PRINCIPIUM

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Scientia ad sidera
Knowledge to the stars

Editorial

Welcome to issue 34 of Principium, the quarterly magazine of i4is, the Initiative and Institute for Interstellar Studies. Our lead feature this time is *Optimal Strategies for Exploring Near-by Stars* by Johannes Lebert of the Technical University of Munich (TUM).

Our cover images have a common thread this time - obstructions to our ambitions in space.

Our front cover image is the star system LL Orionis with its "solar wind" colliding with the interstellar medium (ISM) - reminding us that interstellar space is a fine vacuum but not a perfect one - a significant obstacle for high-speed probes.

The rear cover image is a visualisation by the European Space Agency of the scale of the space debris problem around Earth. If we don't solve the space debris problem then it will be increasingly difficult to get off Earth, never mind to the rest of the Solar System and the stars.

In this issue Adam Hibberd suggests missions to an enormous visitor from the Oort cloud in *2014 UN 271 Spacecraft Missions* and John Davies explains the background in a News Feature *Mission to 2014 UN271 using OITS*. We summarise the relevant papers we expect in October in *International Astronautical Congress 2021 - The Interstellar Papers*. In another News Feature John I Davies looks at recent peer-reviewed publications in *The Journals: JBIS and Acta Astronautica*. Patrick Mahon discusses another review of Avi Loeb's *Extraterrestrial*, this time in the London Review of Books.

We have our regular i4is Members' Page and eight pages of Interstellar News with 22 items ranging from the possibility of a Dyson Sphere around a black hole to the possible effects of gigawatt laser arrays on the atmosphere and, as always, a number of items on a range of propulsion technologies.

The two pieces on interstellar downlink communications have been postponed for organisational reasons. We plan to have both in our next issue; the "heavy brigade" based on the Icarus Firefly downlink and its predecessor the BIS Daedalus downlink, and the (very) "light brigade" - the ideas of David Messerschmitt *et al* for swarming micro-probes.

In our next issue, November 2021, we will report on interstellar items from the October International Astronautical Congress in Dubai and from the September IRG 7th Interstellar Symposium in Tucson. The first running of the course, *Human Exploration of the Far Solar System and on to the Stars*, by i4is for the Limitless Space Institute in July will be summarised and we'll have more to say about the future of this course.

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

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More in *The i4is Members' Page* - page 49

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

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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 page 52 of this issue and at i4is.org/membership.

Please print and display our posters - regular membership - on black page 10, on white 37, student membership - on black page 51, on white page 53.

All our poster variants are available at -

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

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Optimal Strategies for Exploring Near-by Stars

Johannes Lebert

LEAD FEATURE

In Principium 32, February 2021, David Gahan suggested ways in which intergalactic civilisations might meet at a "Treffpunkt"*. Here Johannes Lebert explores the more immediate problem which we will face once the basic technologies of interestellar probes have been achieved - How do we route our explorers to achieve optimal research results at minimum expenditure of effort? More about this in Johannes' Author's Introduction below.

Note that all references appear at the end of this article.

Author's Introduction

Last year, I decided to break the travel restrictions due to the pandemic and to leave our solar system to explore close-by stars. The result of my journey is documented in my Master Thesis with the title Optimal Strategies for Exploring Near-by Stars [1]. My thanks go to my supervisors Andreas Hein and Martin Dziura, who gave me the possibility to work on this specific topic and John Davies, who offered me the opportunity to present a summary of my work here.

Motivation and Thesis Objective

Driven by exoplanet discoveries and the ongoing progress in related technologies, the idea of interstellar travel and exploration has gained momentum in the recent decade. However, while there are already various suggestions for probe concepts (eg [2], [3]) and considerations on relevant technologies, only few, limited research activities on suitable exploration strategies exist (eg [4], [5]). The overarching objective of this thesis is to develop strategies for the exploration of star systems in the solar neighbourhood (approximately 1,000-10,000 stars), based on optimization algorithms, taking advantage of current knowledge of nearby star systems and interstellar spacecraft.

* *AMiTe Treffpunkt - A proposal for communication between Kardashev Type IIb civilisations* David F Gahan, P32, Feb 2021 i4is.org/wp-content/uploads/2021/06/AMiTe-Treffpunkt-Principium32-print-2102221659-opt.pdf

Interstellar Exploration as an Optimisation Problem

As part of the thesis, the planning of interstellar exploration strategies is categorized as **bi-objective multi-vehicle open routing problem with profits:**

- **Bi-objective:** There are two objectives which are the mission return (J_1) and the mission duration (J_2). The mission return is the sum of all rewards provided by the stars which have been visited during the mission. The mission duration is equal to the overall travel time of the probe - if the mission consists of several probes, the probe which has the longest overall travel time is considered. The optimization aims to maximize the mission return while keeping the mission duration minimal.
- **Multi-vehicle:** Several probes can be used to explore different stars simultaneously.
- **Open:** Probes are not required to return to Earth once the mission is completed but can choose arbitrarily where to end their trip.
- **Routing Problem with Profits:** We assume the stars as a set of locations with each of it providing a certain reward or score *Si*. From this set, a subset needs to be selected and arranged as a route in a way which optimizes the given objectives (see Figure 1).

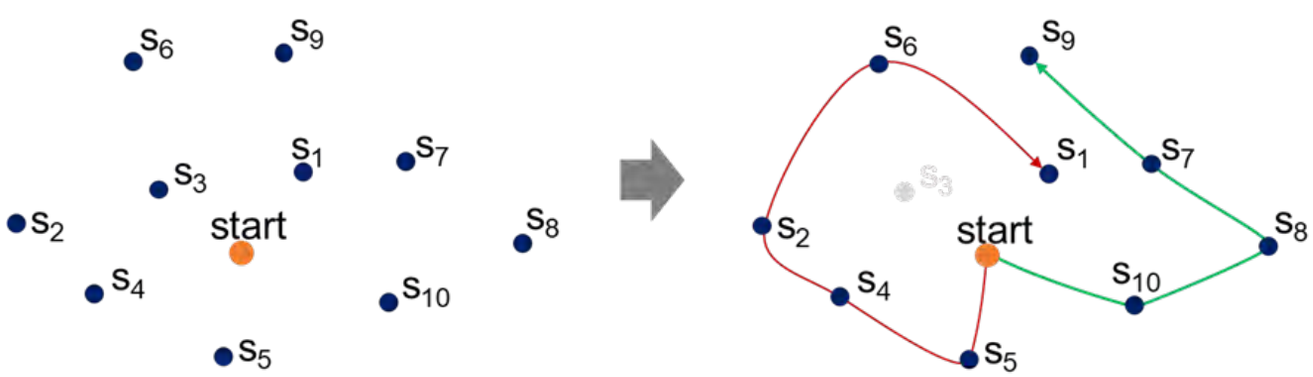

Figure 1: Visualization of the multi-vehicle open routing problem with profits.

Generally, the score of a star system can be adjusted depending on the mission interests (eg according to its probability to host (habitable) exoplanets) but for now it is assumed that each star system has the same score (*Si* =1). Hence, the mission return will be equal to the number of stars that are visited during the mission.

Modelling and Optimization Algorithm

Probe, Mission Architecture and Star Model

All probes are launched at the same time from Earth and limited to performing flyby manoeuvres. Furthermore, they are assumed to travel along straight-lined trajectories at an average velocity of 10 % of the speed of light, which is in line with suggestions from literature (eg [4]). Other parameters, such as mass or propulsion technology, are not considered.

The used star data is taken from the **Gaia Data Release 2** (available online through the Gaia Archive [6]), which is currently considered to be the most complete and accurate star database*.

To eliminate spurious data sources, a filtering is applied, which follows the suggestions from Lindegren *et al* [7]. The resulting star model is shown in Figure 2. It contains **10,000 stars** and represents a spherical domain with a radius of roughly **110 light years** around the solar system. The stars are assumed to maintain fix positions, which can be shown to be a valid simplification within this context for mission timeframes up to 7,000 years.

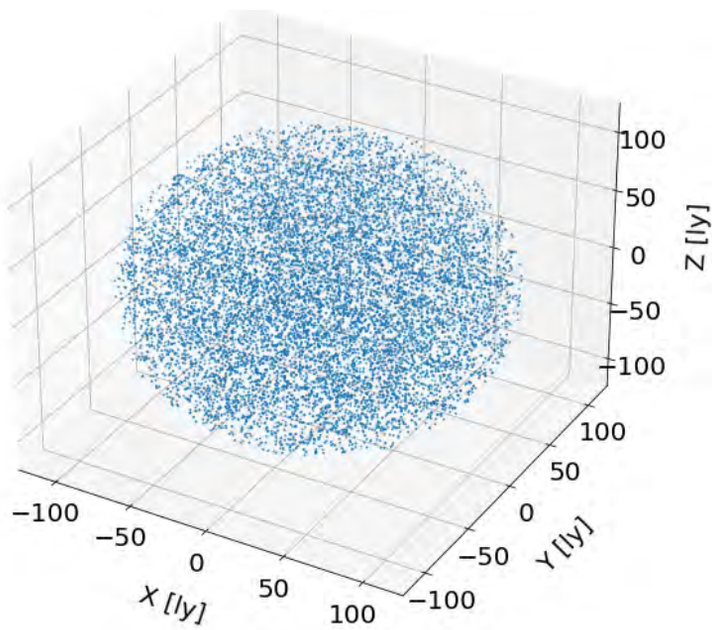

Figure 2: Star model based on Gaia DR2.

The Optimization Algorithm

To solve the described problem, a **hybrid genetic algorithm** presented by Bederina and Hifi [8] is selected. Genetic algorithms are a very intuitive optimization approach, as they try to imitate the process of natural evolution, which consists basically of reproduction and survival of the fittest. The required genetic encoding is shown in Figure 3: Exploration missions are represented by chromosomes while each gene embodies a sequence of stars or travel route which is assigned to a probe. For more details and explanations on the workflow and mechanisms of the algorithm please refer to the thesis document [1].

To improve the convergence behaviour the genetic algorithm is combined with a local search operation. The local search is applied in regular intervals to all current solutions to improve routes individually (eg by swapping two stars from the same route). That is why this method is referred to as hybrid genetic algorithm.

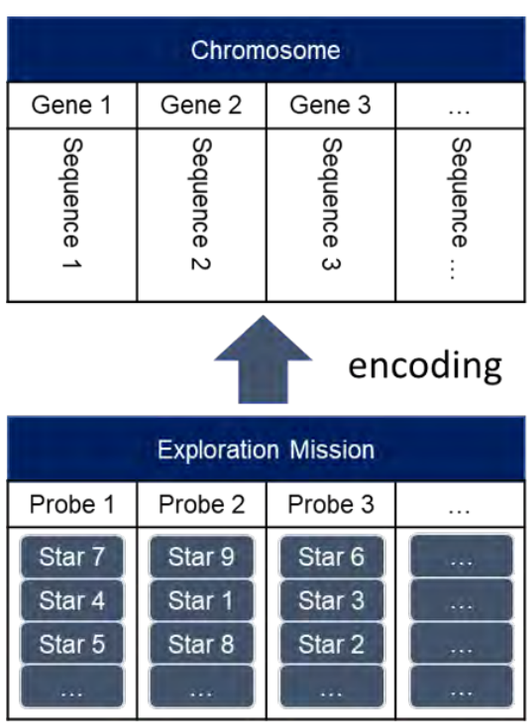

Figure 3: Genetic encoding

* Note that there is already an updated Data Release (Gaia DR3), which was not available yet during this thesis.

