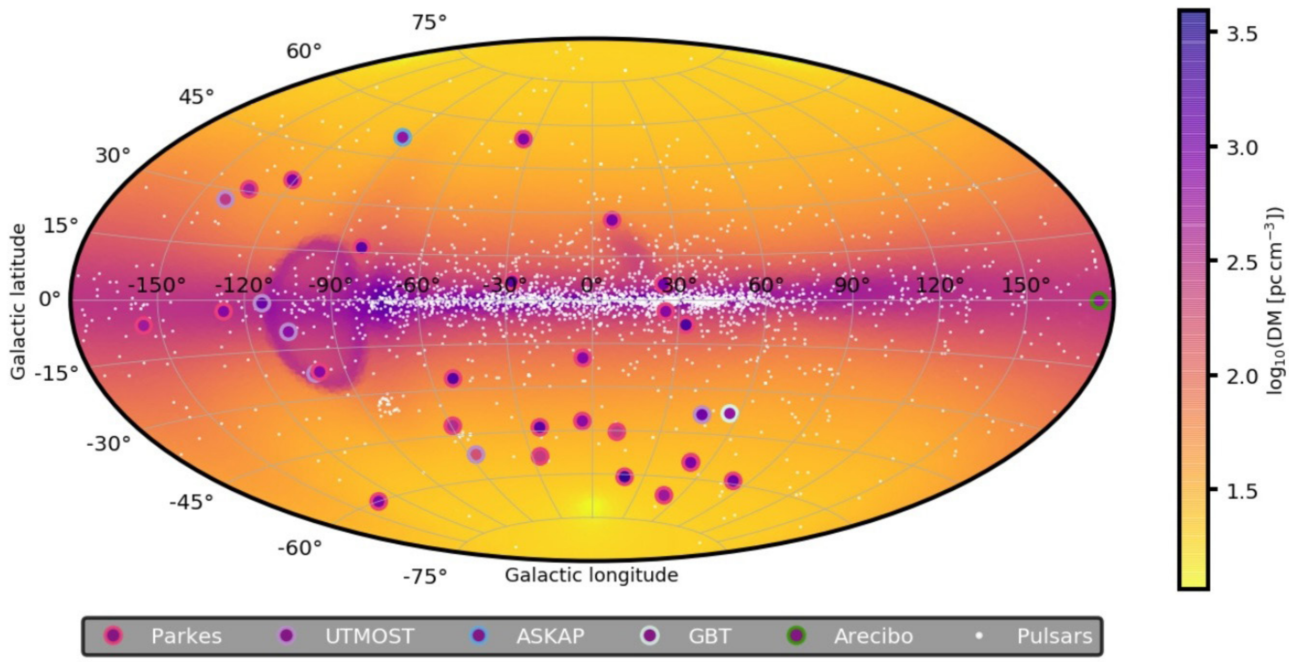
[1] Gupta et al *The upgraded GMRT: opening new windows on the radio Universe*, 2017, https://tstwww.currentscience.ac.in/Volumes/113/04/0707.pdf

A4,1,12,x72537 iafastro.directory/iac/paper/id/72537/summary/	Upper bounds on technoemission rates from 60 years of silence	Mr Claudio Grimaldi	Ecole Polytechnique Fédérale de Lausanne (EPFL)	Switzerland

The lack of detection to date of electromagnetic technosignatures implies either that we have been unable to detect them due to incomplete sampling of the search space or that we cannot detect them because the Earth has been located during the entire history of SETI in a region of space not covered by artificial extraterrestrial emissions. Starting from the latter hypothesis, and assuming that technoemissions are generated in our galaxy at a constant rate. This paper derives probabilistic upper bounds on that rate. In the case of isotropic emissions, it finds a 5% probability that there are more than one to five emissions per century that are generated across the entire Milky Way and that higher emission rates can only be derived by assuming that a significant fraction of all technoemissions are anisotropic and randomly oriented narrow beams.

IAC-22,A4,1,15,x69772 iafastro.directory/iac/paper/id/69772/summary/	An Investigation of Fast Radio Bursts and its Feasibility as Technosignature	Ms Koena Maji	Manipal Institute of Technology	India

Fast radio bursts are astrophysical radio pulses which occur for a fraction of a millisecond to a few milliseconds. They appear sporadically - the first was discovered in 2007. They vary in terms of their periodicity, occurrence, and energy profile (but with unusually high intensity given their expected distance from Earth). Their origins and emission mechanism are unknown. Possible theories to explain them include astrophysical candidates such as magnetars (highly magnetized young neutron stars). But other theories suggest that they are from extragalactic civilisations - technosignatures. This paper studies the energy signature and responsible magnetic field strength for repeater and non-repeater FRBs including the possibility of originating from intelligent life.



The approximate locations of FRBs. The large coloured dots are the FRB positions from FRBcat, the colour of the edge of the dot indicates the observatory that detected the FRB. Credit (image and caption): MeerTRAP, or "more TRANsients and Pulsars", is a project to commensally use the MeerKAT telescope to search the sky for pulsars and fast transients. www.meertrap.org/science-goals/fast-radio-bursts/

SETI 2: SETI and Society IAC-22,A4,2

iafastro.directory/iac/browse/IAC-22/A4/2/

A4,2,2,x73236 iafastro.directory/iac/paper/id/73236/summary/	Fifty Years of SETI in the IAF Digital Library	Prof Claudio Maccone	International Academy of Astronautics (IAA) and Istituto Nazionale di Astrofisica (INAF)	Italy

Claudio Maccone is one of the most-distinguished and most long-engaged researchers in SETI. Here he reports that the IAF Digital Library covers fifty years of progress in SETI begining in 1959 with Giuseppe Cocconi and Philip Morrison [1]. He presents three conclusions:

1) Historians of SETI now have the IAF Digital Library to explore. Popular descriptions of the seventy years of SETI progress could be published and attract widespread attention even among non-technical readers.

2) Young SETI researchers should explore the IAF Digital Library to enrich their philosophical and technical SETI background. Only then will they be able to make good progress towards the future of SETI research.

3) The discovery of a host of exoplanets is now transforming SETI in the search for technosignatures by virtue of space missions like Tess and more. Then, exploring the IAF Digital Library is the best way to merge classical SETI learning with current and future scientific space missions.

Prof Maccone also has *Moon Farside Protection for SETI and Astronomy* (iafastro.directory/iac/paper/id/68273/summary/) in the same session.

A4,2,7,x70624 iafastro.directory/iac/paper/id/70624/summary/	SETI Space Telescope Mission Concepts Designed Around Upcoming Fully-Reusable Launch Vehicles	Mr Eric Michaud	Massachusetts Institute of Technology (MIT)	USA

Space-based radio telescopes would be highly desirable for conducting SETI observations. A primary reason for this is that such telescopes, if placed in a high Earth orbit or ideally on the Moon's far side, would experience far less Radio Frequency Interference (RFI) than ground-based observatories. But radio telescopes are bulky and heavy - think of Greenbank, Parkes and Jodrell Bank as single instruments or the Atacama Large Array (ALMA) and the Square Kilometer Array (SKA) under construction. The James Webb telescope shows how even one of the biggest launchers available, Ariane 5, requires much tricky folding to launch what is, by terrestrial standards, a fairly modest-sized optical telescope.

This paper notes that over the next few years fully-reusable launch systems like SpaceX's Starship may fundamentally change the tradeoffs and costs involved in designing and launching space telescopes. Starship resurrects the idea of the "big dumb booster" but it is re-usable, so not so dumb! The paper suggests that it may soon be cheaper to launch 100 tons of payload with Starship than any amount of mass with any other rocket and thus that we should design space telescopes around the payload capacity of the Starship. The paper discusses possible mission designs for a space-based radio telescope for SETI built around the Starship launch vehicle.

A4,2,15,x73175 iafastro.directory/iac/paper/id/73175/summary/	Romanticism in Science as a form of cognitive bias and SETI	Prof Gabriel G De la Torre	University of Cádiz	Spain

Romanticism was a reaction to the 19th century European Enlightenment driven by nationalism and physical materialism. This paper suggests that this represents the best early example of romanticism within astronomy supported by a perception of the beauties of nature. It suggests some SETI hypotheses may be at risk of suffering from a similar romantic tendency and risks anthropocentric cognitive bias. It will discuss several examples of this form of Neo-Romanticism, cultural implications, cognitive bias in human perception, information processing and science work relevant to SETI.

[1] *Searching for Interstellar Communications*. Nature, vol. 184, no. 4690, pages 844- 846, Sept. 19, 1959 - no open source version found.

◀ A6. 20th IAA SYMPOSIUM ON SPACE DEBRIS

iafastro.directory/iac/browse/IAC-22/A6/

As elsewhere, there is much more on this topic than you see below. This subset seems especially relevant to interstellar since access to space is a prerequisite for a wider solar system culture and economy upon which any major move to interstellar must be built. More at the URL above.

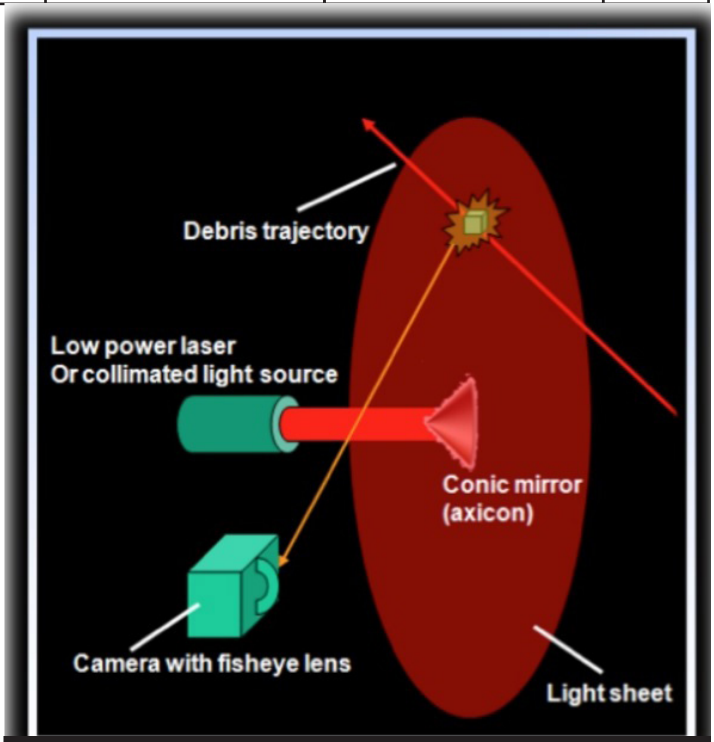
Space Debris Detection, Tracking and Characterization - Space Surveillance and Tracking (SST)

iafastro.directory/iac/browse/IAC-22/A6/1/

A6,1,8,x71592 iafastro.directory/iac/paper/id/71592/summary/	On-orbit Optical Detection of Lethal Non-Trackable Debris	Mr Andrew Nicholas	Naval Research Laboratory	USA

Objects in the size range of 0.1 mm to 3 cm are not currently trackable but have enough kinetic energy for lethal consequences to spacecraft. This paper proposes a light sheet sensor similar to the LARADO concept of the US Naval Research Laboratory (NRL).

Recent technology maturation efforts in an NRL laboratory successfully detected small debris (1.6 mm diameter) moving at 6.38 km/s ready for a flight demonstration on STPSat-7, under the Space Test Program (STP) of the US Department of Defense, in 2024.



LARADO concept [1]

Political, Legal, Institutional and Economic Aspects of Space Debris Mitigation and Removal - STM Security

iafastro.directory/iac/browse/IAC-22/A6/8-E9.1/

A6,8-E9.1,10,x69130 iafastro.directory/iac/paper/id/69130/summary/	Financial Incentives for Debris Removal Services	Mrs Morgane Lecas	Astroscale Ltd	UK

This paper starts from the premise that "Our use of space is already unsustainable". It assesses financial incentives for satellite operators to adopt debris removal services. The challenge is to develop commercially viable debris removal services bringing together mature technological solutions, favourable regulatory environment, and cost-effective solutions that customers are willing to pay for. The problem now is that "As in other sectors, once satellites reach their end-of-life they are no longer providing revenue to the operator, which means funds are not necessarily available for decommissioning at the required time." The paper assesses financial incentives for debris removal services - value to government and space agencies, external sinking or accrual funds, decommissioning guarantees and subsidies.

[1] breakingdefense.com/2019/04/nrls-larado-project-hopes-to-track-tiny-space-debris/

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◀ B2. IAF SPACE COMMUNICATIONS AND NAVIGATION SYMPOSIUM

iafastro.directory/iac/browse/IAC-22/B2/

Advances in Space-based Navigation Technologies IAC-22, B2, 1

iafastro.directory/iac/browse/IAC-22/B2/1/

IAC-22,B2,1,1,x69864 iafastro.directory/iac/paper/id/69864/summary/	Methods for Navigation in the Nearby Interstellar Medium	Dr John Christian	Georgia Institute of Technology	USA

This paper asserts that navigation is expected to be amongst the most challenging tasks for missions to the nearby interstellar medium (ISM) due to the immense distances involved. The paper presents detailed models for all of the major sources of navigation information, including Earth-based radiometric tracking, visible-spectrum star sightings, X-ray pulsar navigation (XNAV), StarNAV, and others - examining their utility and presenting numerical results to illustrate their efficacy.