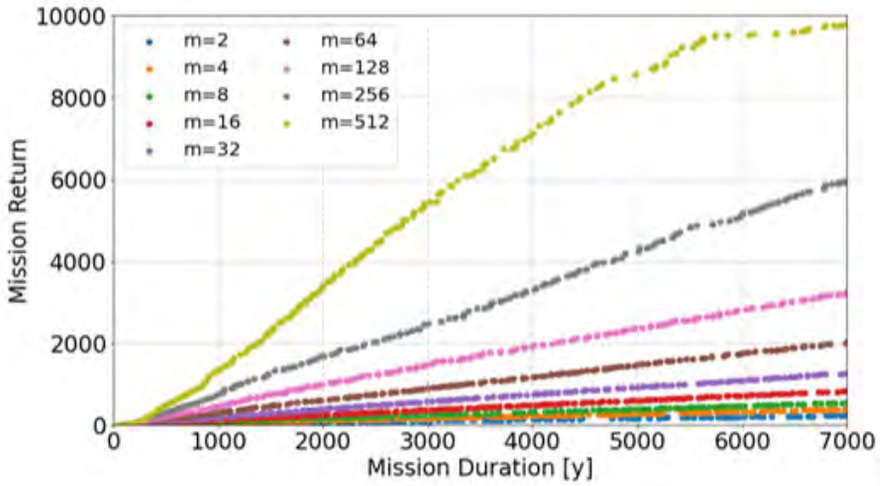

Figure 4: Optimization results for different probe numbers (model with 10,000 stars).

Optimization Results

Several optimization runs are performed whereby between each run maximum probe number *m* is doubled, starting with m=2. The resulting solutions are plotted in Figure 4 where the missions are evaluated with respect to both optimization objectives. Different runs (and thus different probe numbers) are indicated by different colours, each dot represents one possible exploration mission.

From Figure 4 one can observe that the mission return (which we assumed equal to the number of explored stars, just as a reminder) increases almost linearly with mission duration. For a given mission duration, the mission return can be increased by launching more probes. After doing some further analysis, both observations can be condensed in the following scaling law, which puts mission return J_1, mission duration J_2 and probe number m into relation:

$$J_1 \sim J_2\, m^{0.6}$$

As J_1 grows only with $m^{0.6}$, **the beneficial impact of additional probes on the mission return diminishes with increasing probe numbers**. This phenomenon is similar to the concept of diminishing returns in economics, which denotes the effect that an increase of the input yields progressively lower or even reduced increase in output.

An analysis of the route structure (visualized in Figure 5 for two solutions with different probe number but similar mission return) reveals strong differences depending on the probe number:

High probe number missions focus on the immediate solar neighbourhood and consist mainly of single-target routes whereas low probe number missions are built of longer routes which include also more distant stars. This could explain the lower efficiency of high probe numbers revealed through the scaling law before: With each additional probe being launched, the distance to the nearest star which is still unexplored increases. Accordingly, with higher probe numbers more distant transfers are required to provide the same mission return while lower probe numbers enable a quite efficient routing due to the shorter transfers.

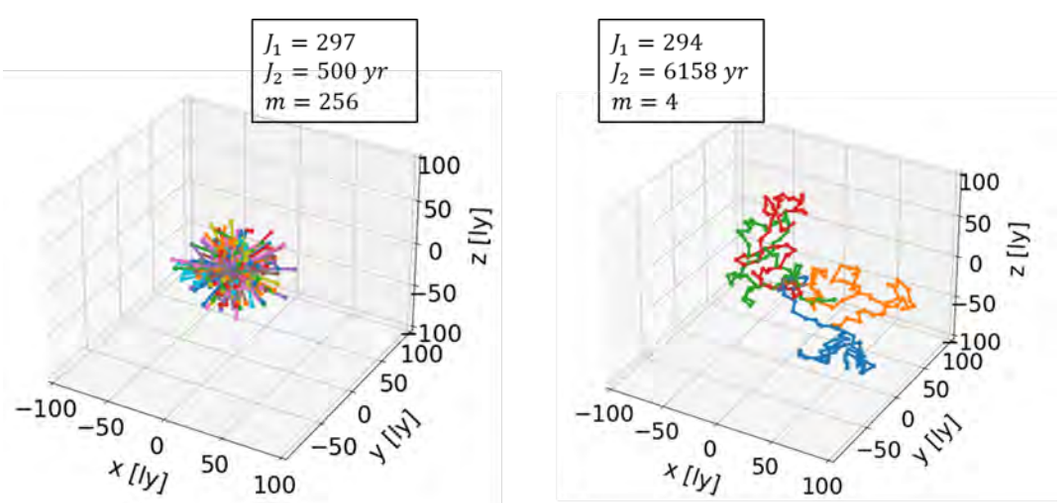

Figure 5: Route structure depending on probe number, each colour refers to one probe -

left: 256 available probes, right: 4 available probes

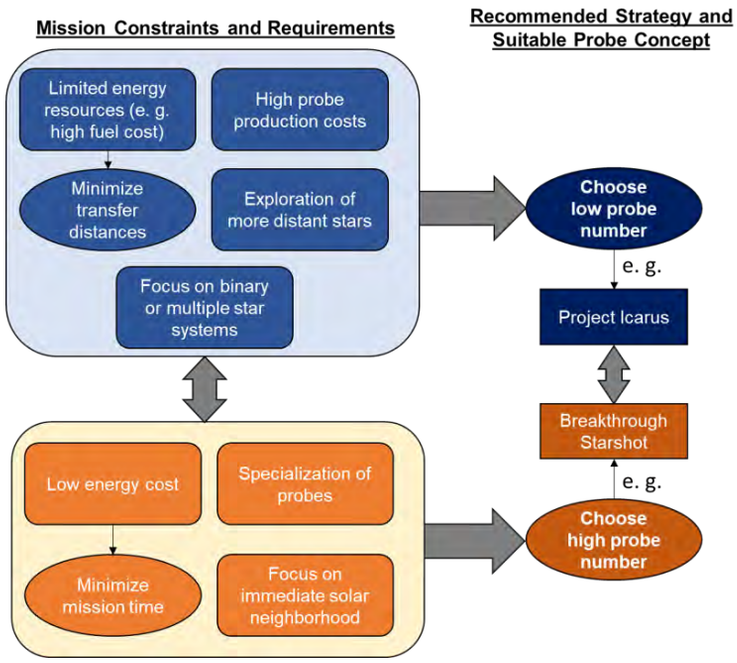

Figure 6: Strategy recommendations based on mission constraints and requirements including suitable probe concepts from literature

Conclusions with respect to Exploration Strategies

Based on the optimization results, several recommendations for exploration strategies can be derived (summarized in Figure 6): Due to the efficient routing low probe numbers are more suitable in case of limited energy resources (eg high fuel cost) and when the exploration mission is not restricted to very nearby stars. Conversely, high probe numbers enable a faster exploration of the nearest stars at the expense of less resource-optimal transfers and therefore match better with strategies based on small-scale, remotely propelled concepts (eg Breakthrough Starshot described by Parkin [3]). As further advantage, high probe numbers allow a higher specialization of the probes as each probe explores only few stars. However, according to the derived scaling law high probe numbers bear the risk of less efficient probe deployment, which is probably due to local crowding effects. Swarm-based concepts which include a mother ship that transports a fleet of smaller probes to a more distant star could help to mitigate this effect (see Figure 7).

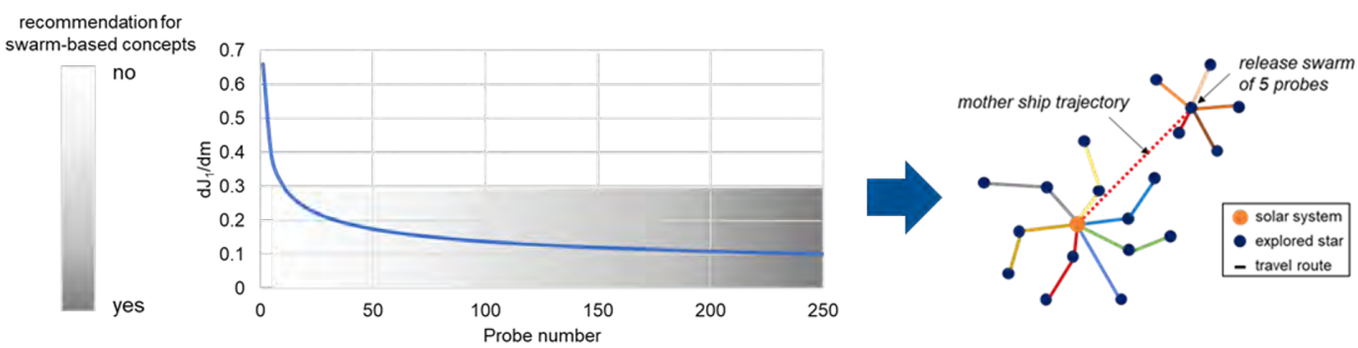

Figure 7: Left: Recommendation for swarm-based concepts based on qualitative analysis of the scaling law's first derivative (blue curve), right: Sketch of a possible mission which includes swarm-based concepts

References

Open access links given where available.

[1] J Lebert, " Optimal Strategies for Exploring Near-by Stars," München, 2021.
mediatum.ub.tum.de/doc/1613180/

[2] R L Forward, "Starwisp: An Ultra-Light Interstellar Probe," 1985.
interstellar-flight.ru/design/base_e/starwisp.pdf

[3] K L G Parkin, "The Breakthrough Starshot System Model," 2018,
Acta Astronautica Volume 152, November 2018, Pages 370-384.
parkinresearch.com/wp-content/uploads/2018/07/starshotmodel.pdf

[4] R Bjørk, "Exploring the Galaxy using space probes," 2007.
arxiv.org/abs/astro-ph/0701238

[5] D Cartin, "Exploration of the local solar neighborhood I: Fixed number of probes," 2013.
International Journal of Astrobiology , Volume 12 , Issue 4 , October 2013 , pp. 271 - 281
www.researchgate.net/profile/Daniel-Cartin-2/publication/238949645_Exploration_of_the_local_solar_neighborhood_I_Fixed_number_of_probes/links/53fc988e0cf2dca8ffff34cb/Exploration-of-the-local-solar-neighborhood-I-Fixed-number-of-probes.pdf

[6] ESA, "Gaia Archive," [Online]. Available: gea.esac.esa.int/archive/.

[7] L Lindegren *et al*, "Gaia Data Release 2 - The astrometric solution," 2018
Astronomy & Astrophysics, Volume 616, August 2018
www.aanda.org/component/article?access=doi&doi=10.1051/0004-6361/201832727

[8] H Bederina and M Hifi, "A Hybrid Multi-objective Evolutionary Algorithm for the Team Orienteering Problem," Barcelona, 2017.
2017 4th International Conference on Control, Decision and Information Technologies (CoDIT), 2017, pp. 0898-0903
ieeexplore.ieee.org/abstract/document/8102710 [no open access version found]

About The Author

Johannes Lebert has just completed a degree of Master of Science in Aerospace at the Technische Universität München (TUM). He also holds a Bachelor of Science in Mechanical Engineering (TUM) and was visiting student in the field of Aerospace Engineering at the Universitat Politècnica de València (UPV), Spain. He has worked at Starburst Aerospace (a global aerospace & defense startup accelerator and strategic advisory practice headquartered in Los Angeles, California), AMDC GmbH (a consultancy with focus on defense located in Munich) and Mainsite Technologies GmbH (an industry engineering company near Frankfurt/Main).

His thesis Optimal Strategies for Exploring Near-by Stars, the basis for this piece, is presented in support of his masters degree at TUM. His thesis supervisors were Andreas Hein (Initiative for Interstellar Studies) and Martin Dziura (Institute of Astronautics, TUM).

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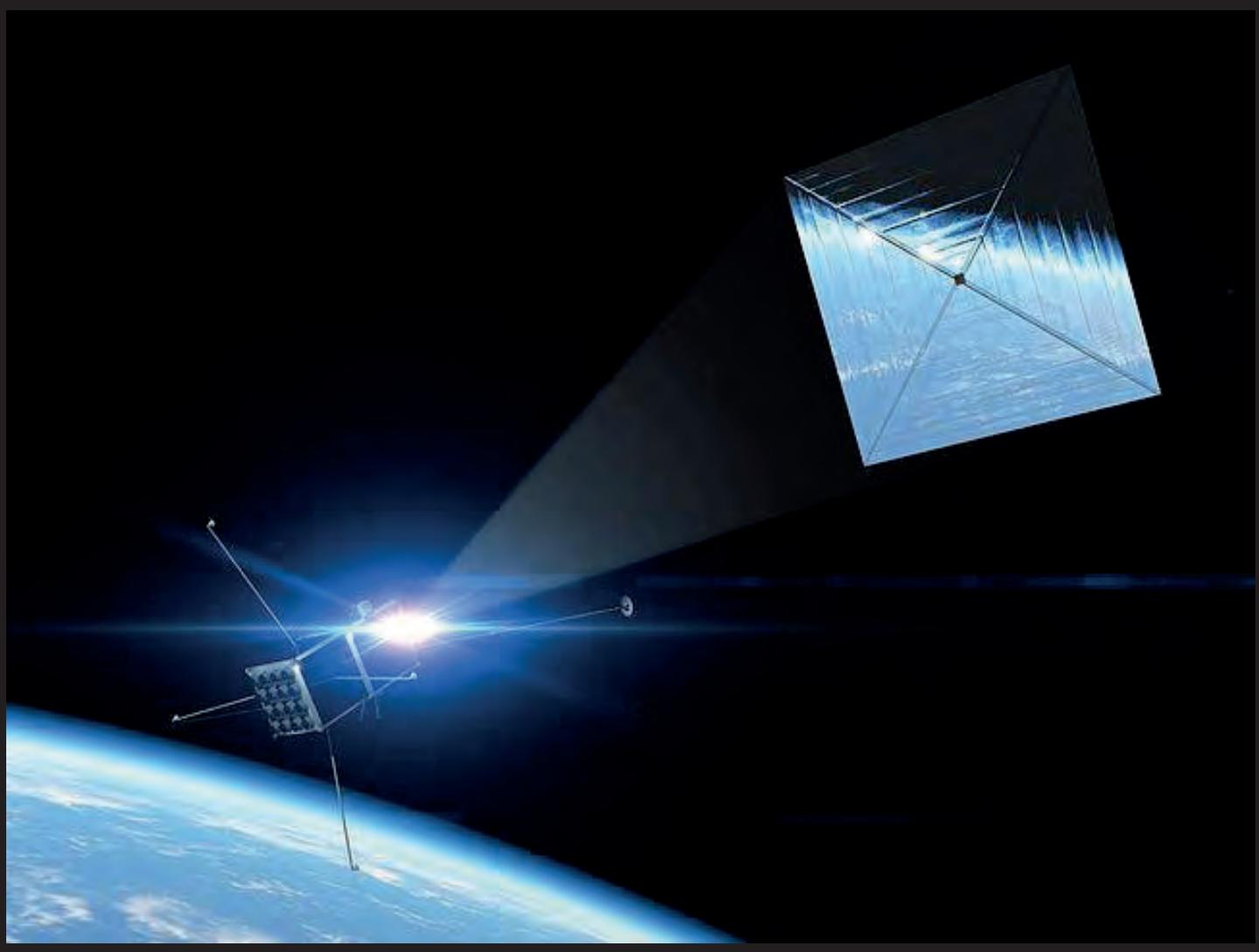

The Initiative for Interstellar Studies (i4is) has launched a membership scheme intended to build an active community of space enthusiasts whose sights are set firmly on the stars. We are an interstellar advocacy organisation which:

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Interstellar News

John I Davies reports on recent developments in interstellar studies

A Dyson Sphere around a black hole?

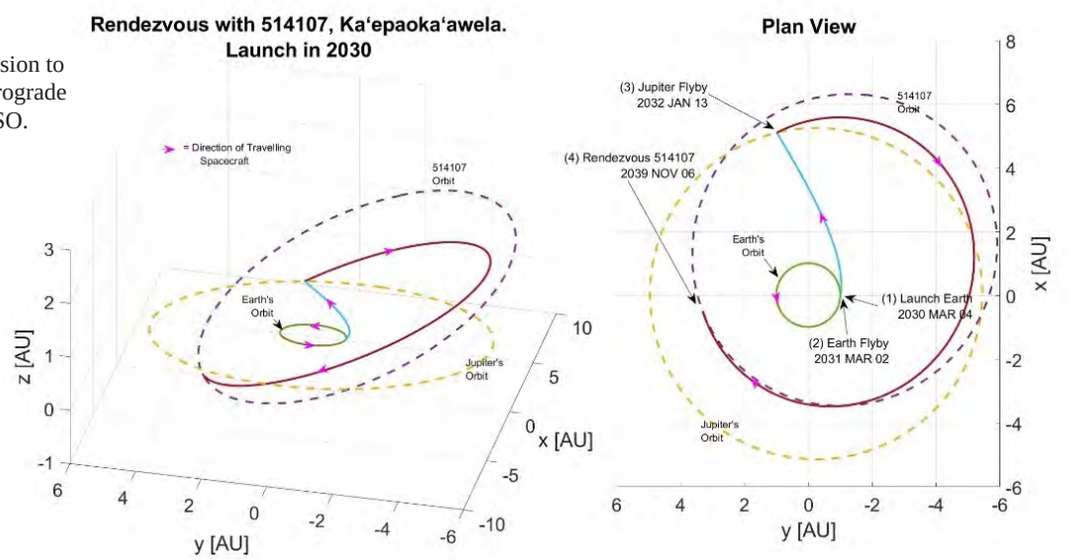
Principium readers are likely to be familiar with Freeman Dyson's concept of a sphere around a star capturing all of its radiant energy [1]. Researchers in Taiwan, UK and Turkey have been investigating the feasibility of a black hole as an alternative energy source [2]. The possible thermodynamics is complex. A black hole may be "colder" than the cosmic microwave background (CMB - the radiation remaining from the Big Bang) and the heat flow could thus be inwards or outwards depending on the temperature of the CMB (now or in the earlier universe) and the black hole. But a heat engine works as long as there is a temperature difference. Energy sources might also include -

- Hawking radiation which, in theory, causes a black hole to "boil away" its mass.
- Radiation from the accretion of matter falling into the black hole.
- Radiation from the corona (like our solar corona) of plasma around the black hole.
- Plasma jets from the axes of rotation of the black hole.

The paper considers which variants of a Dyson sphere might be used by developing civilisations and the characteristic radiation we might expect this to detect. They conclude that, in terms of usable energy "a black hole can be a promising source and is more efficient than harvesting from a main sequence star".

Interstellar Now! - in Advances in Space Research

In our November issue P31 last year we announced a preprint *Interstellar Now! Missions to and Sample Returns from Nearby Interstellar Objects*. The paper *Interstellar Now! Missions to Explore Nearby Interstellar Objects* has now been published in Advances in Space Research [3]. Adam Hibberd gave a summary of the work in *Interstellar Objects and Sample Returns* in that November issue.
The paper makes the case for in situ exploration of Interstellar Objects (ISOs) to allow the direct determination of both their structure and their chemical and isotopic composition, enabling an entirely new way of studying small bodies from outside our solar system - describing flyby, rendezvous and sample return missions.



Possible rendezvous mission to Ka'epaoka'awela - a retrograde object and possibly an ISO.

Launch 2030.

Credit: Hein *et al*

[1] *Search for Artificial Stellar Sources of Infrared Radiation*, Freeman Dyson, 1960 fermatslibrary.com/s/search-for-artificial-stellar-sources-of-infrared-radiation.

See also Dmitry Novoseltsev *Engineering New Worlds: Creating the Future - Part 3* Principium 18 August 2017.

[2] *A dyson sphere around a black hole,* Tiger Yu-Yang Hsiao *et al*, Monthly Notices of the Royal Astronomical Society July 2021 academic.oup.com/mnras/advance-article-abstract/doi/10.1093/mnras/stab1832/6312510. Open publication at arxiv.org/abs/2106.15181

[3] *Interstellar Now! Missions to Explore Nearby Interstellar Objects*, Andreas M Hein (Université Paris-Saclay) T Marshall Eubanks (Space Initiatives Inc) Manasvi Lingam (Florida Institute of Technology) Adam Hibberd (i4is) Dan Fries (University of Texas at Austin) Jean Schneider (Observatoire de Paris) Pierre Kervella (Observatoire de Paris) Robert Kennedy (i4is) Nikolaos Perakis (Space Initiatives Inc) Bernd Dachwald (FH Aachen University of Applied Sciences), Advances in Space Research, © 2021 COSPAR. Published by Elsevier BV. www.sciencedirect.com/science/article/abs/pii/S027311772100538X?via%3Dihub#ab005

Solar sail to an ISO

In *A Fast Response Mission to Rendezvous with an Interstellar Object* [1] Darren Garber and colleagues propose a solar sail-propelled small satellite using ideas from a proposed technology demonstrator of a mission to reach the focal region of the solar gravitational lens line - which begins at 550 astronomical units (AU) - note Voyager 1 and 2 are at 152 and 126 AU - so this is a demanding prototype. The authors anticipate that a solar sail in a close holding orbit around the Sun would be able to "launch on warning" when an ISO orbit is confirmed. This rapid response would allow an intercept within 10 AU from the Sun. A small vehicle could be reproduced so that many successive intercepts were possible.

Gigawatt laser arrays and the atmosphere

Numerical simulation "pipeline"

Inputs: Directed energy phased array (DEPA) and atmospheric models

Note the "beacon" signal which the target produces, illuminating the DEPA after being perturbed by the atmosphere.

Credit: Hettel *et al*, UCSB and MIT

Gigawatt laser arrays and the atmosphere

A team at University of California Santa Barbara (UCSB) have been studying the propagation of laser light from the sort of large Earth-based laser arrays implied by the plans of Breakthrough Starshot. Their paper *Beam propagation simulation of phased laser arrays with atmospheric perturbations* [2] demonstrates that a large array at a high altitude site can produce a stable diffraction-limited spot on a space-based target for Fried length > 10 cm [3] at angles up to 60 degrees from the zenith depending on atmospheric conditions. The paper looks, to this optically naive reader, like a good overview of the maths and simulation requirements for large terrestrial laser arrays. Most of the problems addressed would disappear for a space based system though the authors says "cost and accessibility make it far more practical to start with ground based systems". The paper assumes the target is stationary so it would not necessarily apply to fast moving targets such as interstellar sailcraft. The method used is a numerical simulation "pipeline" which corresponds to the path from source to target.