C2 IAF MATERIALS AND STRUCTURES SYMPOSIUM

C2, 3 Space Structures - Dynamics and Microdynamics

iafastro.directory/iac/browse/IAC-22/C2/

IAC-22,C2,3,8,x73418 iafastro.directory/iac/paper/id/73418/summary/	Dynamic Stability of Flexible Lightsails for Interstellar Exploration	Dr Michael Kelzenberg	California Institute of Technology (Caltech)	USA

The Breakthrough Starshot Initiative requires stabilised propulsion of flexible membrane-like lightsails via radiation pressure from a high power phased-array laser source which can accelerate the lightsail spacecraft to relativistic speeds. This paper reports the first investigation of flexible, large area lightsail membranes driven by laser radiation pressure using a finite element model to describe the light-matter interactions for flexible ultrathin membranes - with attention to ideas such as spinning lightsails and embedded nanophotonic metagrating structures using anisotropic light scattering, for flat as well as curved membrane shapes.

C3. IAF SPACE POWER SYMPOSIUM

iafastro.directory/iac/browse/IAC-22/C3/

Space Power System for Ambitious Missions IAC-22,C3,4

iafastro.directory/iac/browse/IAC-22/C3/4/

IAC-22,C3,4,1,x73419 iafastro.directory/iac/paper/id/73419/summary/	Power Requirements and Technologies for Gram-Scale Interstellar Spacecraft	Dr Mason Peck	Cornell University	USA

The combination of extremely limited mass budget, long mission duration, and harsh operating environment poses considerable challenges to the development of a power source for gram-scale space probes accelerated to relativistic velocities by an earth-based laser source, as envisaged by the Breakthrough Starshot Initiative. This paper presents the results of an investigation into the suitability of various power generation and energy storage technologies for such missions. Base assumptions include requirements for 20 uW periodically during the 20-year transit phase of the mission, 1 W peak power during launch, flyby, and data return phases of the mission, with a total energy budget of 14 kJ. Topics include thin-film photovoltaics and conversion of kinetic energy through interaction with the interstellar medium, analysis of various energy storage schemes including chemical, electrical, and nuclear technologies, ranking these in terms of viability, risk, and technology readiness level (TRL). And identifying topics for future research and development.

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◀ C3. IAF SPACE POWER SYMPOSIUM C4. IAF SPACE PROPULSION SYMPOSIUM

iafastro.directory/iac/browse/IAC-22/C3/

iafastro.directory/iac/browse/IAC-22/C4/

Joint Session on Advanced and Nuclear Power and Propulsion Systems

iafastro.directory/iac/browse/IAC-22/C4/10-C3.5/

This session, organized jointly between the Space Power and the Space Propulsion Symposiums, includes papers addressing all aspects related to advanced and nuclear power and propulsion systems for space applications.

IAC-22,C4,10-C3.5,2,x69597 iafastro.directory/iac/paper/id/69597/summary/	Early Progress toward the Feasibility of the Centrifugal Nuclear Thermal Rocket	Dr Dale Thomas	University of Alabama in Huntsville	USA

The Centrifugal Nuclear Thermal Rocket (CNTR) is a Nuclear Thermal Propulsion (NTP) concept designed to heat propellant directly by the reactor fuel [1] potentially delivering high specific impulse (1,800 seconds), similar to ion thrusters at much higher thrust. This paper reports further research progress in analytical modelling and simulation of the two-phase heat transfer between the liquid metallic uranium fuel and the gaseous propellant.

See also - C4,10-C3.5,3,x69402 iafastro.directory/iac/paper/id/69402/summary/ *Experimentally Backed Model of Bubbly Flow in a CNTP Reactor* and C4,10-C3.5,4,x73738 iafastro.directory/iac/paper/id/73738/summary/ *Exploring the Feasibility of a Power-Generating Pulsed Nuclear Magnetic Nozzle*, both from University of Alabama in Huntsville.

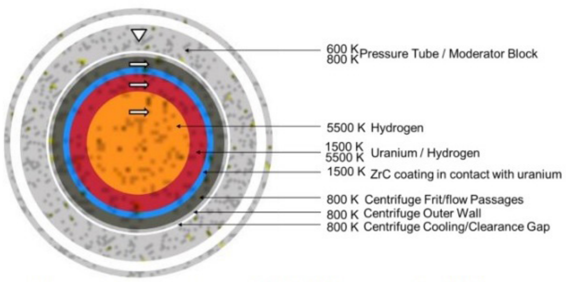

Fig. 2. Cross-section of CNTR Rotating Fuel Element

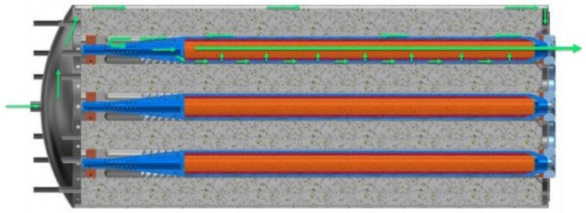

Fig. 3. Propellant Flow Path in the CNTR

Configuration of a Centrifugal Nuclear Thermal Rocket [2]

LBA,C4,3,x74497 iafastro.directory/iac/paper/id/74497/summary/	First laser beam to orbit Demonstrations, Modelling Spacecraft and Reflector, Beam Laser Propulsion Missions	Mr Kolemann Lutz	Mars University	USA

Mars University (MarsU, www.marsu.space) is an international academic and research organisation, a student run organisation and eSchool with a team of 20+ researchers, faculty, and staff. Kolemann Lutz outlines a laser demonstration of beam energy toward a spacecraft in MEO/GEO by Summer/Fall 2023. Using a 3 kW ground-based laser focused into a propellant heating chamber with up to 300-500 kg of hydrogen gas to reach up to 30,000 K achieving 1000 - 3,000 seconds specific impulse (Isp).

[1] See our earlier IAC reports IAC-21, C4.10- C3.5.11,x65142 *Toward the Engineering Feasibility of the Centrifugal Nuclear Thermal Rocket*, by Dr Thomas in Principium 36, page 32. and C4,10-C3.5,5,x66797 *Overview of the High Performance Centrifugal Nuclear Thermal Propulsion System* by Jimmy Allen (Dynetics) in Principium 36, pages 27 & 28. P36 is at i4is.org/wp-content/uploads/2022/02/Principium36-AW-2202191002opt.pdf

[2] from *Overview of High-Performance Centrifugal Nuclear Thermal Rocket Propulsion System*, Allen et al, 2021. local.ans.org/ne/wp-content/uploads/2021/02/OverviewCNTR-ANS-Winter-2020-summary-paper.pdf

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◀ D2. IAF SPACE TRANSPORTATION SOLUTIONS AND INNOVATIONS SYMPOSIUM
iafastro.directory/iac/browse/IAC-22/D2/

Future Space Transportation Systems

iafastro.directory/iac/browse/IAC-22/D2/4/

D2,4,9,x67466 iafastro.directory/iac/paper/id/67466/summary/	Interplanetary transfer network design and technology roadmap for a sustainable off-world human community	Mr Koldo Zuniga	Cranfield University	UK

An interplanetary human civilization that expands beyond Earth to settle on other planets of the Solar System will require a transport network to connect the different human outposts via fast transfers and high-capacity spacecraft. This paper reports work to understand the requirements for such fast transfers in terms of engine technology and dry mass fraction, and identify when these capabilities could be available based on current TRLs [1] using models of one-way and round-trip Earth – Mars trajectories and the resulting ΔV requirements compared against minimum viable Isp, spacecraft dry mass fraction and refueling capability. It concludes that nuclear electric propulsion could yield 60 day trips to Mars within 20 years and, later, nuclear thermal propulsion could halve that trip time [2]. The paper identifies key requirements and constraints to be considered when designing and roadmapping an interplanetary transfer network capable of enabling a sustainable off-world human community.

Space Transportation Solutions for Deep Space Missions: D2,8-A5,4

iafastro.directory/iac/browse/IAC-22/D2/8-A5.4/

IAC-22,A5,4-D2.8,1,x68209 iafastro.directory/iac/paper/id/68209/summary/	Interstellar terminal and starship assembly in the Kuyper Belt	Giorgio Gaviraghi	Unispace Exponential Creativity	Italy

If starships carrying humans (or biology based ETIs) are built then it can be assumed that their civilisations will want to go beyond a single destination system. This paper suggests that "shipyards" for such proliferating civilisations might best be situated at the radius of trans-Neptunian objects. This paper aims to define and analyse these "terminal space settlements", their design, assembly and operations as well as the starships that would be built in the facilities including the definition of technologies and capabilities required.

We have visualised a "shipyard" for a first fusion starship for the cover of Principium 22. It would not, of course, accelerate from low Earth orbit!

Cover of Principium 22, Assembly of an Icarus Firefly vehicle in low Earth orbit. Credit: Michel Lamontagne.

A5,4-D2.8,2,x72880 iafastro.directory/iac/paper/id/72880/summary/	NASA Envisioned Future Priorities for In-Space Transportation	Mr John Dankanich	NASA	USA

A high-level overview of NASA's plans for the development of in-space transportation capabilities, a description of the state of the art, capability goals, technical challenges and gaps, and options for partnerships with industry and other agencies towards developing a robust logistics infrastructure to support NASA's objectives. Note this is purely in-space showing that NASA is getting more interested in getting around in space, perhaps leaving the literal "heavy lifting" to the likes of SpaceX, ULA and Blue Origin.

[1] Technology Readiness Level www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level
[2] Compare current missions around 180 days to Mars and note the importance of steam over sail for world trade, 15 knots (32 km/hour), when the wind blew, for a small "racer" cargo sailer like *Cutty Sark* in the 1870s versus the monster*Great Eastern* already achieving that speed in the 1860s.

▶

D2,8-A5.4,4,x68378 iafastro.directory/iac/paper/id/68378/summary/	Mission to Mars Using Space-Sourced Propellant	Dr Jan Thoemel	University of Luxembourg	Luxembourg

This paper anticipates storing propellant in space, specifically in a lunar orbit and Sun-Earth-Lagrange point 2 (where the James Webb and Gaia telescopes reside). Simulating missions for the 2026, 2028, 2030 departure windows, comparing propellant consumption of a direct mission versus missions refuelling in lunar orbit or at that Lagrange point and concluding refuelling can be cost effective.

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

iafastro.directory/iac/browse/IAC-22/D4/

Innovative Concepts and Technologies IAC-22,D4,1

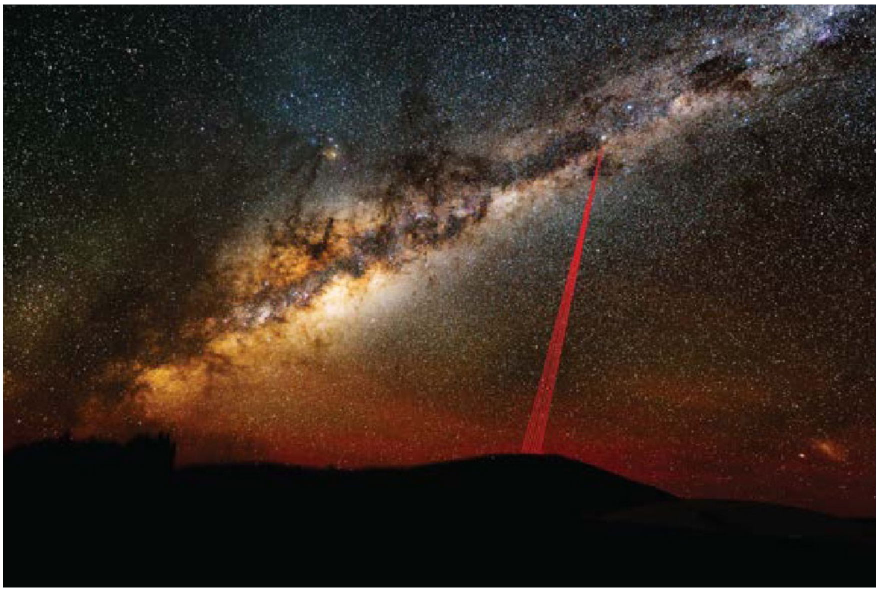
iafastro.directory/iac/browse/IAC-22/D4/1/

D4,1,4,x73256 iafastro.directory/iac/paper/id/73256/summary/	Benchmarking von Neumann's universal constructor architectures for in situ production in space environments	Mr Hussain Bokhari	Space Forward Lab	Sweden

In-situ self-contained resilience, providing redundancy and logistics of spare parts and consumables, is a vital part of long term exploration and exploitation of space. This paper looks at John von Neumann's Universal Constructor, a self-replication machine [1] and finds advantages of reduced costs of transportation by use of self-replicating seed payloads and self-reparation or self-replication in case of malfunction. Advances in synthetic biology, chemical computing, and soft living matter can contribute. It examines architectures of various universal constructor concepts and approximates, discusses and interprets for typical space exploration use cases the minimal thermodynamic costs, energy consumption, production time, external energy supply requirements and constraints of building an incremental unit in different space environments.

D4,1,12,x70259 iafastro.directory/iac/paper/id/70259/summary/	Advancements in laser propulsion for relativistic lightsail missions	Mr Wesley Green	Breakthrough Initiatives	USA

A summary of the Breakthrough Starshot Photon Engine research showing viable paths to create a gigawatt-level, kilometre-scale coherent phased array, including advances in beam control and adaptive optics, fibre amplifiers and nonlinear effects, semiconductor lasers, photonic integrated circuits, and cost estimations. Critical technology areas are highlighted, indicating where advancements are needed and where some technology branches are determined to be incompatible with Starshot.