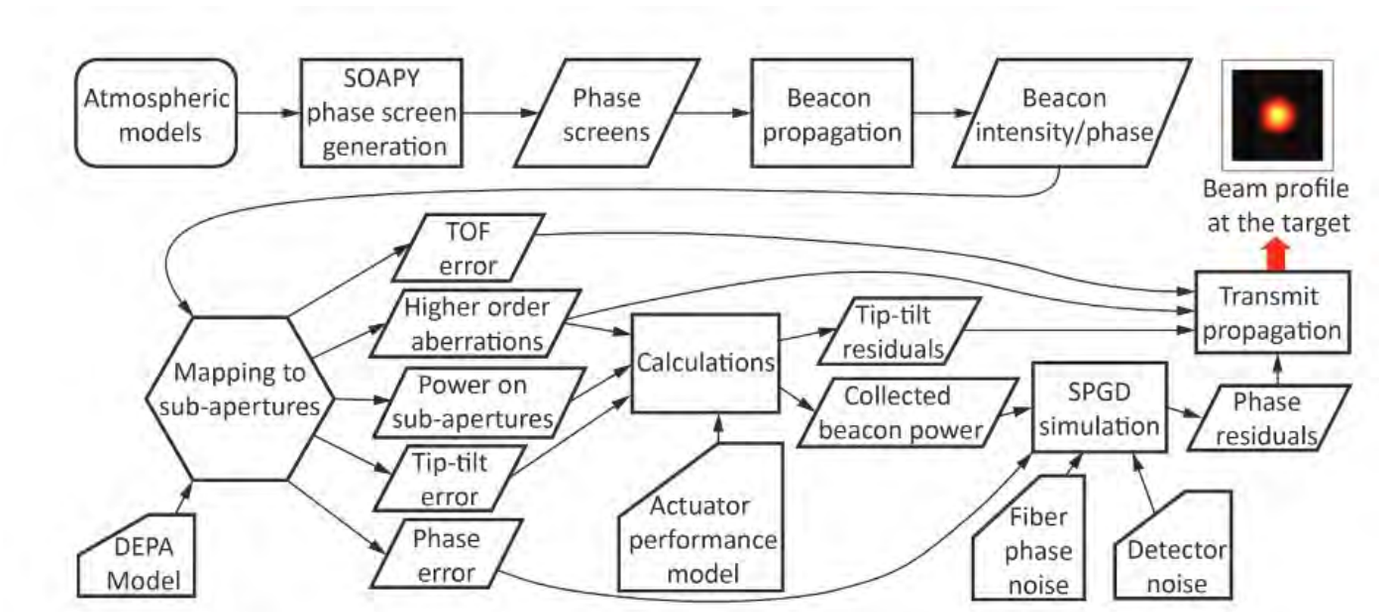


Fig. 2. Simulation flow diagram including the various processes and noise inputs.

[1] *A Fast Response Mission to Rendezvous with an Interstellar Object* Darren Garber (Xplore Inc), Louis D Friedman (The Planetary Society), Artur Davoyan (UCLA), Slava G Turyshev (JPL), Nahum Melamed (Aerospace Corporation), John McVey (JPL) Todd F Sheerin (Aerospace Corporation) arxiv.org/abs/2106.14319

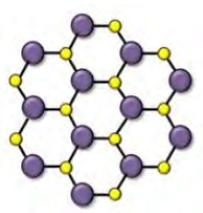
[2] *Beam propagation simulation of phased laser arrays with atmospheric perturbations*, Will Hettel, Peter Meinhold, Jonathan Y Suen, Prashant Srinivasan, Peter Krogen, Allan Wirth, Philip Lubin (all UCSB apart from Allan Wirth, MIT) arxiv.org/abs/2107.00568,

[3] The Fried length or atmospheric coherence length approximates to the size of the atmospheric turbulence cell through which light passes (see L10: Adaptive Optics slittlefair.staff.shef.ac.uk/teaching/phy217/lectures/telescopes/L10/index.html).

Optimise acceleration & thermal for lightsails

Gigawatt laser banks can deliver the acceleration to reach substantial fractions of light speed but nothing in physics and engineering is 100% efficient and the result in this case, as usual, is unwanted heating. In *Thermo-accelerative optimization of relativistic lightsails,* Brewer *et al* [1], researchers at UCLA and the University of Pennsylvania demonstrate optimisation of both acceleration and thermal performance using a sail with multilayer connected photonic crystal of layered 2H-phase Molybdenum Disulphide and crystalline Silicon Nitride. They point out that, as the sail accelerates, the received laser light is red-shifted in the sail's frame of reference - it is receding just like most of the galaxies. The requirement for near 100% reflective efficiency across the whole red-shifted frequency band is demanding and the sail must also radiate the waste heat which is generated, tolerate the stress implied by the force of the beam and remain stable in the beam. The paper references the substantial related work in this area, much of it funded by Breakthrough Starshot. The sail materials suggested in the paper are-

- 2H-phase Molybdenum Disulphide MoS_2 is a semiconductor with a planar hexagonal structure (though the compound can also be found in lubricants).
- Silicon nitride Si_3N_4 has a three dimensional molecular structure.

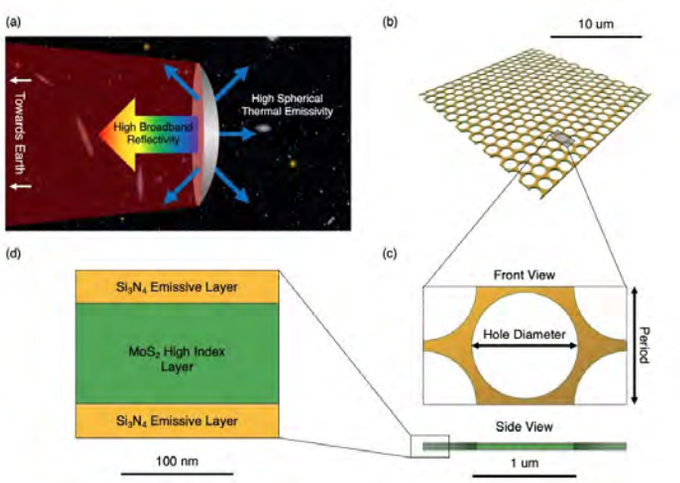


MoS_2 molecules

The paper proposes two layers of Si_3N_4 sandwiching a layer of MoS_2 in a honeycomb-like lattice structure. In the required bands MoS_2 has a high refractive index, yielding reflectivity and unmeasurably low absorption. Si_3N_4 is chosen largely for its emissivity yielding the required ability to radiate waste heat. The lattice structure provides good strength to mass properties while retaining the required thermal and optical properties. As in other contexts the holes in the structure mitigate any crack propagation. The full analysis uses basic parameters from Starshot - 10 Gw/m², 1.2 μm laser wavelength and 1 gram payload mass.

Cold fusion rises again!

Some readers may recall the cold fusion bubble which burst in 1989. Martin Fleischmann and Stanley Pons suggested that fusion might be achievable at "room temperature" but their reported experiment could not be replicated. The possibility remains very attractive and IEEE Spectrum published, *Whether Cold Fusion or Low-Energy Nuclear Reactions, U.S. Navy Researchers Reopen Case,* in March this year (spectrum.ieee.org/tech-talk/energy/nuclear/cold-fusion-or-low-energy-nuclear-reactions-us-navy-researchers-reopen-case). They reported work in progress at the US Naval Surface Warfare Center, Indian Head Division, with other US government labs including the National Institute of Standards and Technology (NIST). The Spectrum reports that the team expect results, positive or negative, by the end of the year.

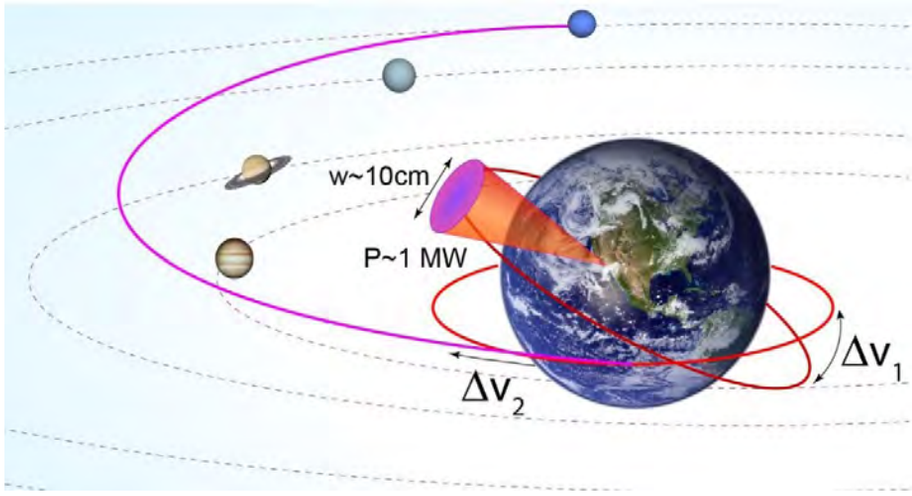


Starshot sail design.
(a) Schematic diagram demonstrating relevant optical considerations for accelerating lightsail
(b) Section of sail, approximate hole-fill ratio of 76%
(c) Front and side view of single design period.
(d) Enlarged view of multilayer structure.Yellow regions represent Si_3N_4 while green regions represents MoS_2.
Credit (image and caption): Brewer *et al.*

[1] *Thermo-accelerative optimization of relativistic lightsails* John Brewer (UCLA) and Matthew F Campbell, Pawan Kumar, Sachin Kulkarni, Deep Jariwala, Igor Bargatin, Aaswath P Raman (all University of Pennsylvania), arxiv.org/abs/2106.03558

Laser sails for manoeuvring and solar system/ISM missions

In *Light-Sail Photonic Design for Fast-Transit Earth Orbital Maneuvering and Interplanetary Flight* arxiv.org/abs/2107.09121 Ho-Ting Tung and Artur Davoyan of UCLA suggest the use of laser-driven light-sailing for agile Earth orbital maneuvering and for fast-transit exploration of the solar system and interstellar medium. They describe lightweight (1 g – 100 g & ~10 cm) spacecraft propelled by lasers to orbits that are beyond the reach of current systems, comparing their findings with previous interstellar laser propulsion studies.



Schematic illustration of laser sailing for Earth orbital maneuvering and for fast transit interplanetary missions. Here a laser beam with ~1MW power propels a wafer-scale (~10 cm) light-sail. Powered by laser propulsion such a spacecraft can perform highly energetic orbital maneuvers that require very large velocity gain, Δv. Two examples (not to scale) of such maneuvers are schematically shown: inclination change at low Earth orbit and fast transit to Neptune and beyond.

Credit (caption and image) ; Ho-Ting Tung and Artur Davoyan

AIAA Propulsion and Energy 2021 Forum

A number of papers of interstellar significance have been announced for the AIAA Propulsion and Energy 2021 Forum August 9-11, 2021[1]. Here are the ones we spotted so far -

Continued development of the pulsed magnetic nozzle for the Pulsed Fission Fusion (PuFF) vehicle, Schilling *et al*, arc.aiaa.org/doi/10.2514/6.2021-3608 "High thrust, high specific impulse propulsion systems, such as PuFF (Pulsed Fission-Fusion) offer a new paradigm of speed and safety when exploring the solar system. To realize these possibilities, PuFF needs a mature magnetic nozzle design." See *The State of the Art in Fusion Propulsion,* Kevin Schillo, in Principium 26 August 2019 for an overview of PuFF technology.

Experimental Validation Testing of a Paired-Particle Matter/Anti-Matter Propulsion System, with Proposed Project Management, Mark Pickrell, arc.aiaa.org/doi/10.2514/6.2021-3251 "This paper outlines experimental steps and proposed project management for experimental validation of the feasibility of a paired-particle matter/anti-matter propulsion system. The purpose of the experiments is to determine the practical feasibility of a matter/anti-matter propulsion system for generating relativistic speeds in space."

Numerical Optimization of Warp Drive Geometries, Helmerich *et al*, arc.aiaa.org/doi/10.2514/6.2021-3596 "Warp drive research has primarily focused on the evaluation of analytic solutions to Einstein's field equations. In this paper, we take a different approach and compute the stress-energy-momentum tensor numerically using Einstein's field equations for a given space-time metric."

Crilly (Green Bank) on interstellar communications

William J Crilly Jr, Green Bank Observatory, West Virginia, USA, has published two papers on interstellar communications -

An interstellar communication method: system design and observations, arxiv.org/abs/2105.03727 "A system of synchronized radio telescopes is utilized to search for hypothetical wide bandwidth interstellar communication signals. Transmitted signals are hypothesized to have characteristics that enable high channel capacity and minimally low energy per information bit, while containing energy-efficient signal elements that are readily discoverable, distinct from random noise."

Radio interference reduction in interstellar communications: methods and observations, arxiv.org/abs/2106.10168 "The discovery of interstellar communication signals is complicated by the presence of radio interference. Consequently, interstellar communication signals are hypothesized to have properties that favor discovery in high levels of local planetary radio interference. A hypothesized type of interstellar signal, delta-t delta-f polarized pulse pairs, has properties that are similar to infrequent elements of random noise, while dissimilar from many types of known radio interference."

[1] American Institute of Aeronautics and Astronautics (AIAA) Propulsion and Energy 2021 Forum, August 9-11, 2021, Virtual Event arc.aiaa.org/doi/book/10.2514/MPEF21

i4is Human Exploration course delivered

As we announced in our last issue P33, May 2021, i4is delivered the first running of the course, *Human exploration of the far solar system and on to the stars*, for the Limitless Space Institute, 26-30 July 2021. We hope and believe that this will advance both our subject and the reputation of the Initiative and Institute for Interstellar Studies as one of the leading organisations beating a path for humanity to the stars. We will be reporting in detail on this in our next issue, P35 November 2021.

Frequency of Life in the Universe

Karl-Florian Platt, Department of Media and Social Science, Fresenius University of Applied Sciences, Berlin, has reviewed some modifications to the Drake equation, *Drake-like Calculations for the Frequency of Life in the Universe*, in the journal Philosophies, Vol 6, Issue 2 (www.mdpi.com/2409-9287/6/2/49). He summarises the history (and pre-history) of Drake's 1961 formula including the work of the "Order of the Dolphin" who he believes to have been behind the original version. He mentions some objections to Drake and suggests a modified Drake Equation as motivation to pursue astrobiology using an estimate of the number of life-carrying planets rather than the number of communicating civilisations. Drake was, of course, essentially interested in SETI rather than the existence of life, astrobiology. He also suggests that stellar type is a factor since this affects biological evolution.

Embryo space colonisation 'considered harmful'

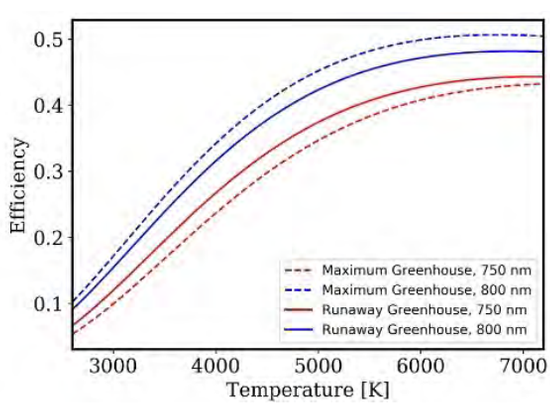
A recent paper in the International Journal of Astrobiology (pay-walled publication and no open publication found) examines the idea that humanity will send cryopreserved embryos on a mission to an exoplanet to forestall the extinction of our species. In *Humanity should colonize space in order to survive but not with embryo space colonization*, [1] Konrad Szocik suggests that, technology permitting, though this is an interesting, very rational and quite effective way to guarantee the survival of the human species it "departs from what should be understood by the concept of saving humanity through space colonization" and that there are "ethical controversies that make this concept perhaps unsuitable for implementation" by contrast to "the concept of saving humanity by sending adult living persons on space missions".

Are Earth-like biospheres on other planets rare?

A news item from the Royal Astronomical Society (RAS), *Earth-like biospheres on other planets may be rare* [2] announces a paper in Monthly Notices of the Royal Astronomical Society. The paper *Efficiency of the oxygenic photosynthesis on Earth-like planets in the habitable zone*, arxiv.org/abs/2104.01425, by Giovanni Covone, Riccardo M Ienco, Luca Cacciapuoti and Laura Inno (Università di Napoli Federico II and Parthenope University of Naples) argues that, since oxygenic photosynthesis is the most important biochemical process in the Earth biosphere and thus likely on other habitable terrestrial planets, we should evaluate the possibility of oxygenic photosynthesis on exoplanets as a function of their spectral type and planet-star separation. They state that so far, we have not observed terrestrial planets comparable to Earth in terms of useful photon flux, exergy and exergetic efficiency [3]. But their conclusion mentions that -

- Kepler-442b receives a photosynthetically active radiation (PAR) photon flux slightly larger than necessary to sustain a large biosphere,
- Earth processes are often grossly energy-inefficient and could thus be out-performed elsewhere, and
- thus the estimated PAR could permit a biosphere comparable to Earth.

So their conclusion looks much less gloomy than implied by the RAS news headline.

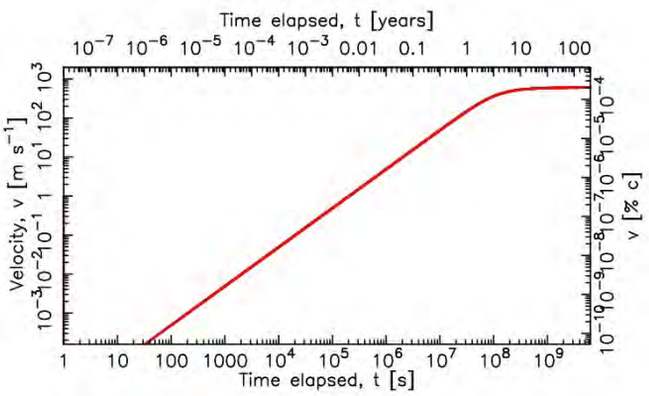


Exergetic efficiency versus the host star effective temperature for planets at the edges of the HZ for the two different PAR ranges
Credit (caption and image); Covone *et al*

[1] www.cambridge.org/core/journals/international-journal-of-astrobiology/article/abs/humanity-should-colonize-space-in-order-to-survive-but-not-with-embryo-space-colonization/474332A09E34142E77684A49B95A7684

[2] ras.ac.uk/news-and-press/research-highlights/earth-biospheres-other-planets-may-be-rare

[3] exergy is the thermodynamic limiting energy available when a system is brought into equilibrium.



Velocity of ‘Oumuamua based upon its observed acceleration - showing terminal velocity.
Credit: Stephen Curran

Peaceful Use of Lasers in Space

Given that laser sails are currently our most promising candidate for propulsion of interstellar probes the safe regulation of large laser arrays will be vital. A paper, *Initiative for the Peaceful Use of Lasers in Space* from Petr Bohacek of the Institute of Political Studies, Charles University, Prague, addresses this issue [1]. It reports on the Prague Laser SpaceApps Workshop 2019 in the Czech Republic, September 25-27 2019. This included laser and optics scientists from Russia, United States, Europe and Australia. The workshop identified three concrete follow-up steps -

- draft a declaration to inspire and motivate global scientific and diplomatic participation and put forward non-binding objectives and visions [2].
- establish scientific working groups to review the state of research, define main challenges and bottlenecks, and outline the discussion about solutions and steps forward.
- organise a series of international conferences on the *Peaceful Use of Lasers in Space* with adequate support and coordination from the United Nations, national governments, and scientific bodies.

This topic falls under the United Nations General Assembly (UNGA) Resolution 75/36, *Reducing space threats through norms, rules and principles of responsible behaviours*, 7 December 2020 [3].

Parent population of known ISOs

A recent paper, *Interstellar objects follow the collapse of molecular clouds*, asserts that the parent population of 1I/Oumuamua and 2I/Borisov, are abundant in the interstellar medium of the Milky Way [4]. It infers that a typical molecular cloud of 10 parsec (about 33 light years) diameter contains some 10^{18} ISOs at typical sizes ranging from hundreds of metres to tens of km. Using simulations of the collapse of molecular clouds containing ISOs toward the point where stars form, the authors conclude that ISOs are a relevant component of star formation.

Oumuamua not artificial (again)

In *‘Oumuamua as a light sail – evidence against artificial origins* (arxiv.org/abs/2105.09435) Dr Stephen Curran (Victoria University of Wellington, NZ) examines the non-gravitational acceleration of this ISO. He concludes that if radiation pressure is responsible for this acceleration then such an artificial solar sail cannot accelerate to considerable fractions of the speed of light and thus cannot be capable of rapid interstellar travel. He cites the technical challenges associated with the laser sources proposed by Breakthrough Starshot but his principal argument appears to be based on the inability of less powerful sources to overcome the problem of the decrease of accelerating force by the inverse square law as the sail accelerates much more slowly than proposed by Starshot. He observes that ‘Oumuamua, from known evidence, cannot have the extreme properties required for the proposed Starshot probe. He also cites sources ruling out cometary outgassing as the source of the non-gravitational acceleration of this ISO. He reaches no specific conclusion as to the cause of the acceleration and leaves open the possibility that ‘Oumuamua is simply a very poor solar sail and thus likely to be a natural object with unprecedented properties. This paper may thus provide further support for the idea of a mission to ‘Oumuamua to discover its nature - the objective of numerous papers published by the i4is Project Lyra team.

[1] lasers4space.com/wp-content/uploads/2021/05/Bohacek_PeacefulUseOfLasersInSpace.pdf

[2] *Declaration on the Peaceful Use of Lasers in Space* lasers4space.com/wp-content/uploads/2020/06/PULS-Declaration-eng-v2.4.4-1.pdf.

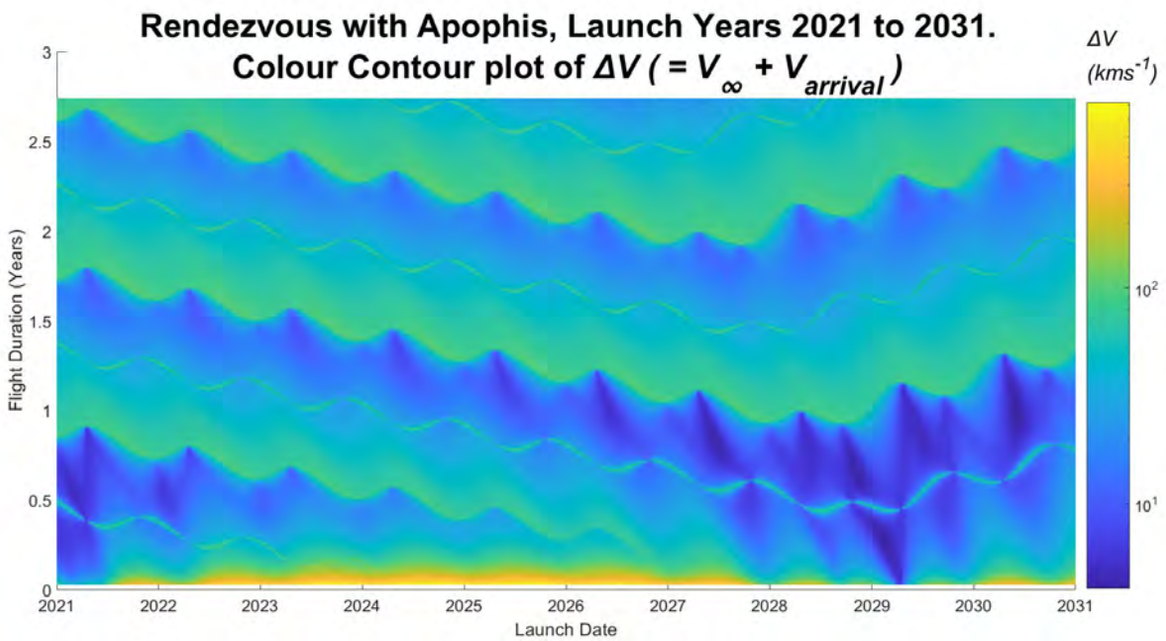
[3] UNGA A/RES/75/36 digitallibrary.un.org/record/3895440?ln=en

[4] *Interstellar objects follow the collapse of molecular clouds*, Susanne Pfalzner (Jülich Supercomputing Center, Germany), Dylan Paterson & Michele T Bannister (University of Canterbury, Christchurch, NZ) and Simon Portegies Zwart (Leiden Observatory, the Netherlands) arxiv.org/abs/2106.08580

Proposed rendezvous missions to asteroid Apophis

Two papers discuss missions to asteroid (99942) Apophis, a potentially hazardous asteroid. Though no danger is anticipated for at least 100 years this asteroid looks like a good opportunity to examine a near-Earth object. In *Apophis Rendezvous Mission for Scientific Investigation and Planetary Defense*, Moon (Seoul National University) *et al* [1] observed that Apophis will approach the Earth to come within the geostationary orbit in 2029 and suggest that launch windows in July 2026 and in January 2027 are the best opportunities for a rendezvous. Following up, Fumi Yoshida *et al* (Planetary Exploration Research Center, Chiba Institute of Technology, Japan), have published *Photometric observations of the potentially hazardous asteroid (99942) Apophis from Kawabe Cosmic Park* [2].