Header image from Breakthrough Initiatives - Breakthrough Starshot - Photon Engine RFP issued 6 Oct 2017. https://breakthroughinitiatives.org/i/docs/RFP_Photon_Engine_Final.pdf Credit: Breakthrough Initiatives

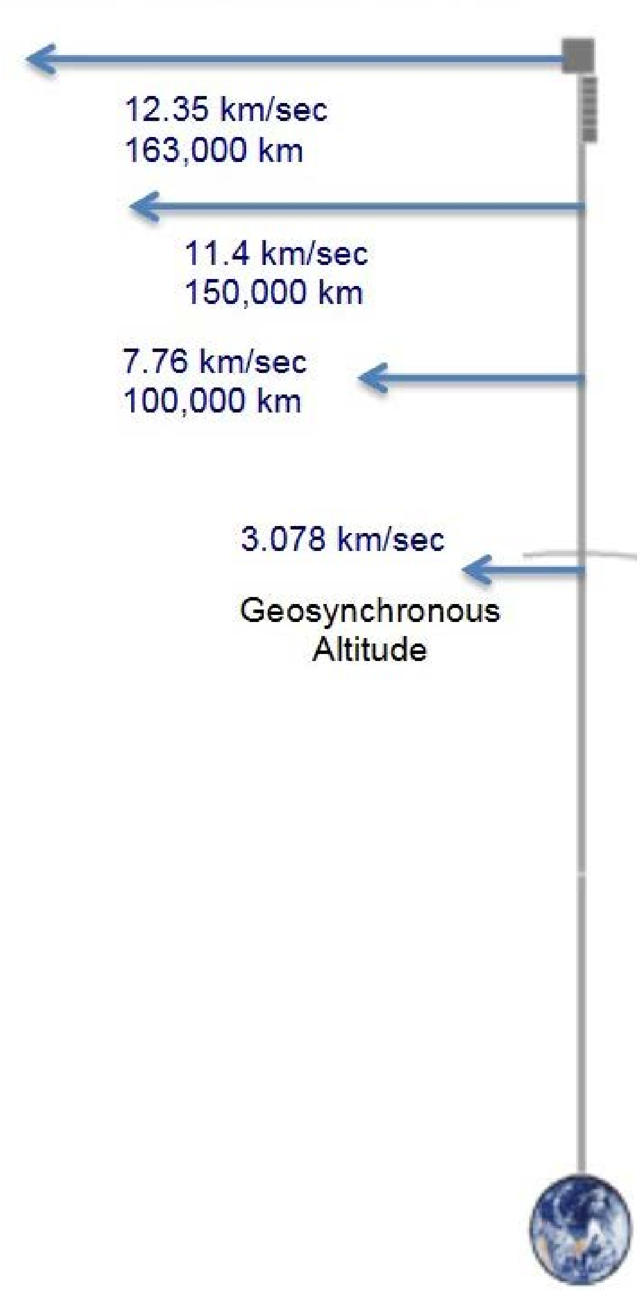
[1] *The Universal Constructor: Theory of Self-Reproducing Automata*. John von Neumann. Edited by Arthur W Burks. University of Illinois Press, Urbana, 1966 also en.wikipedia.org/wiki/Von_Neumann_universal_constructor

Modern Day Space Elevators Entering Development

iafastro.directory/iac/browse/IAC-22/D4/3/

IAC-22,D4,3,1,x67635 iafastro.directory/iac/paper/id/67635/summary/	KEYNOTE: Space Elevators as a Transformational Leap For Human movement off-planet	Dr Cathy Swan	SouthWest Analytic Network	USA

The International Space Elevator Consortium (ISEC) observes that a Permanent Space Infrastructure would enable massive movement of cargo to GEO and beyond in a safe, environmentally friendly, inexpensive, daily and routine way – thus transforming the approach for humanity to escape the Earth's gravity. This supports goals including Space Solar Power, lifting payloads to help to save our atmosphere, lunar villages and, longer term, Lagrange 5 settlements. The paper uses a Mars settlement as an example describing work by ISEC and Arizona State University.



Velocities achievable using a space elevator.
Credit: ISEC Report: Space Elevators are the Transportation Story of 21st Century, **Figure 4.1, Space Elevator Launch Geometries** www.isec.org/s/ISEC2020-2Study.pdf [1]

[1] Torla et al IAC-18-D4.3.4 *Optimization of Low Fuel And Time-Critical Interplanetary Transfers Using Space Elevator Apex Anchor Release: Mars, Jupiter And Saturn.*

D4,3,4,x69339 iafastro.directory/iac/paper/id/69339/summary/	Space Elevator tether materials: An overview of the current candidates	Dr Adrian Nixon	-	UK

Session D4/3 includes 16 papers on both opportunities and technologies for space elevators. For example, the tether is clearly a major technical challenge and this paper reviews manufacturing progress in making materials with the strength necessary to form the tether for the space elevator falling into two categories, nanotubes and 2D materials and concluding that carbon nanotubes are the material of choice for the tether. This paper will detail the current state of the art of manufacturing for these tether candidate materials. See also www.isec.org/tether-materials.

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

iafastro.directory/iac/browse/IAC-22/D4/

Strategies for Rapid Implementation of Interstellar Missions: Precursors and Beyond

/iafastro.directory/iac/browse/IAC-22/D4/4/

D4,4,1,x70268 iafastro.directory/iac/paper/id/70268/summary/	10%: The First 10 Years of The 100 Year Starship™	Mr Jason Batt	100 Year Starship	USA

100 Year Starship™ was funded in 2012 by the US Defense Advanced Research Projects Agency. Mr Batt is editor of the *100YSS Symposium Conference Proceedings*. He will look back at the first ten years of The 100 Year Starship and explore how 100YSS has changed the landscape of interstellar development in the last ten years. What are the results of the activities and initiatives 100YSS has championed? What are the challenges that we must face in the next ten years? What have been the challenges that have arisen in accomplishing the 100YSS mission and what are the challenges to come? And finally, explore what the potential roadmap might be for the next ten years.

D4,4,2,x67412 iafastro.directory/iac/paper/id/67412/summary/	Case Study of a Mission to Epsilon Eridani: Unmanned Interstellar Probe Using Gas Core Nuclear Reactors with Early 21st Century Technology	Dr Ugur Guven,	UN CSSTEAP	UK

UN CSSTEAP is the Centre for Space Science and Technology: Education in Asia and the Pacific (www.cssteap.org/). This paper discusses the possibility of an interstellar mission to Epsilon Eridani by comparing different modes of propulsion and plotting the distance, time and specific impulse for gas core nuclear propulsion system which promises to reach its target in a reasonable amount of time with the existing early 21st century technology presenting the challenges of such a mission in detail with the effects of semi-relativistic speeds, mass expansion and time dilation. Its intention is to become a reference point for similar unmanned interstellar missions in the future.

D4,4,3,x73132 iafastro.directory/iac/paper/id/73132/summary/	Advanced Electric Propulsion Concepts for Fast Missions to the Outer Solar System and Beyond	Mr Angelo Genovese	Initiative for Interstellar Studies	Germany

Electric Propulsion (EP) comprises all types of space propulsion in which propellant is ionized and then accelerated by electric and/or magnetic fields. It allows for much higher specific impulses (order of 5000 seconds) than conventional chemical propulsion resulting in a major reduction of the propellant mass or a considerably higher final speed. This paper suggests that an EP system coupled with an advanced nuclear reactor could enable fast manned missions to Mars (one-way travel times less than 4 months). A breakthrough in power source specific mass is needed in order to enable missions with ultra-high specific impulses (order 10,000 seconds); this could be realised using an external power source, Laser-powered Electric Propulsion (LEP). The on-board power source is now limited to a light-weight photovoltaic receiver/converter. This could enable the most challenging interstellar precursor missions up to the Oort Cloud and beyond. This paper gives an update on the status of these advanced propulsion concepts and provides examples of interstellar precursor missions enabled by advanced EP systems which could be launched before 2040.

◀

D4,4,4,x69452 iafastro.directory/iac/paper/id/69452/summary/	Stella: Europe's contribution to a NASA interstellar probe	Prof Stanislav Barabash	Swedish Institute of Space Physics	Sweden

The Interstellar Probe (ISP) is a potential NASA large strategic mission candidate - concept study report: *Interstellar Probe: NASA Solar and Space Physics Mission Concept Study* [1] has shown that an ISP mission is realistic and can be designed, built, and launched by 2036, at 7.0 au/year it would reach 350 au during its nominal 50-year life-time but system resources could allow traveling to, at least, 525 au. ESA contributions could include scientific instruments, communication system including the 5 m high-gain antenna, an extension of ESA's DSA [2] with a new antenna array and a major contribution to ISP operations. Stella contributes to achieving ISP goals by answering five specific 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? [3]

ESA assumes a model European payload including neutral gas mass spectrometer, plasma package, cosmic ray spectrometer, UV spectrograph, and radio science (using the spacecraft radio for that last fundamental physics question).

See also D4,4,9,x69502 below.

D4,4,5,x72336 iafastro.directory/iac/paper/id/72336/summary/	Performance Map for Laser-Accelerated Sailcraft Missions	Dr Kevin Parkin	Breakthrough Initiatives	USA

Dr Parkin has previously delivered key studies on the overall system design of the Starshot mission [4] and in a range of advanced propulsion technologies. This paper maps the wider design space for cost-optimal missions with 0.1 mg to 100 kt payload, 0.0001 c to 0 .99 c (6.3 au/y to 63,000 au/y) cruise velocity, and 10 y to 100 y development time. This mapping is made possible by a simplified system model that swaps numerical trajectory integration for closed-form equations. The new code computes 2-3 orders of magnitude more point designs per unit time than the earlier more general code. Parkin notes that for missions that require only a few gigawatts of laser power or less, an electrical transmission line connected to a regional grid can directly drive the laser instead of, or in addition to, on-site energy storage. This greatly reduces system cost for some precursor missions.

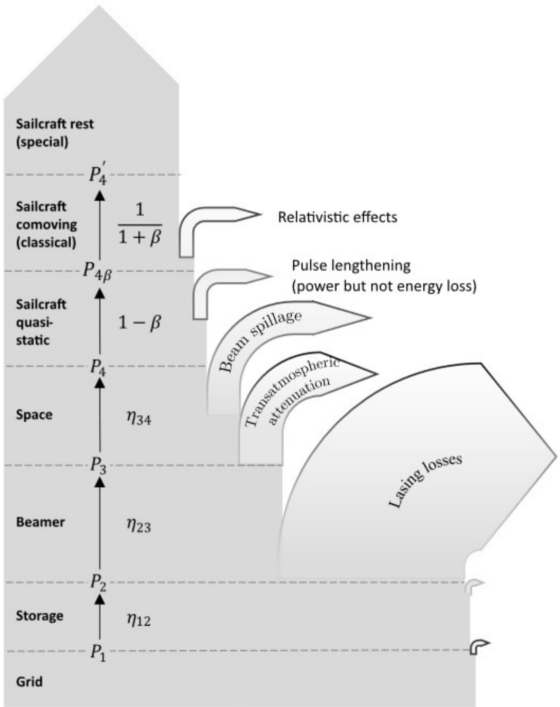


Figure 1: Power and efficiency relationships

Power and efficiency relationships, Figure 1 in Parkin (May 2022) [5]

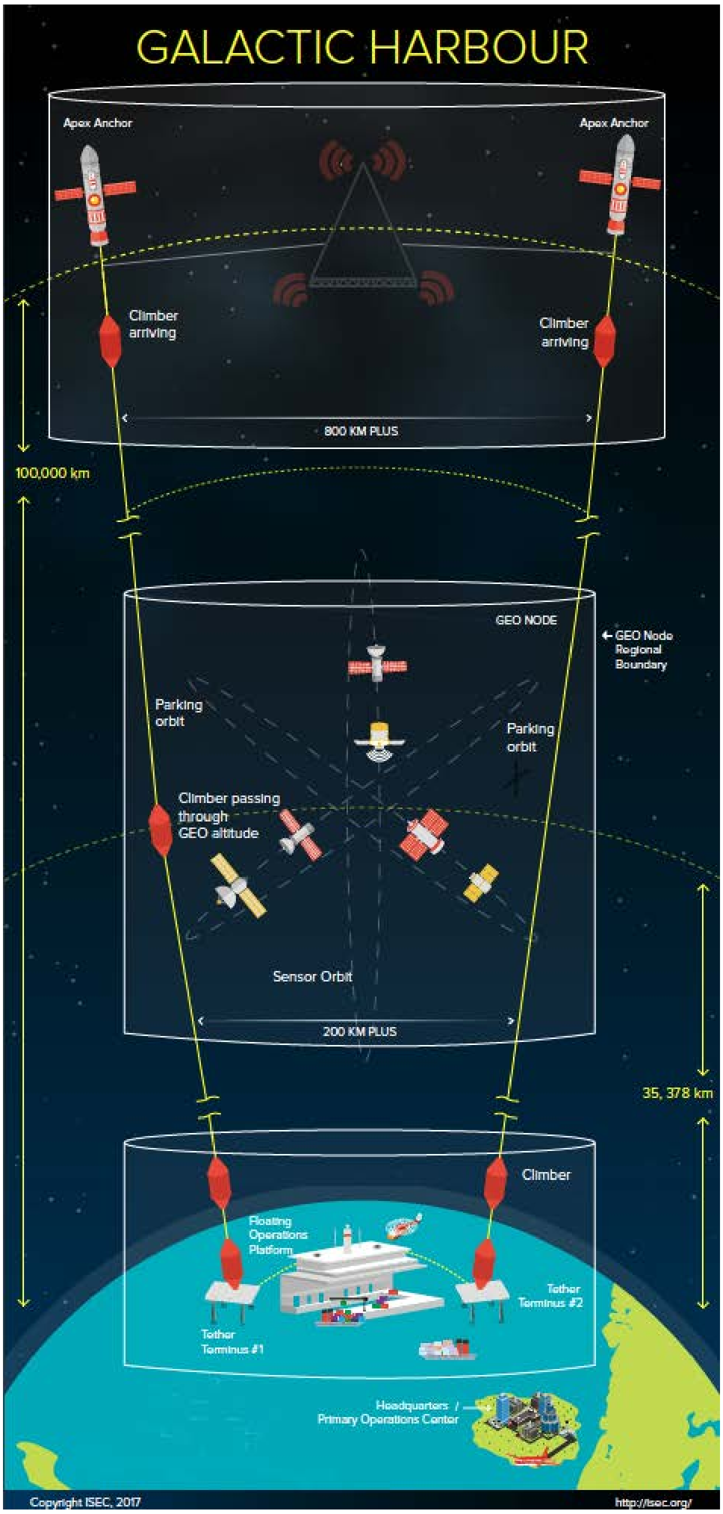
[1] Published December 2021. For the full 498 page report - kiss.caltech.edu/papers/ism/papers/Interstellar-Probe-MCR.pdf
[2] ESA Deep space communication and navigation. www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Deep_space_communication_and_navigation
[3] This looks like an error "when I went to school" it was $1/r^2$ but this is probably an IAF re-keying error rather than a mistake by Prof Barabash.
[4] An early example - *The Breakthrough Starshot system model*, Acta Astronautica, Vol 152, November 2018, Pages 370-384 arxiv.org/abs/1805.01306
[5] *Cost-Optimal System Performance Maps for Laser-Accelerated Sailcraft*, Kevin L G Parkin, arxiv.org/abs/2205.13138

▶

D4,4,6,x67947 iafastro.directory/iac/paper/id/67947/summary/	Transformational Release of Scientific Payloads from the Apex Anchor - Any Size, Every Day, Anywhere	Dr Peter Swan	International Space Elevator Consortium	USA

The International Space Elevator Consortium (ISEC) has been working for some years on the challenging but potentially transformational idea of an Earth to GEO orbit tether with cargo vehicles climbing and descending at costs a small fraction of any current or envisaged launchers. The Apex Anchor of such a system would be 100,000 km, about three times GEO height. Contrast current launches from Earth to Mars taking 8-months, separated by 26 months until the next launch window and Mars payload a small fraction of launch mass. The elevator Apex Anchor would enable release towards Mars every day taking around two months and deliver hundreds of thousands of tons at around 8 km/sec. The advantages for deep space and even interstellar missions are obvious. See also D4,3,1,x67635 above.

More about ISEC in reports from IAC21, Dubai, in Principium editions 36 - *A brief on IAC2021: Inspire, Innovate and Discover For the Benefit of Humankind* - Samar AbdelFattah and at this IAC the session D4,3 *Modern Day Space Elevators Entering Development*, iafastro.directory/iac/browse/IAC-22/D4/3/ with presenters from ISEC, Obayashi Corporation and Shonan Institute of Technology (both Japan), Politecnico di Torino, Arizona State University, Royal Institute of Technology (Sweden), National Institute for Space Research (Brazil), the USA National Space Society (Mumbai chapter, India) and York University (Canada).



Galactic Harbour architecture, see P36, *A brief on IAC2021: Inspire, Innovate and Discover For the Benefit of Humankind*, Samar AbdelFattah, i4is.org/wp-content/uploads/2022/02/A-brief-on-IAC2021-Principium36-AW-2202191002opt.pdf

D4,4,9,x69502 iafastro.directory/iac/paper/id/69502/summary/	The Pragmatic Interstellar Probe Study: Results	Dr Ralph L McNutt, Jr	The Johns Hopkins University (JHU)	USA

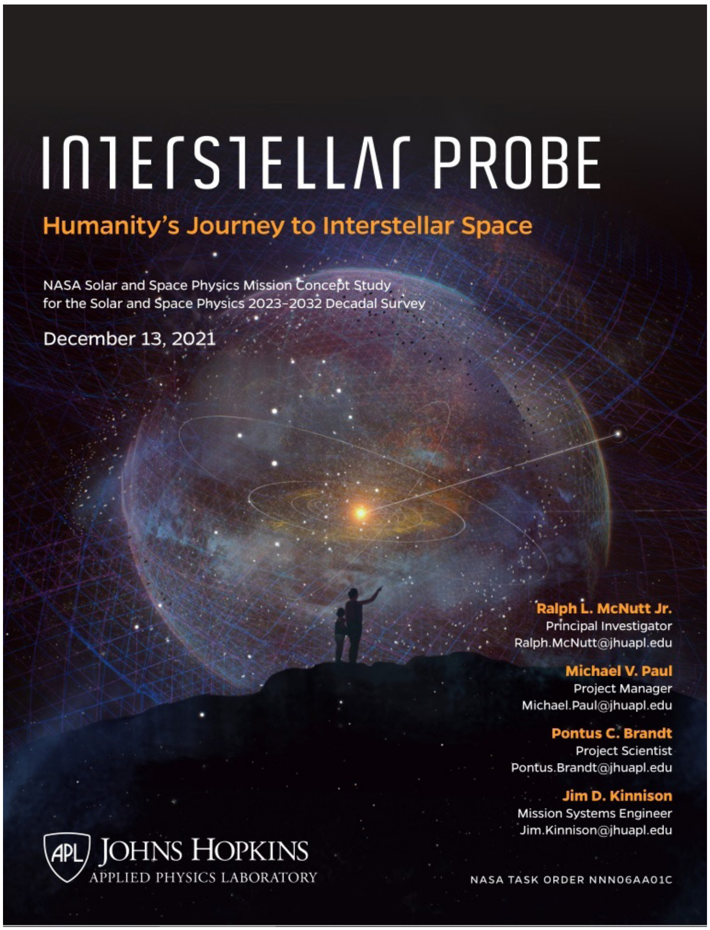
The JHU Interstellar Probe is a proposed NASA mission to the interstellar medium and the heliosphere, in effect a faster and much more capable Voyager probe. Working Groups from within and beyond JHU have refined the science payload. The proposal now suggests a spacecraft of 860 kg (about the same as the 45-year old Voyagers) carrying about 90 kg of instruments launched by a super heavy lift launch vehicle (SHLLV) [1] with additional 3rd and 4th stages. It will now use a Jupiter Oberth manoeuvre rather than a Solar Oberth manoeuvre, trading less impulse for less spacecraft mass since no heatshield would now be required. Later i4is Project Lyra studies have made a similar trade-off.

The paper has co-authors from University of Kiel (Germany), Viterbi School of Engineering-University of Southern California and NASA.

See also -

- summarised above - D4,4,10,x73530, *Stella science for interstellar probe*, Prof Dr Robert F Wimmer-Schweingruber, University of Kiel et al (co-authors from Swedish Institute of Space Physics, JHU, University of Bern, Institut de Recherche en Astrophysique et Planétologie (IRAP) - France, Sapienza University of Rome - Italy, CNRS-LATMOS - France, Mullard Space Science Laboratory-UK). Science for the proposed European contribution to NASA's Interstellar Probe. iafastro.directory/iac/paper/id/73530/summary/
- D4,4,11,x70087, *The Pragmatic Interstellar Probe Study: The Evolutionary Journey of our Habitable Astrosphere*, Dr Pontus Brandt, JHU Applied Physics Laboratory. The paper has 40 co-authors from institutions ranging from JHU to Northumbria University in UK. iafastro.directory/iac/paper/id/70087/summary/

The comprehensive JHU-APL study of December 2021 is at interstellarprobe.jhuapl.edu/Interstellar-Probe-MCR.pdf.



Interstellar Probe, Humanity's Journey to Interstellar Space, JHU-APL December 2021 Report

[1] SHLLV examples include the operational SpaceX Falcon Heavy and the near term SpaceX Starship & NASA Space Launch System (SLS)

The Journals

John I Davies

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

JBIS

Five issues of JBIS (February, March, April, May & June 2022) have appeared in our last issue, P37 in May.

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

JBIS VOLUME 75 NO.2 February 2022		
Revisiting Voyager 2's Trajectory	K ARNOTT & B CHANDRA	University of the West of England
This paper presents a reconstruction of Voyager 2's trajectory to examine how the mission was optimised for fuel and Time of Flight (TOF), as well as to find out if there is a more efficient trajectory for the full Earth-Jupiter-Saturn-Uranus-Neptune (EJSUN) sequence. Variable TOFs between each interplanetary maneuver for launch dates ~1 year from the original were considered. Brute force search algorithms were developed to find optimized trajectories, the solution to Lambert's problem for fast computation, and a patched conic integrator to plot the optimal trajectories. Multiple 'unpowered' gravity assist trajectories were found: the minimum total change in velocity (ΔV) at perigee found was less than 0.0035 km/s for a total TOF of 4,978 days (13.64 years), the shortest TOF trajectory found spanned 3,299 days (9.04 years), with a total ΔV at perigee requirement less than 0.11 km/s. With consideration to the trajectories found, it was determined that the Voyager 2 trajectory was likely to have been optimized for TOF.		

JBIS VOLUME 75 NO.4 April 2022		
Cultural Evolution and Minimal Crew Size to Maintain Culture Level During Interstellar Travel	Sano Satoshi	Japan Aerospace Exploration Agency
Designing multigenerational interstellar ships requires defining the capacity of a spaceship first, which affects many variables, including food production, air/water circulation systems, electric power and propulsion. A published Monte Carlo code called EVOLVE (Sano, 2021) first suggested a minimal crew size of 2,000 people to maintain a genetically healthy crew, including genetic parameters such as genetic mutation rate and natural selection on interstellar travel, and that the speed of human evolution on interstellar travel would be approximately 10 times higher than that on Earth due to a higher mutation rate in space. However, cultural change must be considered in addition to biological change when considering multigenerational human space travel, because culture is one of the most uniquely human traits and deeply related to the survival and evolution of Homo sapiens. Therefore, EVOLVE was updated to version 3, which includes cultural parameters to estimate adequate crew size to maintain an appropriate technological level during multigenerational interstellar travel. This paper shows that a minimal crew size of 1,500 people for simple technologies and 11,000 people for complex technologies is necessary to maintain a human technological level for interstellar travel. Finally, this paper shows that the genetic evolution rate and cultural evolution rate during interstellar travel would be approximately 10 times and 5 times higher, respectively, than those on Earth due to the high mutation rate in space.		

On the Application of Pulse Propulsion Frequency in Inertial Fusion Space Mission Design	Kelvin F Long	Interstellar Research Centre
The transport of a spacecraft using an Inertial Confinement Fusion (ICF) based propulsion engine exhibits an acceleration and thrust profile which depends on the pulse unit detonation frequency, propellant mass, capsule mass, mass flow rate and exhaust velocity. This paper discusses how the pulse frequency depends on the overall mission parameters and explores the limit of a small mass and high mass capsule design. It is argued that in the limit of a high pulse frequency (>1,000 Hz) and low capsule mass (<<mg) the engine will tend towards an analogue for a continued thrust design (interstellar ramjet), whereas in the limit of a low pulse frequency (1-50 Hz) and high capsule mass (>10 kg) the engine will tend towards a nuclear propelled pulse engine (bomb propulsion) similar to the historical Project Orion. Therefore propulsion from ICF methods with a pulse frequency (10-1,000 Hz) and capsule mass (1-10,000s mg) represents a compromise between these two regimes. Spacecraft driven by an ICF engine are likely realisable in the later part of this century using mg scale capsule designs driven by MJ scale laser beamers to produce GW jet powers at MW/kg specific powers. This may enable interplanetary missions at 0.001-0.0015 c in trip durations of weeks to months to ~100s AU by around 2070, interstellar precursor missions at 0.01-0.015 c in trip durations of months-years to ~1,000s AU by 2110, and interstellar missions at 0.05- 0.15 c in trip durations of decades to ~ly distance by around 2150. Some of the critical technological roadmap steps required are presented leading up to the early part of the 22nd century where all of these missions may become feasible.		

Engineering an Interstellar Communications Network by Deploying Relay Probes	John Gertz & Geoff Marcy	Zorro Productions, Berkeley, CA & Space Laser Awareness, Santa Rosa, CA
We develop a model for an interstellar communication network that is composed of relay nodes that transmit diffraction-limited beams of photons. We provide a multi-dimensional rationale for such a network of communication in lieu of interstellar beacons. We derive a theoretical expression for the bit rate of communication based on fundamental physics, constrained by the energy available for photons and the diffraction of the beam that dilutes the information by the inverse square law. We find that meter-scale probes are severely limited in their bit rate, under 1 Gbps, over distances of a light year. However, that bit rate is proportional to the 4th power of the size of the optics that transmit and receive the photons, and inversely proportional to the square of the distance between them, thus favoring large optics and short separations between nodes. The optimized architecture of interstellar communication consists of a network of nodes separated by sub- light-year distances and strung out between neighboring stars. (https://arxiv.org/abs/2204.08296)		

Interstellar Photon Sailing: Trajectory Errors Due to Sail Unfurlment Timing Delay	Gregory Matloff	New York City College of Technology, CUNY
One method of launching space probes towards interstellar destinations is the application of solar-photon sails unfurled from the near-Sun perihelion of an initially parabolic solar orbit. One issue with this technique is trajectory direction errors caused by sail-unfurlment timing delays. This paper quantifies such delays in a manner that can be readily applied by mission planners. A number of possible techniques that could be applied to the correction of these errors are also briefly considered.		