Our i4is colleague Adam Hibberd has developed rendezvous contours for missions to Apophis.



Rendezvous contours for missions to Apophis.
Credit: Adam Hibberd (personal communication).

Relativistic light sails need to billow

Maintaining the geometry of light sails is one of the major challenges for laser-propelled interstellar probes and indeed for all sailcraft. In *Relativistic light sails need to billow*, Matthew F Campbell (University of Pennsylvania) *et al* (arxiv.org/abs/2105.10849) argue that light sails that are rapidly accelerated to relativistic velocities by lasers must be significantly curved in order to reduce their mechanical stresses and avoid tears - and that when sufficient laser power is available, a sail's acceleration length decreases and its chip payload capacity increases as its curvature increases. They observe that this mirrors the behaviour of parachutes and nautical sails. They consider the sail's acceleration length, the photon pressure on it, and the equilibrium temperature attained as a result of imperfect reflection of photons and determine how these parameters scale in relation to fundamental design properties. They observe that photon pressures and sail temperatures increase inversely with the acceleration length, so that mechanical factors constrain feasible light sail designs and that the sail's reflectivity decreases as it becomes more curved (ie as its spherical radius of curvature decreases), suggesting a trade-off between the sail's mechanical integrity and its optical attributes.

[1] Presented at conference *Apophis T–9 Years: Knowledge Opportunities for the Science of Planetary Defense* : November 4–6, 2020 https://repository.hou.usra.edu/handle/20.500.11753/1760.

[2] Astronomical Society of Japan, July 2021, academic.oup.com/pasj/advance-article/doi/10.1093/pasj/psab072/6327221.

ET Technology - the Galileo Project

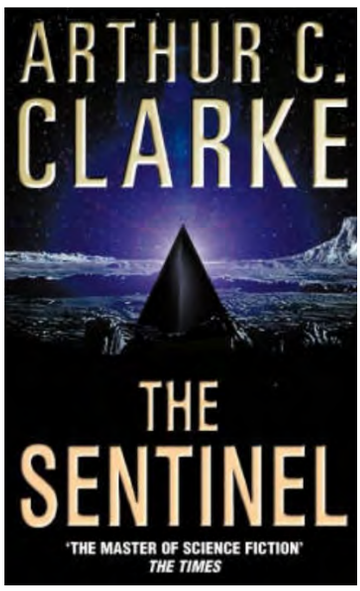
Professor Avi Loeb is not backing down in his contention that ET technologies are, or have been, in our Solar System. In *The Galileo Project: "Daring to Look Through New Telescopes - The Galileo Project for the Systematic Scientific Search for Evidence of Extraterrestrial Technological Artifacts"* (projects.iq.harvard.edu/galileo) he and his team declare that the scientific community "needs the determination to systematically, scientifically and transparently look for potential evidence of extraterrestrial technological equipment". They assert that their ground-based project is complementary to traditional SETI, in that it searches for physical objects rather than interstellar signals or technosignatures.

His team includes project co-founder Frank Laukien, president and CEO of Bruker Corporation (a major manufacturer of scientific and medical instrumentation), academics at Caltech, the universities of Princeton, Harvard, Bern, North Carolina at Chapel Hill, Chicago, California at Berkeley, Aberdeen and Cambridge,

The Galileo Project has set three major tasks -

- High-resolution, Multi-detector Images of Unidentified Aerial Phenomena (UAP), UFOs to the pop press.
- Find and research 'Oumuamua-like Interstellar Objects (ISOs) using existing and future astronomy.
- Find Potential Satellites from Extraterrestrial Technological Civilisation (ETC).

This is clearly a major addition to the search for ETI. If it yields a positive result then we will need to rethink not only the existence of ETI but its immediate importance for the whole of our species. The clear parallel is the story *The Sentinel* by Arthur C Clarke and film *2001: A Space Odyssey* by Clarke and Stanley Kubrick.



Cover of an anthology of stories by Arthur C Clarke with title from the story, The Sentinel. The was the first appearance of Clarke's idea of a monolith buried on the Moon, set by an ETI as an alarm to be triggered by human activity.

Credit: HarperCollins

Origins of Directed Panspermia

In *The History and Origins of Directed Panspermia* [1], Idan Ginsburg (Georgia State University) and Manasvi Lingam (Florida Institute of Technology), emphasise the long history of the idea of deliberate "seeding" of life throughout the universe. Early scholars were Francis Crick (the DNA Crick) and Leslie Orgel in 1973 but biologist J B S Haldane in 1954 suggested it as one possible origin of life on Earth and thought that a check of molecular chirality (left or right handedness) might suggest different ancestries, on and off Earth. This is a brief piece but it is peppered with references. A good starting point if you suspect that your great^{n} grandma might be from Mars or even Epsilon Eridani!

IRG 7th Interstellar Symposium, Tucson - next month

The Symposium will be in Tucson, Arizona, September 25-27, 2021 (with pre-symposium seminars on Friday 24 September). Details at irg.space/irg-2021/. Sign up at www.eventbrite.com/e/7th-interstellar-symposium-registration-148839060637 and note that, for those of us who can't make it to Tucson either for virus, cost or calendar conflict reasons, it is also being streamed online. Just $50 to register and participate by Zoom. All the talks will be available and you will be able to ask questions via online chat. And, of course, we'll be reporting in our next issue.

Topics (irg.space/irg-2021-abstracts-accordion/) include much on propulsion of course but also on aspects of SETI, cryopreservation, communications, ISRU and synthetic biology. Speakers include Pete Worden, David Messerschmitt, Ken Roy, Marc Millis, James Benford, Louis Friedman, Jeffrey Greason, Sonny White, Andrew Higgins, Al Jackson, Geoff Landis, Philip Mauskopf and Avi Loeb.

[1] in Research Notes of the AAS June 2021 iopscience.iop.org/article/10.3847/2515-5172/ac0f5a

News Feature: Another review of Avi Loeb's *Extraterrestrial*

Sky at Night presenter Professor Chris Lintott weighs in on Avi Loeb's controversial book about 1I/'Oumuamua

Patrick Mahon

In the last issue of *Principium*, we reviewed *Extraterrestrial*, Professor Avi Loeb's book about our first interstellar visitor, 'Oumuamua [1, 2]. There, Loeb puts forth his radical view that the simplest hypothesis to explain various anomalies in the observational data that was gathered in 2017 is that 'Oumuamua is some sort of ultrathin solar sail, and thus likely evidence of the existence of an intelligent alien civilisation elsewhere in our galaxy, since a natural origin for an object of this nature is extremely difficult to conceive.

Loeb's book has recently been reviewed in the prestigious London Review of Books [3] by the co-host of the longest-running popular astronomy programme on TV, *The Sky at Night*. Chris Lintott is Professor of Astrophysics and Citizen Science Lead at the University of Oxford. He may also be known to some *Principium* readers due to his involvement in running several citizen science projects, including *Planet Hunters*, which employs the help of interested members of the public to identify potential exoplanets by interrogating data from NASA's TESS (Transiting Exoplanet Survey Satellite) mission [4].

BBC Sky at Night
First broadcast in 1957
www.bbc.co.uk/programmes/b006mk7h

Lintott takes a pretty conventional view of the controversy, somewhat akin to that of Professor Alan Aylward, who critiqued Loeb's side of the 'Oumuamua debate for us two issues ago [5]. Lintott is similarly unconvinced by Loeb's arguments, sees greater validity in the alternative natural explanations of 'Oumuamua's various anomalies, and reminds readers of previous instances when highly unusual astronomical discoveries have turned out to have a purely astrophysical explanation – the periodicity of pulsars, as discovered by Dame Jocelyn Bell Burnell in 1967, being a good example.

If you haven't already made up your mind about Avi Loeb and his views on 'Oumuamua, Lintott's review in the LRB may be worth reading to gain another perspective.

References:

[1] Avi Loeb, *Extraterrestrial: The First Sign of Intelligent Life Beyond Earth*, John Murray, 2021.

[2] Patrick Mahon, review of Loeb's *Extraterrestrial*, Principium issue 33, May 2021, pp.34-37.

[3] Chris Lintott, 'Flying Pancakes from Space', the London Review of Books, Vol. 43, No. 11, 3 June 2021. Available online at www.lrb.co.uk/the-paper/v43/n11/chris-lintott/flying-pancakes-from-space.

[4] Details of the *Planet Hunters* citizen science project can be found at www.zooniverse.org/projects/nora-dot-eisner/planet-hunters-tess.

[5] Alan Aylward, *An Interstellar Visitor: sorting the fact from the speculation*, Principium issue 32, February 2021, pp.53-59.

News Feature: The Journals

John I Davies

Principium has been logging interstellar papers published in the Journal of the British Interplanetary Society (JBIS) for some years. In this issue we also log interstellar papers in Acta Astronautica (ActaA), the commercial journal published by Elsevier, with the endorsement of the International Academy of Astronautics. On this first occasion we have aimed to capture ActaA papers in the current year so far. Subsequent Principium issues will add relevant papers published in later issues of ActaA.

Title (open publication)	Author	Affiliation
Précis/Highlights		
JBIS 74.6 Jun 2021	**General Issue**	
Terraforming the Dwarf Planet: Interconnected and growable Ceres megasatellite world (https://arxiv.org/abs/2011.07487)	Pekka Janhunen	Finnish Meteorological Institute
A megasatellite settlement built from Ceres materials in high Ceres orbit, local nitrogen for an earthlike atmosphere, 1 g artificial gravity spinning habitats attached to a disk-shaped megasatellite frame by passively safe magnetic bearings, habitats illuminated by concentrated sunlight from planar and parabolic mirrors. Mass per person is 10^7 kg mostly radiation shield and soil lifted from Ceres by space elevator exploiting its fast rotation. The result would be a long-term sustainable world with propellantless intra-settlement travel.		
Space Colonies: An Alternative to the Globus Cylinder (no open publication)	Mark Hempsell	Hempsell Astronautics Ltd
Globus argues for a cylinder with a height 1.3 times the floor radius as optimum overall shape for a large spinning space habitat thus minimising overall wall area, maximising floor area while maintaining an inertia ratio compatible with stable spin. We look at the impact of using a roof to create a hollow cylinder, reducing the pressurised volume for a given usable floor area and find structural mass differences are small and secondary factors would have a larger influence. So selection would be based on saving in mass of atmosphere and aesthetic of overhead sky.		

The Journal of the British Interplanetary Society uses a distinctive red design for interstellar issues.