◀ Acta Astronautica

Title	Number+date	Author	Affiliation
Abstract/Précis/Highlights			

Title	Number+date	Author	Affiliation
How to decode interstellar messages	192, March 2022	M Matessa et al	METI International (San Francisco), Pacific Lutheran University (Tacoma), Dalhousie University (Canada), University of Arizona

How can we determine the meaning of a message from a distant civilization if we do not have a common language? This paper presents a general technique and principles for decoding interstellar messages: First, find the dimension of the message. Prime numbers may be useful in determining the proportions of messages. Next, find the symbols. This can be done considering symbol types: delimiters, values, relationships, and functions. Then, find the symbol meanings. Features that can help in determining meaning include sub-symbolic type, redundant symbols, expression consistency, physics ratios, and physics expression patterns. Concepts in this paper can be used when a message from another civilization is received, or they can be used to create messages, which can teach communication theory concepts.

Title	Number+date	Author	Affiliation
Interstellar Probe: Humanity's exploration of the Galaxy Begins	200, July 2022	Pontus C Brandt and 22 others	Johns Hopkins University, University of California Berkeley, University of Iowa, University of Bern (Switzerland), University of Kiel (Germany), University of Colorado, Weslayan University (CT, USA), Boston University

During the course of its evolution, our Sun and its protective magnetic bubble have plowed through dramatically different interstellar environments throughout the galaxy. The vast range of conditions of interstellar plasma, gas, dust and high-energy cosmic rays on this "solar journey" have helped shape the solar system that we live in. Today, our protective bubble, or Heliosphere, is likely about to enter a completely new regime of interstellar space that will, yet again, change the entire heliospheric interaction and how it shields us from the interstellar environment. Interstellar Probe is a mission concept to explore the mechanisms shaping our heliosphere and represents the first step beyond our home, into the interstellar cloud to understand the evolutionary journey of our Sun, Heliosphere and Solar System. The idea of an Interstellar Probe dates back to the 1960's, when also the ideas of a probe to the Sun and its poles were formed. An international team of scientists and a team of engineers at the Johns Hopkins University Applied Physics Laboratory (APL) are funded by NASA to study pragmatic mission concepts that would make a launch in the 2030's a reality. The ground breaking science enabled by such a mission spans not only the discipline of Solar and Space Physics, but also Planetary Sciences and Astrophysics. Detailed analyses including the upcoming SLS Block 2 and powerful stages demonstrate that asymptotic speeds around 7 Astronomical Units (au) per Year are already possible with a Jupiter Gravity Assist. Here, we give an overview of the science discoveries that await along the journey, including the physics of the heliospheric boundary and interstellar medium, the potential for exploration of Kuiper Belt Objects, the circum-solar dust disk and the extra-galactic background light. The scientific rationale, investigations and implementation of an Interstellar Probe are discussed including also example payload, trajectory design and operations.

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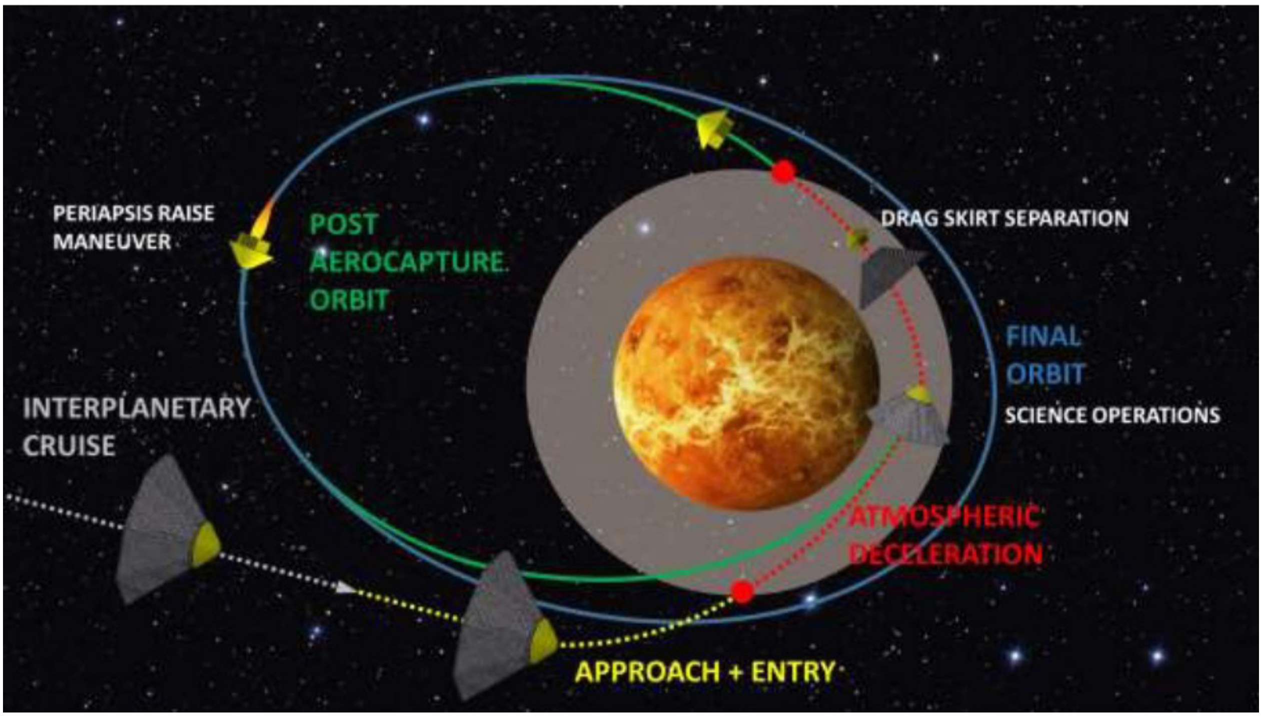
Defining and characterizing self-awareness and self-sufficiency for deep space habitats	198 June 2022	AE Rollock, DM Klaus	University of Colorado Boulder
Future deep-space crewed exploration plans include long duration missions (>1,000 days) that will be constrained by lengthy transmission delays and potential occultations in communications, as well as infrequent resupply opportunities and likely periods of habitat unoccupancy. In order to meet the high level of autonomy needed for these missions, many essential capabilities and knowledge previously accomplished through ground support and human operators must now be designed into onboard systems to enable increasing self-reliance. Emergent technologies, including autonomous systems, have the potential to be mission enabling in deep space; however, as these technologies are often low-TRL and without defined mass, power, or volume, their net impact to the design must be assessed through alternative means, especially during the early planning phases. This paper proposes the concept of designing for self-reliant space habitats as the foundation for assessing potential contributions from the integration of emergent technologies. The term 'self-reliance' can be thought of as a combination of the spacecraft system and onboard crew's knowledge (self-awareness) and capabilities (self-sufficiency) independent of external intervention. In order to provide context for human spaceflight, these terms are first derived from related terrestrial applications. Subsequently, a methodology for characterizing the degree of self-awareness and self-sufficiency in a space habitat is outlined to provide designers with logic for assessing the contributions of emergent technologies to the overall self-reliance of the habitat as needed to allow future Earth-independence. The definitions and characterization logic provided in this work offer a systematic process for designing toward self-reliance in future deep space missions.			



An example of earlier work by AE Rollock, University of Colorado Boulder - "Fig. 3. The aerocapture maneuver, with all of the critical steps to enter orbit" from *SmallSat Aerocapture: Breaking the Rocket Equation to Enable a New Class of Planetary Missions*, lead author Alex Austin. NASA Jet Propulsion Laboratory, Caltech.

Searching for technosignatures in exoplanetary systems with current and future missions	198 September 2022	Jacob Haqq-Misra and 10 others	Blue Marble Space Institute of Science (Seattle), University of California Riverside, Instituto de Astrofísica de Canarias (Spain), Universidad de La Laguna (Spain), NASA Goddard Space Flight Center, ETH Zürich,, University of Arizona, Leibniz-Institut für Sonnenphysik (Germany), Catholic University of America, NASA Ames Research Center, University of Cadiz, The University of Arizona
Technosignatures refer to observational manifestations of technology that could be detected through astronomical means. Most previous searches for technosignatures have focused on searches for radio signals, but many current and future observing facilities could also constrain the prevalence of some non-radio technosignatures. This search could thus benefit from broader participation by the astronomical community, as contributions to technosignature science can also take the form of negative results that provide statistically meaningful quantitative upper limits on the presence of a signal. This paper provides a synthesis of the recommendations of the 2020 TechnoClimes workshop, which was an online event intended to develop a research agenda to prioritize and guide future theoretical and observational studies technosignatures. The paper provides a high-level overview of the use of current and future missions to detect exoplanetary technosignatures at ultraviolet, optical, or infrared wavelengths, which specifically focuses on the detectability of atmospheric technosignatures, artificial surface modifications, optical beacons, space engineering and megastructures, and interstellar flight. This overview does not derive any new quantitative detection limits but is intended to provide additional science justification for the use of current and planned observing facilities as well as to inspire astronomers conducting such observations to consider the relevance of their ongoing observations to technosignature science. This synthesis also identifies possible technology gaps with the ability of current and planned missions to search for technosignatures, which suggests the need to consider technosignature science cases in the design of future mission concepts.			

Searching for technosignatures in exoplanetary systems with current and future missions, Jacob Haqq-Misra et al, https://arxiv.org/abs/2206.00030

Figure 1: A concept image illustrating various types of technosignatures described in this paper, including atmospheric, optical, and radio technosignatures. Atmospheric technosignatures may include obviously artificial molecules such as sulfur hexafluoride (SF6) in addition to common molecules expected for an inhabited terrestrial planet, such as oxygen (O2), carbon dioxide (CO2), and methane (CH4). The top left inset shows the absorption cross-sections of S6. Optical technsignatures include highly collimated laser pulses that can outshine the host star at narrow wavelengths (i.e., Optical SETI). The middle left inset illustrates the narrow power distribution of an optical (green) laser pulse. Active radio beacons or passive radio leakage from the planetary surface, orbit, or elsewhere in the stellar system would be recognizably artificial (i.e., traditional SETI). The bottom left inset illustrates the narrow distribution of power versus frequency anticipated for an artificial radio signal. Additional potentially detectable technosignatures in this planetary system include artificial lighting on the planetary nightside, recognizable spectral breaks from solar arrays on the planet's moon, and anomalous transit signatures from the orbiting habitats and satellite arrays.

A glint in the eye: Photographic plate archive searches for non-terrestrial artefacts	194, May 2022	B Villarroel et al	KTH Royal Institute of Technology and Stockholm University, Instituto de Astrofísica de Canarias, Centro de Astrobiología (Spain), Spanish Virtual Observatory, Gran Telescopio Canarias, Center for Basic Space Science (Nigeria), Durham University (UK)
In this paper, we present a simple strategy to identify Non-Terrestrial artefacts [NTAs; Haqq-Misra and Kopparapu (2012)] in or near geosynchronous Earth orbits (GEOs). We show that even the small pieces of reflective debris in orbit around the Earth can be identified through searches for multiple transients in old photographic plate material exposed before the launch of first human satellite in 1957. In order to separate between possible false point-like sources on photographic plates from real reflections, we present calculations to quantify the associated probabilities of alignments. We show that in an image with nine "simultaneous transients" at least four or five point sources along a line within 10x10 arcmin^2 image box are a strong indicator of NTAs, corresponding to significance levels of 2.5 to 3.9σ. This given methodology can then be applied to set an upper limit to the prevalence of NTAs with reflective surfaces in geosynchronous orbits. (see also the Members Page in this issue and Members Newsletter May 2022)			

A glint in the eye: Photographic plate archive searches for non-terrestrial artefacts, B Villarroel et al http://export.arxiv.org/abs/2110.15217
Figure 5: Triple glints. An example of a triplet glints in a red POSS-I image from 1950s. The left column shows the POSS-I image, and the right column the Pan-STARRS image (> year 2015). The example is from Villarroel et al. (2021) [1]and uses the VASCO citizen science web interface

[1] *Exploring nine simultaneously occurring transients on April 12th 1950*, Beatriz Villarroel et al, 2021
https://www.nature.com/articles/s41598-021-92162-7

BECOME AN i4iS MEMBER

Let's 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?

"Earth is the cradle of humanity, but one cannot live in a cradle forever. "

Konstantin Eduardovich Tsiolkovsky 1911

If you like what you see in Principium, and want to help us do more, then become a member!

i4is was founded in 2012. Our organisation -

- Conducts theoretical and experimental research and development projects.
- Supports interstellar education and research in schools and universities.
- Spreads the interstellar vision through advocacy, outreach and education.

We are a growing community of professionals and enthusiasts passionate about taking the first steps on the path beyond our solar system. Our ambitions are higher than sky high! And to achieve them we need your support.

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Members have access to exclusive benefits:

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- early access to Principium articles before public release - Principium preprints;
- newsletters keeping you up to date with the latest interstellar news;
- videos of i4is lectures and presentations; and
- corporate publications, including our annual report.

The i4is talk programme (videos on the members' section of the website) include:

- The role of In-Space Resource Utilisation (ISRU) as an enabler of human expansion;
- Guidance of the Ariane 4 launch vehicle; and
- Visions of our interstellar future. Videos from our 2021 summer course ***Human Exploration of the Far Solar System and on to the Stars***, delivered by i4is on behalf of Limitless Space Institute are available to members.

The opening session featuring Sonny White of LSI and Rob Swinney of i4is is open to all - i4is.org/videos/lsi-course-2021/

- Videos from our 2022 summer course will also be available to members

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Two Equations to the Stars - Part Two: The Photon Sail Equation

How to explain photon sail maths to mid-secondary school students

John I Davies

There are currently two feasible ways to propel a space probe to the stars - fusion rockets and laser sails - each governed by a simple equation.
In the last issue, P38, we explained the first of these equations, governing rockets, and how middle secondary school students can be introduced to the mathematics, physics and engineering behind all rockets, including the ones that can propel us to the stars. In this second part we explain the simple equation for laser and solar sail propulsion.

Interstellar propulsion theorist Robert Forward. Credit (image and caption): *A Photon Beam Propulsion Timeline*, *www.centauri-dreams.org/2016/06/24/a-photon-beam-propulsion-timeline/*

$$\alpha = \frac{2\eta P}{Mc}$$

The Photon Sail Equation

Who is this article for?

Like the first, this article is primarily intended for teachers introducing school students to space physics, maths and engineering in mid-secondary school (middle school in USA) and their students. The objective is to give these students an accessible yet fairly rigorous understanding of the fundamentals of photon propulsion. It also introduces students to the consequences of the equation, and physics and maths behind it. The equation governs the propulsion challenges of low mass probes such as i4is Project Dragonfly (2014) and the ongoing Project Starshot financed by Breakthrough Initiatives (breakthroughinitiatives.org/initiative/3). These ideas look like our best route to early interstellar probes.

1 Reading order

Teachers - read parts *2-Introduction*, *3-The Equation* and as much of the rest as you can easily understand. If the approach is interesting then get in touch with i4is via info@i4is.org to discuss how we can take this further for you and your students. If it is not interesting then tell i4is why so we can refine it (address as above).

School students - read parts 2-*Introduction*, 5-*The Problem*, 6-*The Story* and 8-*For School Students - What you can achieve*. If you feel confident then read - from *3-The Equation* as far as you understand and then report progress to your maths, science or engineering teacher and ask them to take a look at this article. If you don't feel confident then ask a teacher to help with any difficult maths, science or engineering.

For both teachers and school students, get in touch at any time with questions, suggestions and requests for help - always info@i4is.org.

2 Introduction

This is the second of two articles for Principium explaining how to understand the equations which define our ability to reach our outer Solar System and the stars. Our aim in this article is to provide a way to understand Robert Forward's photon sail equation without using mathematics beyond basic secondary school level. It is intended for teachers, self-motivated secondary school students and interested people in general. More about its objectives in section 8 - *For School Students - What you can achieve.*

The photon sail equation was introduced by visionary physicist and engineer, Robert Forward, in his paper *Roundtrip interstellar travel using laser-pushed lightsails* [1].

3 The Equation

Dr Forward's equation works for anything pushed by photons including laser light, microwaves and the light of the Sun.

Dr Forward advocated -

> "...beamed-power propulsion in that the "engines" of the vehicle are left behind in the solar system and the power and reaction mass are transmitted out to the rest of the vehicle that carries the payload. This system will use large solar-pumped lasers to convert sunlight into coherent radiation, large lightweight optics to transmit the coherent laser beam over interstellar distances, and large lightweight reflective sails carrying the payload that are pushed by the momentum of the reflected laser photons."

This is close to the idea applied in two early i4is projects -

- **Project Dragonfly:**

Project Dragonfly: A feasibility study of interstellar travel using laser-powered light sail propulsion, Perakis et al [2].

Project Dragonfly: Sail to the stars, Häfner et al [3].

The i4is Project Dragonfly logo (Credit: Adrian Mann). The project name Dragonfly refers to Dr Forward's novel, {i}*The Flight of the Dragonfly*, Timescape Books, 1984 (en.wikipedia.org/wiki/Rocheworld) about an interstellar mission using a laser driven light sail propulsion system.

[1] *Roundtrip Interstellar Travel Using Laser-Pushed Lightsails*, Robert L Forward Hughes Research Laboratories, 1984, Journal of Spacecraft and Rockets, Vol. 21, No. 2, p. 187 - 195. web.archive.org/web/20170808080011id_/http://interstellar-flight.ru/design/base_e/rit-1.pdf

[2] *Project Dragonfly: A feasibility study of interstellar travel using laser-powered light sail propulsion*, Nikolaos Perakis, Lukas Schrenk, Johannes Gutsmiedl, Artur Koop, Martin J Losekamm - all Technical University of Munich (TUM), www.nperakis.com/_files/ugd/b85f56_76b3eb456a3f4ebeb5e819ca6c682367.pdf

[3] *Project Dragonfly: Sail to the stars* Tobias Häfner (Université Paul Sabatier Toulouse - UPST, Manisha Kushwaha (Cranfield University, UK), Onur Celikb (Cranfield), Filippo Bellizzi (Cranfield), Acta Astronautica, V154, January 2019, Pages 311-319. www.researchgate.net/profile/Onur-Celik-2/publication/317491721_Dragonfly_Sail_to_the_Stars/links/593bb891a6fdcc17a9c89270/Dragonfly-Sail-to-the-Stars.pdf

• **Project Andromeda:**
The Andromeda Study: A Femto-Spacecraft Mission to Alpha Centauri, Hein et al, 2017[1].
It shares the basis for the major Breakthrough Starshot programme - with the variation that Starshot currently aims to use lasers based on Earth rather than in space.

Project Andromeda logo

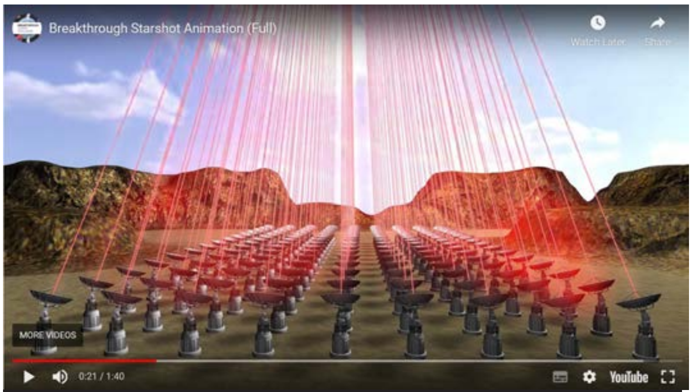
Credit: Adrian Mann
i4is.org/what-we-do/technical/andromeda-probe/

Dr Forward gives his equation as follows -
"The acceleration of a vehicle of mass M and reflectance η driven by an incident laser power P is -

$$\alpha = \frac{2\eta P}{Mc}$$

- where c is the velocity of light and the factor 2 comes from the double momentum transfer to the sail by the reflected photons."

What this means is that more reflectance and more laser power gives more acceleration but more mass gives less acceleration. The units of this are -
α acceleration in metres per second per second.
η (Greek letter eta) is dimensionless - it's just the ratio of reflected to absorbed light - so, with the massive laser powers we need for missions like this it needs to be very close to 1 which is perfect reflection. P is the power of the photons in watts (joules of energy per second). M is the mass of the vehicle to be accelerated in kilograms.
The problem here is, c, the velocity of light, an unchangeable constant of 100,000 kilometres per second or 100,000,000 metres per second in MKS units. This very large value means projects like this need to use extremely powerful photon sources and to keep the mass of the vehicle very small.



Visualisation 100 gigawatt scale laser beamer. Credit: Breakthrough Initiatives, *breakthroughinitiatives.org/concept/3, i4is.org/what-we-do/technical/andromeda-probe/*

4 The Implications

We have a specific objective, an interstellar probe. Let's compare Dr Forward's photon sail equation with the rocket equation of his predecessor, Tsiolkovsky (for more about him and his rocket equation see *Two Equations to the Stars - Part One: The Rocket Equation* - in the last issue of Principium, P37 [2]. This also shows how Al-Khwarizmi and Isaac Newton taught us things about algebra and physics which are relevant here too).
So here are the two equations side by side -

Tsiolkovsky	Forward
$\Delta V = Ve \ln(Mo / Mf)$	$\alpha = 2\eta P / Mc$

On the left ΔV is the change in velocity produced by using all the rocket propellant, Ve is the exhaust velocity of the rocket, Mo is the original mass of the rocket including the propellant, Mf is the final mass of the rocket when all the propellant has been expelled and ln is the natural logarithm function (log to the base **e** = 2.71828 - rather than 10).
On the right is Dr Forward's equation as before.

What is ΔV (DeltaV)?

ΔV is "change in velocity". It's important in both our equations because of what we are seeking from a rocket or a laser sail - speed. We only care about accelaration because it delivers ΔV but to get that speed we don't care if it's a big acceleration for a short time or a small accelaration for a long time.

[1] *The Andromeda Study: A Femto-Spacecraft Mission to Alpha Centauri*, Andreas M Hein et al, August 2017. arxiv.org/abs/1708.03556
[2] Principium 37 i4is.org/principium-37/, *Two Equations to the Stars - Part One: The Rocket Equation*
i4is.org/wp-content/uploads/2022/05/Two-Equations-to-the-Stars-part-one-Principium37-AW-2205261003-opt.pdf

Now let's make the equation comparable, with the same units on the left side of both equations- writing Dr Forward's equation with ΔV to the left of the "=". The two equations are now easily comparable -

Tsiolkovsky	Forward
$\Delta V = Ve \ln(Mo / Mf)$	$\Delta V = 2\eta Pt / Mc$

ΔV is the change in velocity on both left and right. On the left it's produced by using all the rocket propellant. As before, Ve is the exhaust velocity of the rocket and the ratio of original and final masses Mo/Mf, the mass ratio. As before ln is the natural logarithm function.

On the right ΔV is the change in velocity produced by the photons hitting the sail, η remains the reflectivity of the sail, P the power of the photons hitting the sail, c is the velocity of light and the factor 2 comes from the double momentum transfer to the sail by the reflected photons. **The added component is t - the time for which the photons hit the sail.**

This already has interesting consequences -

- **Tsiolkovsky** tells us not to worry about how long his rocket operates for. In space this is literally true - using up your fuel quickly gives you no advantage so a rocket which pushes gently for a long time is as good, in terms of velocity added, as one which pushes harder for a shorter time. It's only the exhaust velocity (often converted into specific impulse, I_{sp} [1]) and the ratio of the initial and final masses which make the difference.
- **Forward** tells us not to worry about propellant (since we are not carrying any) and only think about photon power and reflectivity and worry about vehicle mass. Again no worry about how long his sail is pushed for; a little push for a long time is as good as a big push for a short time. The snag here is that the photon source, a laser or the Sun, is fixed and the vehicle is moving away from it so the inverse square law applies, double the distance and divide the power by four.

This leads to hard engineering judgements. You will see this in any discussion of either of these two known ways of achieving the enormous velocities we need to get to the stars in any reasonable time.

5 The Problem

The problem with rockets (or reaction propulsion generally) for interstellar flight is the same using photon sailing (or externally driven propulsion generally). It's a long way to anywhere really interesting (with apologies to all the scientists studying the interstellar medium, ISM). How do we get there in any reasonable time -

- less than a lifetime?
- less than the duration of European exploration of the Earth?
- or (even) less than the duration of recorded human history?

Recall that our fastest and furthest probes, the two Voyagers, won't reach the distances required for tens of thousands of years.

Pyotr Nikolaevich Lebedev (1866 –1912). Credit: Wikipedia/slovari.yandex.ru

Thinking about this led to the idea of sailing as long ago as 1899 by Russian physicist P N Lebedev quoting James Clerk Maxwell -

> "...the rays of light must exert pressure on those bodies on which they fall. The fact that this property of light escaped the researchers was easily explained by the exceptionally low behaviour of these forces: Maxwell calculated (1873) that in the clear sky at lunchtime [he was British!] the compressive force of solar radiation on four square metres hardly equals the weight of one-tenth of a gram."

- Lebedev's ideas were taken up by the ubiquitous pathfinder for our move into space, Konstantin Tsiolkovsky. He wrote in his paper *The Spaceship*, 1924-1926-

> "...the third and most attractive method of obtaining speed. This is to transmit energy to the vehicle from outside, from the earth. The vehicle itself need not store up material energy (that is, ponderable energy - in the form of explosive or fuel). The energy is transmitted to it from the planet in the form of a parallel beam of electromagnetic rays of short wave-length.

[1] I_{sp} is measured in seconds, a ratio of the thrust produced to the mass flow of the propellant(s). This comes out as (metres/sec) / (metres/sec^2) , velocity/acceleration so the units are just seconds. A good high I_{sp} propellant example is Xenon, typical I_{sp} 1500-4000 secs, 8 times as much I_{sp} as LOx+LH_2, but not enough thrust to liftoff from Earth.

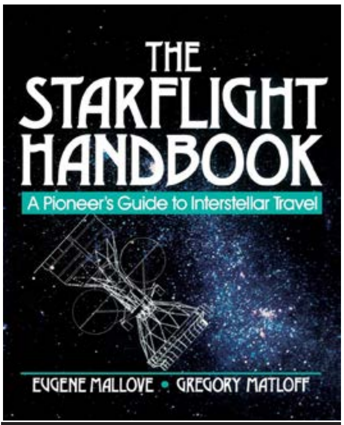
[2] *Untersuchungen über die Druckkräfte des Lichtes* (*Investigations on the pressure forces of light*) - see - https://it.wikisource.org/wiki/Scientia_-_Vol._VII/Die_Druckkr%C3%A4fte_des_Lichtes (German text)

"...This parallel beam of electric or even light (solar) rays should exert pressure by itself (there can be no doubt that such pressure exists [citing Lebedev]) such pressure can give the vehicle a sufficient speed. In that case, one would not need any supplies for ejection. **The last method would seem to be the most refined."** [1] (my **emphasis**)

More about this early thinking in *Tsiolkovsky - Interstellar Pioneer*, Principium 20, February 2018 (i4is.org/wp-content/uploads/2018/02/Principium20.pdf).