JBIS 74.7 Jul 2021	**General Interstellar Issue**	
Of Aliens and Exoplanets - Why the search for life, probably, requires the search for water (https://arxiv.org/abs/2104.01683)	Darius Modirrousta-Galian & Giovanni Maddalena	Osservatorio Astronomico di Palermo & University of Edinburgh
It is not currently possible to create a living organism ab initio, how biological organisms form from non-living matter is unknown. So some researchers have taken water out of their models and opted for more exotic approaches. Such assumptions have strong implications for astronomical observations and future space exploration. By breaking down water properties to the physical, chemical and biological level it is demonstrated to be the most adequate medium for the formation of life.		
Minimal Crew and Human Evolution in Multi-Generational Interstellar Travel - based on population genetics (no open publication)	Sano Satoshi	Japan Aerospace Exploration Agency
Defining crew size previously published computations provided critical crew numbers considering inbreeding and infertility, but not including population genetics parameters such as mutation and genetic drift but spaceship capacity is equally important as initial crew size. Presenting a Monte Carlo code, EVOLVE, to estimate critical crew size, spaceship capacity, including genetic parameters. Showing that a crew of a few hundred people can reach the destination without facing extinction but a genetically healthy crew requires minimum crew size of 1,900-2,000. Also estimating possibility of human evolution during travel, possibly affecting spaceship design.		
Furthering a Comprehensive Seti Bibliography (https://arxiv.org/abs/2107.02887)	Julia LaFond, Jason T Wright & Macy J Huston	Pennsylvania State University
Reyes & Wright 2019 used NASA Astrophysics Data System (ADS) to initiate a comprehensive public SETI bibliography but updates have been incomplete. In preparation for a recent update, the scope of the library was revised and reexamined to include social sciences and commensal SETI. A curated library of false positive results is now concurrently maintained to facilitate their exclusion from future searches. A search query and workflow was developed which will enable efficient, consistent updates of the SETI library by future curators.		
The Drake Equation at 60: reconsidered and abandoned (https://arxiv.org/abs/2105.03984)	John Gertz	Zorro Productions, Berkeley, CA
Each of the individual factors of the Drake Equation is considered and each either abandoned or redefined. Finally reduced to a single new factor, f_d , the fraction of technological life that is detectable by any means. But neither the Drake Equation, nor its replacement, can solve for N. Only SETI and, ultimately, alien contact can result in the determination of N.		
Anomalous Stellar Acceleration: causes and consequences (no open publication)	Roman Ya Kezerashvili, Gregory L Matloff & Kelvin F Long	New York City College of Technology & Stellar Engines Ltd, UK
Analysis of the first data release from the ESA Gaia space observatory in 2018 yielded surprising results - most stars in our galactic vicinity are considerably older that our Sun and stars apparently accelerate in galactic revolution by ~1 km/s per billion years. Here some possible modes of stellar acceleration are suggested, discussed and evaluated - unidirectional stellar electromagnetic flux, accelerated stellar winds, galactic cannibalism, coronal mass ejections, unidirectional stellar neutrino flux, and thermal nuclear fusion of stellar winds. The accelerated unidirectional stellar wind and the unidirectional stellar neutrino jet in conjunction with the unidirectional photon jet ejected from the star and non-isotropic stellar wind can yield the stellar linear momentum change required. Some of these acceleration mechanisms may provide evidence of the technosignatures of advanced galactic civilizations.		

Acta Astronautica		
Near-term self-replicating probes - A concept design (arxiv.org/abs/2005.12303)	Olivia Borgue, Andreas M Hein	i4is
▪ Self-replicating probes may enable exponentially accelerating space exploration ▪ We present a concept for a near-term self-replicating probe ▪ At least 70% of its dry mass can be replicated ▪ Operations would be limited to the inner solar system ▪ A technology roadmap for achieving full replication and interstellar exploration		
Exploration of trans-Neptunian objects using the Direct Fusion Drive (arxiv.org/abs/2009.12633)	Marco Gajeria, Roman Ya Kezerashvili	Politecnico di Torino, NYC College of Technology
▪ The Direct Fusion Drive is a revolutionary space propulsion system. ▪ The Direct Fusion Drive is based on the D^3He nuclear fusion reaction. ▪ Fast rendezvous missions to trans-Neptunian objects are analyzed. ▪ The Direct Fusion Drive is a first practical approach to interstellar travel. ▪ Several scenarios to study the heliosphere up to 125 AU are presented.		
A joint mind consideration of the Drake equation in the search for extraterrestrial intelligence (no open publication)	Leslie M Golden	University of Illinois, Chicago
A Monte Carlo analysis to determine the most likely value of the six non-longevity factors (based on random variables and estimates from six studies) in the Drake equation. Results in moderately close agreement with the estimate by both Frank Drake and the Cyclops report.		
Strategies and advice for the Search for Extraterrestrial Intelligence (arxiv.org/abs/2107.07283)	Jason T Wright	Pennsylvania State University
▪ Overview of observational strategies for SETI. ▪ Rough map of the landscape of possible technosignatures. ▪ Discussion of the importance of and strategies for placing upper limits on technosignatures. ▪ Recommendations for those seeking to enter the field.		
ESA F-Class Comet Interceptor: Trajectory design to intercept a yet-to-be-discovered comet (arxiv.org/abs/2107.12999)	Joan PauSánchez *et al*	Cranfield University, UK
▪ Comet-I mission aims to explore a Long Period Comet; ideally, dynamically new. ▪ Such a target will remain unidentified, possibly, even after launch. ▪ The paper analyses the orbital space that will be accessible for Comet-I S/C. ▪ Chemical, electric and hybrid propulsion systems are modelled in patched-conic. ▪ A Monte Carlo analysis shows a 95–99% of completing the mission within 6 years.		
Experimental investigation of Mach-Effect thrusters on torsion balances ([2])	Maxime Monette, Matthias Kößling, Martin Tajmar	Technische Universität Dresden
▪ Claim on Mach-Effect propellantless propulsion scheme identified as vibration artefact. ▪ Investigation of material- and electronics-related setup issues. ▪ 1D balance model and simulations of conditions that lead to false thrust signals.		
Metalaw – What is it good for? (no open publication)	Michael Bohlander	Durham Law School, UK
Aims to critique the intellectual foundations of the metalaw debate about relations with ETI - avoiding anthropocentrism in deontology/Kant's Categorical Imperative, considering diverse scenarios of contact, recognising the expected realpolitik environment.		

[1] 2021 editions - search - https://www.sciencedirect.com/search?qs=interstellar&pub=Acta%20Astronautica&cid=271447&date=2021&years=2021&lastSelectedFacet=years

[2] https://www.researchgate.net/profile/Martin-Tajmar/publication/349845653_Experimental_investigation_of_Mach-Effect_thrusters_on_torsion_balances/links/6049ddfb45851543166ba416/Experimental-investigation-of-Mach-Effect-thrusters-on-torsion-balances.pdf

72nd International Astronautical Congress 2021
The Interstellar Papers

John I Davies

This year the International Astronautical Federation will once more hold the International Astronautical Congress in a selected geographical location, this year in Dubai. At the time of writing it is not clear to what extent the proceedings will be available remotely but precedent suggests that registered attendees will have access to videos of presentations, presentation material and full text of papers. Registration is available at iac2021.org/registration. The catalogue of all technical sessions is at - iafastro.directory/iac/browse/IAC-21/. In this report we attempt to list all the items currently announced 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.

You will find -

■Code & link - the unique IAC code and a link to the Abstract

■Paper title, Speaker, institutional Affiliation and Country

■A brief summary based on the Abstract - credit IAF and authors, errors and omissions my own!

Please contact john.davies@i4is.org if you have comments, find discrepancies or have additional items to suggest.

Session: IAF/IAA SPACE LIFE SCIENCES SYMPOSIUM - Astrobiology and Exploration

iafastro.directory/iac/browse/IAC-21/A1/6/

Code & link	Paper title	Speaker	Affiliation	Country
A1,6,1,x63282 iafastro.directory/iac/paper/id/63282/abstract-pdf/IAC-21,A1,6,1,x63282.brief.pdf	Extended Habitable Zone and biosignature detection of M-dwarf planets	Dr Amri Wandel	The Hebrew University of Jerusalem	Israel
Suggests that the Habitable Zone around M-stars is significantly wider than previously thought and as M-dwarfs dominate planetary systems by number and their small masses and radii make their transiting planets comparatively easy to detect and characterise, in particular to look for bio-signatures.				

Session: IAF SPACE EXPLORATION SYMPOSIUM - Space Exploration Overview

iafastro.directory/iac/browse/IAC-21/A3/1/

Code & link	Paper title	Speaker	Affiliation	Country
A3,1,3,x65095 iafastro.directory/iac/paper/id/65095/abstract-pdf/IAC-21,A3,1,3,x65095.brief.pdf	Why Space Exploration Will Be Soon Unsustainable, Without a Serious Civilian Space Settlement Programme	Adriano V Autino	Space Renaissance International	Italy
Advocates of further space exploration should advocate space settlement. The differences between exploration and expansion analysed. The socio-economic rationale: if remain closed within the boundaries of our mother planet, the multiple crises that are already jeopardising our economy and culture will likely close the “launch window” sooner than what we could expect until a few years ago.				

Session: IAF SPACE EXPLORATION SYMPOSIUM - Mars Exploration – missions current and future

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Code & link	Paper title	Speaker	Affiliation	Country
A3,3A,10,x66846 iafastro.directory/iac/paper/id/66846/abstract-pdf/IAC-21,A3,3A,10,x66846.brief.pdf	Colonizing Mars: In-Situ Resource Utilization of the Martian Moons	Harshit Goel	University of Petroleum and Energy Studies	India
Futuristic case study of an exploration mission to the Martian Moons - and prospect of utilising minerals on Martian moons.				

Session: 50th IAA SYMPOSIUM ON THE SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE (SETI) – The Next Steps - SETI 1: SETI Science and Technology

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Code & link	Paper title	Speaker	Affiliation	Country
A4,1,1,x65248 iafastro.directory/iac/paper/id/65248/abstract-pdf/IAC-21,A4,1,1,x65248.brief.pdf	Breakthrough Listen: Green Bank Telescope Observations, Analysis, and Public Data	Dr Steve Croft	University California Berkeley	USA
Breakthrough Listen (BL) observes as primary user for around 1/5 of the available time on the Green Bank Telescope, to March 2021 almost 14 PB of archival data products. BL have 2 PB available in a publicly accessible archive with an open-source software suite enabling data into Python programs and software search for narrow-band Doppler drifting signals. Also current status of BL's observing program at GBT, the analysis pipeline, highlighted public datasets, collaborations with academia and industry, and some of the latest science results.				

Code & link	Paper title	Speaker	Affiliation	Country
A4,1,2,x65540 iafastro.directory/iac/paper/id/65540/abstract-pdf/IAC-21,A4,1,2,x65540.brief.pdf	Energy-intensive civilisations and their imprint on astronomical data	Prof Mike Garrett	University of Manchester	UK
A non-exhaustive description of some main anomalies astronomers are currently seeking. How long-baseline interferometry can follow-up observations of the Breakthrough Listen candidates. Astronomers need to broaden their horizons to new possibilities including on-biological forms of intelligence and consciousness.				

Code & link	Paper title	Speaker	Affiliation	Country
A4,1,3,x64350 iafastro.directory/iac/paper/id/64350/abstract-pdf/IAC-21,A4,1,3,x64350.brief.pdf	Interferometric SETI searches with the Breakthrough Listen initiative	Dr Cherry Ng	University of Toronto	Canada
Breakthrough Listen has partnered with the SETI Institute to develop commensal SETI search capabilities on some of the most sensitive radio interferometers, including the Allen Telescope Array (ATA), the Very Large Array (VLA) and MeerKAT - providing a larger field of view, maximizing the SETI survey speed. Presenting updates on these surveys and a refreshed outlook on SETI search using next generation telescope facilities.				

Code & link	Paper title	Speaker	Affiliation	Country
CA4,1,4,x65765 iafastro.directory/iac/paper/id/65765/abstract-pdf/IAC-21,A4,1,4,x65765.brief.pdf	The Breakthrough Listen search for intelligent life: machine learning and artificial intelligence approaches [ML & AI]	Ms Shirley Wang	Berkeley SETI Research Center	USA
The abundance of data generated by the BL program makes it infeasible to examine it with traditional methods. Recent work developing improved RF interference rejection and generic anomaly detectors applying unsupervised learning methods like autoencoders, transfer learning with pre-trained Object Detection models. Latest data collection and processing techniques. Describe applying ML and AI models to improve robustness of software pipelines and increase sensitivity to a wider class of technosignatures. Report on a signal injection and recovery in collaboration with industry partners Google and Kaggle.				