6 The Story

Our story begins again with Newton for physics and Al-Khwarizmi for algebra - and I will assume knowledge of the basics of these as explained in the first of these two Principium articles. So, where does Forward's photon sail equation come from? Forward does not give a derivation or cite a source.



The Starflight Handbook.
Credit: Wiley 1989

A good starting point is in a book by Mallove and Matloff (M&M), *The Starflight Handbook* [2]. Back in 1989 M&M told us (see their Technical Note 5-2) that the energy in a photon is given by **E=hv** and the momentum of a photon is implied by **λ=h/p** [3].

In these two equations E is the energy in joules, v is the light frequency in Hz, p is the momentum of the photon in kilogram (kg) metres per second, λ (Greek lambda) is the wavelength in metres and h is Planck's constant in metres squared kilograms per second. Let's re-write that with f as the frequency since v is easily confused with velocity - and transposing the second equation to put momentum of the left side. This gives us E=hf and p=h/λ. But M&M point out that the velocity of a wave is the frequency times the wavelength so the velocity of light c=fλ.

So what is the momentum of our photon?

With p=h/λ and λ=c/f (transposing that third equation) so p=hf/c and because E=hf then p=E/c. Now if the photon is bounced off something, like a sail, then it transfers twice its momentum so a perfectly reflecting solar sail has momentum added p=2E/c. But we want to find the acceleration and since momentum is just mass times velocity so mv=2E/c and so v=2E/mc. Acceleration is **rate of change of velocity** so, with energy in photons per second, we get ΔV = 2Et/cm where t is the time during which the photons are hitting the sail. If our sail is not a perfect reflector we need to include reflectivity η giving ΔV = 2Etη/cm which is Forward's equation in a version comparable with the Tsiolkovsky rocket equation (ie including the time for which the photons hit the sail).

7 The Consequences

Let's compare these two propulsion techniques - mainly as they affect interstellar missions-

	Reaction (rocket)	Photon (sail)
Limitation	Exhaust velocity, mass ratio	1/c means tiny probes, massive laser power requirement
Capability	Fusion required but not yet attained	Very high probe velocity
Difficulties	Massive vehicle demands in-space construction	Tiny probes limit downlink bandwidth and science payload

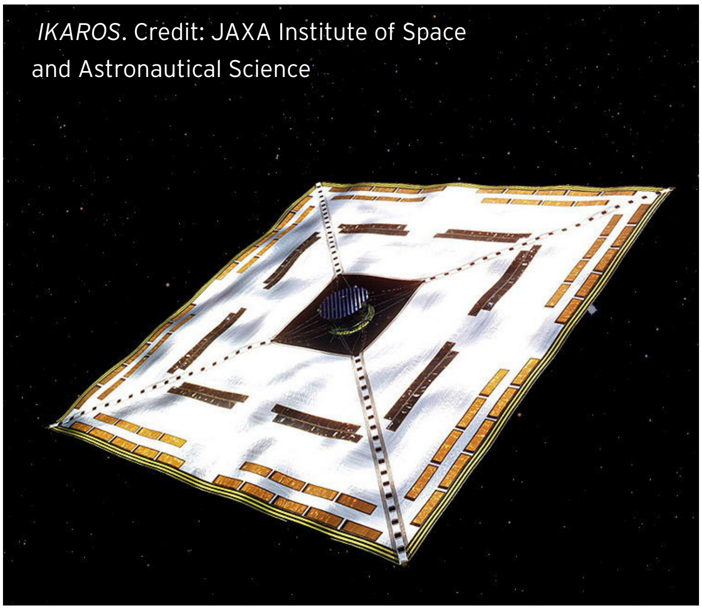
Both techniques require technologies which could become weapons - fusion rocket exhaust and multi-gigawatt lasers respectively. The issues extend beyond the simple list above and there is a lot of published work examining them. See 10 *Further resources*, below.

If you spot a major missing issue or you struggle to understand one of the issues then get in touch with i4is, info@i4is.org, and raise it with us.

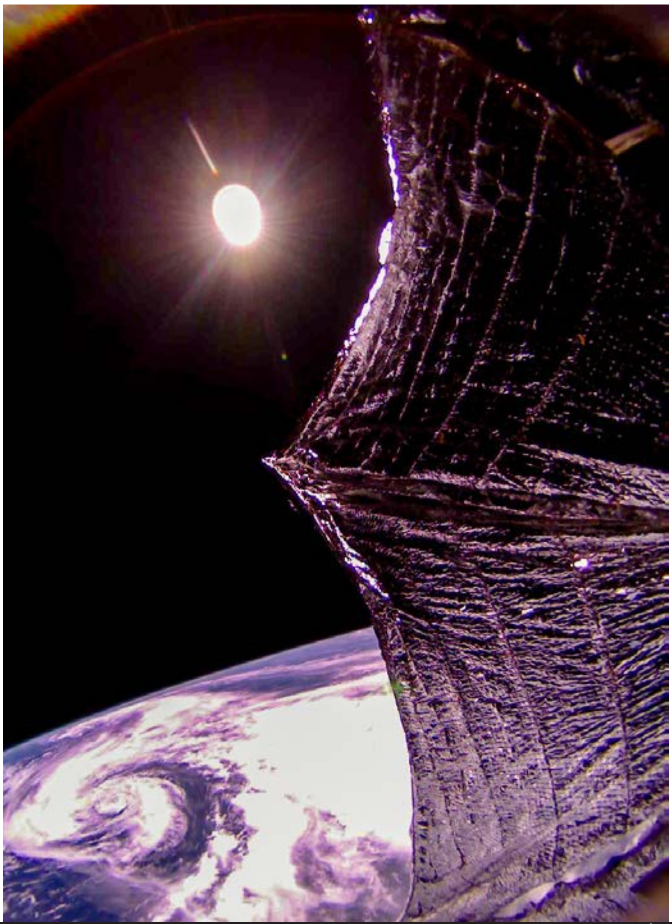
[1] In - *K E TSIOLKOVSKY Selected Works*, compiled by V N Sokolsky, General editor Acad. A A Blagonravov, translated from the Russian by G Yankovsky, University Press of the Pacific, Honolulu, Hawaii, 1968-2004 - the publisher has vanished and URL universitypressofthepacific.com is defunct but the book may still be available.

[2] *The Starflight Handbook: A Pioneer's Guide to Interstellar Travel*, Eugene F Mallove, Gregory L Matloff, Wiley, 1989.

[3] How can a photon, with no mass, have momentum? Here Einstein helps with his famous $E=mc^2$ - so mass is just energy and since photons have energy they have something that can act as mass. The amounts are very small because c, the velocity of light, is very large so a little energy, as in a photon, has that something that can act as mass but in tiny quantities.



IKAROS. Credit: JAXA Institute of Space and Astronautical Science



Lightsail 2. Credit: The Planetary Society, *www.planetary.org/sci-tech/lightsail*

8 For School Students - What you can achieve

The basic physics behind Forward's equation is even simpler than Tsiolkovsky's equation. Tsiolkovsky had to deal with the fact that a rocket loses mass as it uses up its propellant. He used calculus, specifically integration, to account for this. As the first of these articles explained, you can "work around" this using the perfectly mathematically respectable technique of numerical approximation. So a bit of simple algebra and a spreadsheet using only addition and multiplication gives an equivalent result. The light sail equation derivation above, 6 *The Story*, does use the concept of momentum. If you don't yet understand how that works any maths or science teacher can help - find the one you comunicate with best!

With Forward's simple equation you can work out how fast any sailcraft will fly. This includes implemented solar sail missions like Japan's *IKAROS [1]* and the Planetary Society's *LightSail* [2], small laser-propelled demonstrators like the i4is Glowworm proposal [3], early ideas like the i4is Dragonfly work [4] and Andromeda study [5] - and all the way to the mighty 100 gigawatt thinking of Breakthrough Starshot [6].

From there you can move on to the economics of ground based laser banks, as in Starshot, and space based lasers, as in Andromeda. This leads to the issues of public safety of big laser banks, the political or private support you will need for your interstellar thinking and your own attitude and commitment (or not?) to the cause of sending our first probe to the stars. It all starts from the physics and the engineering in this article but that is just the beginning.

[1] *IKAROS Small Scale Solar Powered Sail Demonstration Satellite*, www.isas.jaxa.jp/en/missions/spacecraft/current/ikaros.html
[2] *LightSail, a Planetary Society solar sail spacecraft*, www.planetary.org/sci-tech/lightsail
[3] *Project Glowworm*, i4is.org/what-we-do/technical/project-glowworm/
[4] *Project Dragonfly*, i4is.org/what-we-do/technical/project-dragonfly/ and en.wikipedia.org/wiki/Project_Dragonfly_(space_study) - for a deeper dive into this work see the papers cited above 3 *The Equation* under Project Dragonfly
[5] *Andromeda Probe*, i4is.org/what-we-do/technical/andromeda-probe/
[6] *Breakthrough Starshot*, breakthroughinitiatives.org/initiative/3 and en.wikipedia.org/wiki/Breakthrough_Starshot

9 For Teachers - The Vision

This article and its predecessor aim to inspire both school students and their teachers. We at i4is believe that space can inspire both and that interstellar is the ultimate expression of that outward urge which has driven our species from early times. Looking at interstellar concepts challenges science, maths and engineering in many ways. Propulsion is just one of them but is perhaps the most simple and obvious in its relevance, the easiest to approach mathematically. Yet it contains some of the most extreme physics and challenging engineering - and ultimately maths too.
i4is has numerous resources and capabilities to assist you in handling issues arising from interstellar thinking which range from "hard" science and engineering to economic, moral and sometimes even political problems. Take a look at our website i4is.org. Don't hesitate to contact us via address info@i4is.org - always monitored.

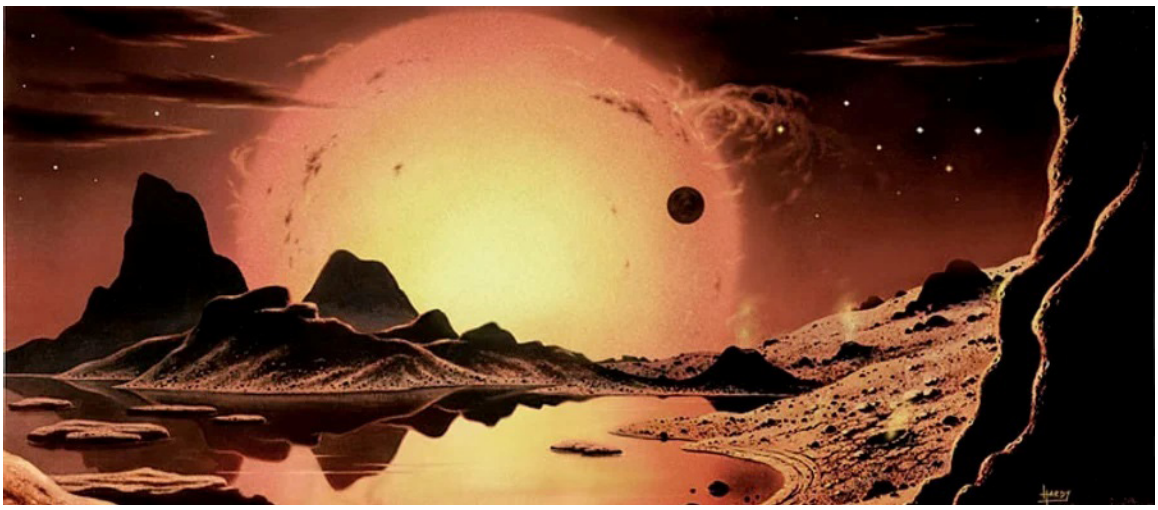
10 Further resources

There is a simple "ready reckoner" on the i4is website, *Exploring Equations* (i4is.org/equations/) which shows the results of inserting values into the terms of both the rocket equation and the photon sail equation. You can meet our Technical team (i4is.org/what-we-do/technical/) and our Education team (i4is.org/what-we-do/education/). Lots of links to ongoing photon sail work in *8 For School Students - What you can achieve*, above. If you are interested in getting more deeply into the maths, science and engineering then search scholar.google.com using terms such as -

Search terms	Example result
interstellar sail	Robert Forward's classic *Roundtrip interstellar travel using laser-pushed lightsails*, 1984, has gathered 281 citations - take a look at some of them but not all!
starshot sail	Kevin Parkin's *The breakthrough starshot system model* (arxiv.org/abs/1805.01306) is a particularly useful starting point. It dates from 2018 and has 105 citations so take a look there too.
tsiolkovsky photon	NASA paper *The Physics of Solar Sails*, 2002 (ntrs.nasa.gov/api/citations/20030093608/downloads/20030093608.pdf)

11 Conclusion

I hope to have shown both teachers and school students that the underlying maths of propulsion for interstellar travel is accessible without profound mathematical expertise - and that it leads on to wider considerations both within and beyond space science and technology. Please get in touch if you have comments, questions or suggestions to add or change any of this.
At info@i4is.org we are always listening.



The Vision: Going Soon? Here is David Hardy's 1972 idea - with his own explanation -
Proxima 1972: The most effective extrasolar scenes are often those with a red sun, whether a red supergiant or a dwarf. One of the latter is our closest stellar neighbour, Proxima Centauri, a small member of the Alpha Centauri triple system. This was painted, in acrylics, for The Challenge of the Stars with Patrick Moore in 1972. In order to have liquid water, the planet would need to orbit the red star in 10 days. The constellation Cassiopeia can be seen, with an extra star - our Sun. Credit: David Hardy, www.astroart.org

The Initiative for Interstellar Studies

image: ©ALEX STORER

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» 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
» John Davies: Editor Principium - john.davies@i4is.org
» 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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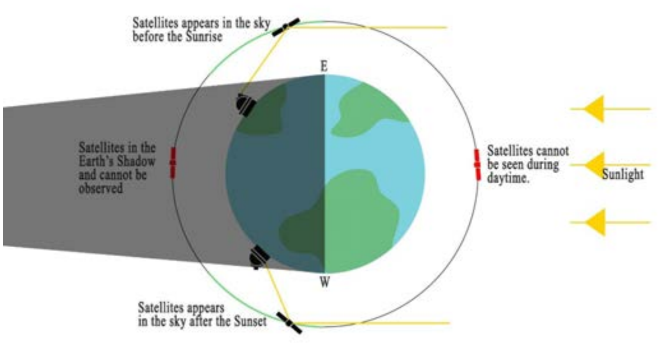
THE i4iS MEMBERS' PAGE

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

Recent members' newsletters and preprints
Two editions of the members' newsletter have come out since the last issue of Principium. The first, issued on 14 May, included coverage of several recent developments of interstellar relevance, including:

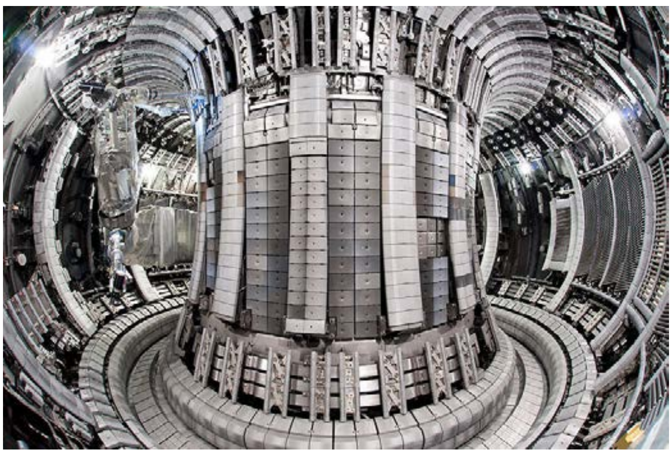
- record-breaking advances in fusion research from the Joint European Torus in Oxfordshire;
- two papers on laser sail design from the Breakthrough Starshot team;
- a paper on thermal-antimatter propulsion concepts;
- a study suggesting that advanced extraterrestrial civilisations might use 'free-floating' planets (ie those not orbiting a star) as a (slow) means of interstellar transportation; and
- a proposal to search old astronomical photographs of the near-Earth environment for historical evidence of non-terrestrial artefacts (such as extra-terrestrial space probes) - as in the diagram below.



From "A glint in the eye: photographic plate archive searches for non-terrestrial artefacts" Figure 1: Illumination of satellites. Satellites are only visible when the Sun illuminates them and the background sky is not too bright. The higher the altitude of the orbit, the longer the satellite is outside the shadow of the Earth.

The second newsletter, issued on 7 August, covered:

- A workshop on 'Fast, Low-Cost, Interplanetary Sailcraft Science Missions', organised in Luxembourg in mid-May by i4is Executive Director Andreas Hein (but in his role as Professor of Space Systems Engineering at the University of Luxembourg);
- A paper on von Neumann probes by long-time friend to i4is, Professor Greg Matloff;
- A paper on antimatter propulsion for exoplanet exploration by Gerald P Jackson, presenting a design capable of exceeding 2% of light speed; and
- A paper by Yiming Huo which discusses the development of an internet of deep-space probes, to enable planetary defence against such scenarios as an asteroid or comet impact with Earth.



The Joint European Torus tokamak reactor near Oxford, UK, is a test bed for the world's largest fusion experiment – ITER in France. Credit: Christopher Roux (CEA-IRFM)/EUROfusion (CC BY 4.0)

Three preprints of articles that will appear in Principium issue 38 have also been placed in the members' area on the website in the last three months:

- Andreas Hein's review of a new book on astrobiology, 'Life in the Cosmos – From Biosignatures to Technosignatures', by Manasvi Lingam and Avi Loeb;
- The second part of John Davies' educational article on explaining the maths and physics of interstellar propulsion to secondary school students – this time focusing on the photon sail equation; and
- A summary of the interstellar-themed technical papers to be presented at the International Astronautical Congress in Paris in late September.

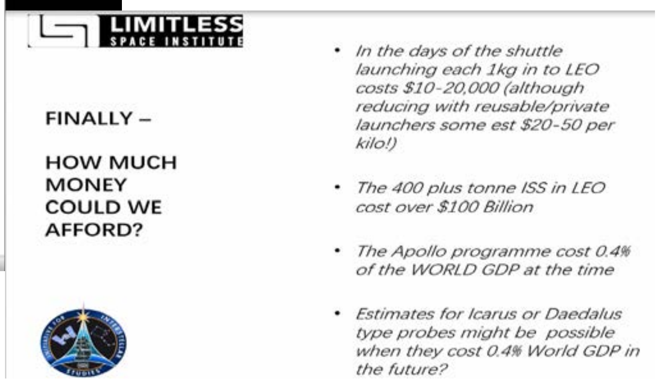
They all appear in this issue of Principium - but you saw them first!

Limitless Space Institute summer course, July 2022: Human Exploration of the Far Solar System and on to the Stars

i4is delivered the summer course, 'Human Exploration of the Far Solar System and on to the Stars' for the Limitless Space Institute from 25 to 29 July 2022. This is the second year that we have presented these lectures. The course was well received by attendees once again. We expect to put videos of the lectures up on the members'-only area of the i4is website soon.

Here are a few snapshots from Rob Swinney's introductory lecture this year.

Snapshots from Rob Swinney's introduction to the 2022 LSI/i4is course. Clockwise from top left - Early Icarus evolution from Daedalus, Rob, Outreach at the Royal Institution of Great Britain 2018/2019 (next in August 2022), How much can we afford for a mission?



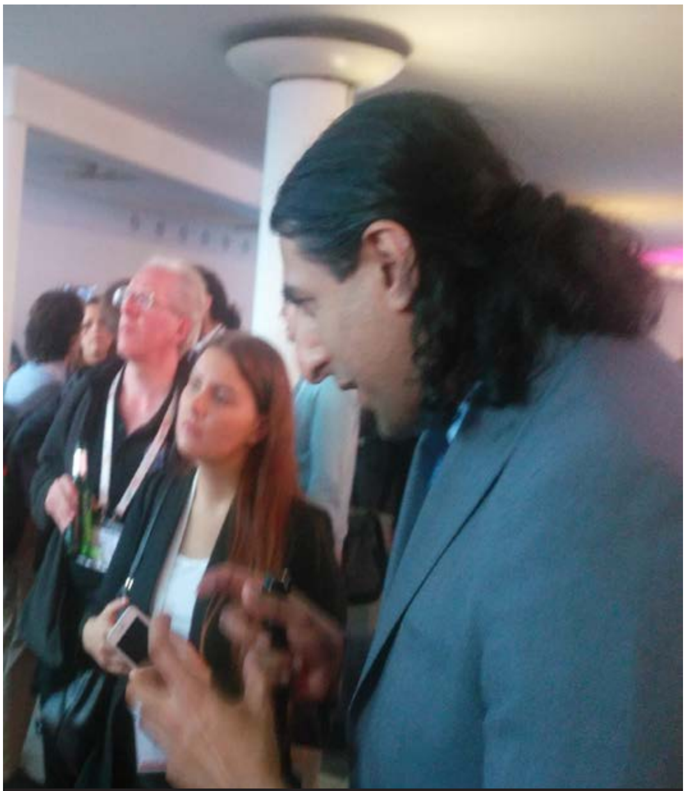
Getting more actively involved

If you'd like to go beyond your membership of i4is, and get involved with our work more actively, we'd love to hear from you! There are lots of different ways you can help us take our programmes forwards, whether your skills are technical, educational, administrative or financial.

Members of i4is who enjoy Science Fiction writing are being invited to contribute stories for an i4is SF anthology - check out the members newsletter or the website here: i4is.org/the-i4is-science-fiction-anthology/

And the 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.

Tishtry and Anna at a BIS event


Satinder explaining in Bremen

We would love to do more. We need more volunteers in Europe, Asia, Africa and the Americas.
We have material you can use or adapt from primary school to university and for professionals and enthusiasts in disciplines like Astronomy, Rocket engineering, Physics, Maths, English, Social sciences, Aviation and media - both popular and heavy!

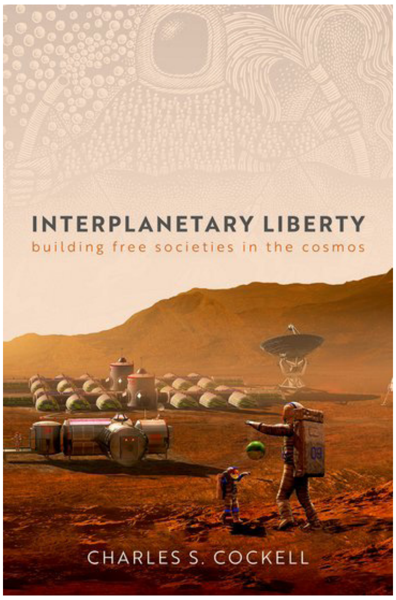

Terry, John & Jeremy at a London school

NEXT ISSUE

i4is Project Lyra logo showing the constellation direction and the hyperbolic trajectory of 1I/'Oumuamua - the first observed interstellar object

- **Oumuamua - A Second Chance:** Adam Hibberd's personal account of his journey to and through his vital contribution to i4is Project Lyra
- **73rd International Astronautical Congress 2022 - The Interstellar Presentations:** First reports of the interstellar themes at the biggest world space conference of the year
- ***Human Exploration of the Far Solar System and on to the Stars* for the Limitless Space Institute:** Patrick Mahon's account of the 2020 and 2021 courses
- **Book review: *Interplanetary Liberty - Building Free Societies in the Cosmos*, Charles S Cockell** by Max Daniels

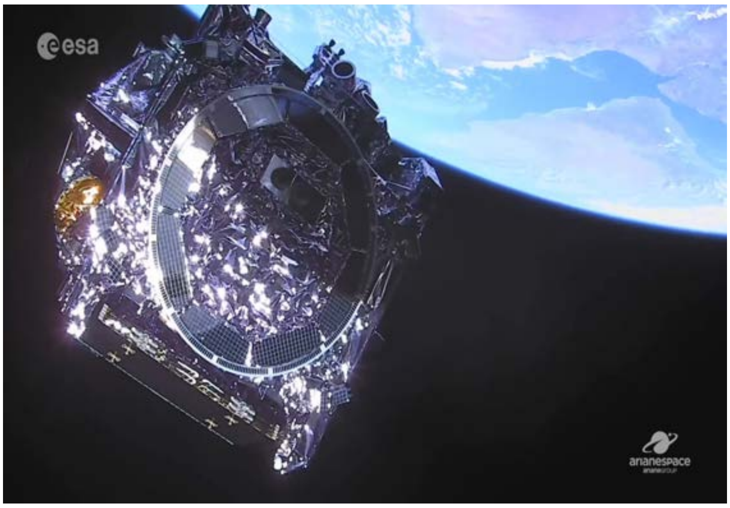
- plus, of course. *Interstellar News* and interstellar papers in *The Journals*.



COVER IMAGES

Our cover images for this issue look near and far! A probe to 1i/'Oumuamua is a near term possibility, galactic warps and collisions are far far away.

FRONT COVER



Webb separation from Ariane 5

The launch of the James Webb Space Telescope on 25 December 2021 was the best collective Christmas present for both astronomers and the interstellar studies community.

You can view video of the separation sequence at dlmultimedia.esa.int/download/public/videos/2021/12/050/orig-2112_050_AR_EN.mp4 Some of us take a look at it every now and then as, I am sure, many of my generation look again at the landing video from Apollo 11.

Host page: www.esa.int/ESA_Multimedia/Videos/2021/12/Webb_separation_from_Ariane_5

Credits: ESA / Arianespace

BACK COVER

Jupiter - an early image from the JWST

Jupiter and its moon Europa are seen through the James Webb Space Telescope's NIRCam instrument 2.12 micron filter.

Credits: NASA, ESA, CSA, and B Holler and J Stansberry (Space Telescope Science Institute - STScI)

Source: blogs.nasa.gov/webb/2022/07/14/webb-images-of-jupiter-and-more-now-available-in-commissioning-data/

On the left is Europa, a moon with a probable ocean below its thick icy crust, and the target of NASA's forthcoming Europa Clipper mission.

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.

EDITOR: John Davies
DEPUTY EDITORS: Patrick J Mahon, Andreas M Hein
CONTRIBUTING EDITOR: Samar AbdelFattah
LAYOUT/PROOF: John Davies, Carol Wright, Lindsay Wakeman

Front cover: Bon Voyage JWST
Credit: ESA / Arianespace
Back cover: Jupter from JWST
Credit: NASA, ESA, CSA, STScI

SCIENTIA AD SIDERA
KNOWLEDGE TO THE STARS

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

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

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

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