Code & link	Paper title	Speaker	Affiliation	Country
A4,1,5,x65784 iafastro.directory/iac/paper/id/65784/abstract-pdf/IAC-21,A4,1,5,x65784.brief.pdf	BL@Scale: Scaling Technosignature Search Pipelines to the Cloud	Yuhong Chen	University of California, Berkeley	USA
Technosignature pipelines deployed at telescope sites and UC Berkeley data center but limitations of on-premise, hardware-centric approach constrain ability to ramp up intensive analysis campaigns on demand. BL@Scale (currently in a pilot phase) using cloud technologies like Docker and Kubernetes yields infrastructure able to flexibly scale with computing demands. Everyday workloads using on-premise machines but able to expand to large workloads quickly in the cloud. Reporting on capabilities, structure of platform, and some recent advances.				

Code & link	Paper title	Speaker	Affiliation	Country
A4,1,6,x65944 iafastro.directory/iac/paper/id/65944/abstract-pdf/IAC-21,A4,1,6,x65944.brief.pdf	Optimal Observing Strategies for Commensal SETI Surveys with Radio Telescope Arrays	Dr Daniel Czech	University of California, Berkeley	USA
Radio telescope arrays using commensal SETI surveys - Ethernet-based architectural approaches by MeerKAT, Jansky Very Large Array and Allen Telescope Array allow multiple commensal users to receive data simultaneously. Breakthrough Listen conducting a commensal SETI survey at MeerKAT, using raw voltage data streams from F-engines[1] with both coherent and incoherent beamforming on the buffered raw voltages. 64 simultaneous beams will be formed on objects of interest within the primary field. Most objects for observation drawn from 26 million stars drawn from Gaia DR2 [2] using reconfigurable processing pipeline. A subset of available stars may be observed ranked according to metrics such as distance and sequencing of observations to maximise results from available observing time + capacity.				

Code & link	Paper title	Speaker	Affiliation	Country
A4,1,7,x66146 iafastro.directory/iac/paper/id/66146/abstract-pdf/IAC-21,A4,1,7,x66146.brief.pdf	Breakthrough Listen Search for Intelligent Life in the Galactic Plane with the Parkes Telescope	Ms Karen Perez	Columbia University	USA
A primary target of BL is a comprehensive blind survey of the entire Galactic Plane to search for artificial narrowband transmitters from ETIs. From two full scans of the Galactic Plane over 1200–1550 MHz using the Parkes Telescope's 21cm Multibeam Receiver, covering roughly 3000 square degrees over Galactic longitudes -174°< l <60° and latitudes|b|<6.5° during 1200 hours and observing billions of stars applying the multibeam coincidence rejection technique used for detecting Fast Radio Bursts to narrowband signals to SETI for the first time.				

[1] FX architecture (Fourier transform 'F' followed by Cross-correlation 'X'). See *Engineering and science highlights of the KAT-7 radio telescope*, Foley *et al*, MNRAS, 2016, academic.oup.com/mnras/article/460/2/1664/2608970

[2] Gaia telescope www.cosmos.esa.int/web/gaia/spacecraft-instruments Gaia DR2 results https://www.cosmos.esa.int/web/gaia/dr2

Code & link	Paper title	Speaker	Affiliation	Country
A4,1,8,x66951 iafastro.directory/iac/paper/id/66951/abstract-pdf/IAC-21,A4,1,8,x66951.brief.pdf	How to Build a Commensal SETI Search Engine for Radio Telescope Arrays	David MacMahon	Berkeley SETI Research Center	USA
Commensal observing trades off control of the telescope for greatly increased amounts of telescope time. For radio telescope arrays with relatively large fields of view (eg MeerKAT, ALMA, ngVLA) this is of less consequence. Digital techniques such as coherent beam-forming afford commensal backend control over where to point narrow synthetic beams within the telescope's primary beam. BL has deployed a commensal digital backend on MeerKAT in South Africa to do this. This paper discusses the design and implementation of this commensal SETI search engine and presents data to show its capabilities.				

Code & link	Paper title	Speaker	Affiliation	Country
A4,1,9,x66549 iafastro.directory/iac/paper/id/66549/abstract-pdf/IAC-21,A4,1,9,x66549.brief.pdf	The Sardinia Radio Telescope in the Framework of the Breakthrough Listen Program: Technical & Scientific Commissioning and First Results	Dr Andrea Melis	INAF - Istituto Nazionale di AstroFisica	Italy
Sardinia Radio Telescope (SRT), a 64-m fully-steerable antenna, surveying the Galactic Center at higher radio frequencies (7 and 22 GHz) to find evidence of artificial transmitters, and following up potential exoplanet candidate announced from the TESS program in collaboration with the BL team. Reporting ongoing activities and in particular the commissioning of the system and first results.				

Code & link	Paper title	Speaker	Affiliation	Country
A4,1,10,x67003 iafastro.directory/iac/paper/id/67003/abstract-pdf/IAC-21,A4,1,10,x67003.brief.pdf	From Dust to Technosignatures: Searching for Stellar Occulters with Machine Learning	Dr Daniel Giles	SETI Institute (SI)	USA
While no theory provides a perfect explanation for the fading events seen in Boyajian's star, the large volume of imaging data emerging from the TESS mission is now enabling a new search for similar behaviour in additional objects. A SI team has created light curves for 50 million relatively bright stars. Using a combination of supervised and unsupervised machine learning to discover and classify rare fading events with follow up on the most unusual objects with ground-based optical and radio observatories to determine the origin of such variability. Ultimately, this program will either discover or put an upper limit on the frequency of transiting artificial megastructures around main sequence stars in our galaxy.				

Code & link	Paper title	Speaker	Affiliation	Country
A4,1,11,x66875 iafastro.directory/iac/paper/id/66875/abstract-pdf/IAC-21,A4,1,11,x66875.brief.pdf	Upgrades to the Allen Telescope Array: wide-band, wide-field radio observations	Dr. Wael Farah	SETI Institute	USA
Allen Telescope Array (ATA), a 42-element, fully steerable, interferometer with unique log-periodic feed design provides an impressive spectral coverage ranging from 1 to 12 GHz and four independent digital signal processing (DSP) chains delivering 650 MHz bandwidth each and 2600 MHz of instantaneous bandwidth if processed simultaneously. Describing ongoing refurbishment programme, astronomical observations including pulsars and fast radio bursts - and planned and ongoing SETI surveys to leverage the wide-field and wide-band capabilities of the telescope.				

Code & link	Paper title	Speaker	Affiliation	Country
A4,1,12,x67028 iafastro.directory/iac/paper/id/67028/abstract-pdf/IAC-21,A4,1,12,x67028.brief.pdf	Searching for Gravitational Lens Probes and Analysis of Tabby's Star Observations using turboSETI Software	Nick Tusay	Pennsylvania State University	USA
KIC8462852, aka Boyajian's Star or Tabby's Star, the artificial nature of this star's dimming is currently disfavoured but analysis developed for this star can be extended to other sources. The graduate SETI course at PennState, has taken observations in X, C and S bands with plans to add L band later to search for signals from potential artificial relay probes positioned to use the gravitational lensing effects of our Sun - as a benchmark for searching for possible probes placed as part of an interstellar communications network.				

Code & link	Paper title	Speaker	Affiliation	Country
A4,1,13,x64992 iafastro.directory/iac/paper/id/64992/abstract-pdf/IAC-21,A4,1,13,x64992.brief.pdf	Search for nanosecond optical transients with TAIGA-HiSCORE array for the SETI problem.	Dr Alexander Panov	Skobeltsyn Institute of Nuclear Physics	Russia
The wide-angle integrating Cerenkov array TAIGA-HiSCORE (FOV ~0.6 steradians) includes nearly 100 optical detector stations distributed over an area of ~1 km used to search for nanosecond astrophysical transients in the optical range. The telescope can register signals of distant nanosecond lasers (up to 1000 light-years and more) with moderate energies and sizes, thus of interest for SETI. The report discusses the method of searching for astrophysical transients - demonstrating performance with the example of laser pulses from Earth satellite. Results of the 2018-2019 winter season include a candidate for recurrent transient with the estimated probability of random chance by fluctuation of background EAS (Extended Air Shower) is at least 10%. An upper bound on the event frequency of optical transients with a spectral energy density of more than 1.5×10^{-3} erg/sec/cm^2 and duration of ≥1 ns has been found to be 0.05 events/ster/day [1].				

Code & link	Paper title	Speaker	Affiliation	Country
A4,1,15,x65656 iafastro.directory/iac/paper/id/65656/abstract-pdf/IAC-21,A4,1,15,x65656.brief.pdf	Numerical simulations for possible Galactic Habitable Islands in the Milky Way	Prof Teófilo Vargas	Universidad Nacional Mayor de San Marcos	Peru
The concept of Galactic Habitable Islands (GHI) refers to locations in our Galaxy outside of the "standard" Galactic Habitable Zone (GHZ) [2] that could be favourable to the development of life. Recent numerical simulation models suggest life could have emerged at the outskirts of the galactic disk and recent observations, show some indications that zones suitable to life have emerged in the galactic centre and in the outer part of the Galaxy. This paper presents new numerical simulations compared to observations. If the simulations confirm the indications, parameters from the former will be extracted and changed to identify more zones suitable to life.				

[1] events/ster/day = events/steradian/day. Steradians are units of solid angle. They are the angle subtended by a unit area of the surface of a sphere so a whole sphere contains 4π steradians and thus 0.05 events/ster/day implies . 0.05*4π=0.63 events/day for the whole celestial sphere or 1.59 days between events..

[2] The idea of a galactic habitable zone is based on the observation that some parts of the galaxy are more hazardous to life than others. Some stars are unstable and others emit hostile radiation continuously so it is not safe for life to be near them. Comets from our Oort cloud are likely to be more frequent if other stars pass close to us and perturb their orbits so planets in more densely populated parts of the galaxy are likely to be subject to more comet bombardment. More at en.wikipedia.org/wiki/Galactic_habitable_zone

Code & link	Paper title	Speaker	Affiliation	Country
A4,1,17,x63320 iafastro.directory/iac/paper/id/63320/abstract-pdf/IAC-21,A4,1,17,x63320.brief.pdf	The Drake equation and SETI in the JWST era	Dr Amri Wandel	The Hebrew University of Jerusalem	Israel
Applying earlier analyses of SETI from the Kepler telescope to James Webb Space Telescope whose biosignature analyses can identify biotic exoplanets within the local habitable zone of M-dwarf solar systems giving better values for the relevant terms of the Drake equation, the Fermi-SETI paradox, the Earth radiosphere explanation of the SETI-Fermi paradox and perhaps a further METI paradox.				

Code & link	Paper title	Speaker	Affiliation	Country
A4,1,18,x63279 iafastro.directory/iac/paper/id/63279/abstract-pdf/IAC-21,A4,1,18,x63279.brief.pdf	Moon Farside Protection and Astronomy Protection are URGENT	Dr Claudio Maccone	International Academy of Astronautics (IAA) and Istituto Nazionale di Astrofisica (INAF)	Italy
The Moon Farside is the only place where radio transmissions and noises produced by humanity may not reach - the Moon blocks them. In 2010 Dr Maccone advocated the creation of a “Protected Antipode Circle (PAC)”, a circular area at the lunar farside centre. The "new race to the Moon” complicates matters. This paper supports Moon Farside Protection by all scientists working in three areas: Planetary Defence, Cosmology and SETI.				

Session: 50th IAA SYMPOSIUM ON THE SEARCH FOR EXTRATERRESTRIAL INTELLIGENCE (SETI) – The Next Steps - SETI 2: SETI and Society

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Code & link	Paper title	Speaker	Affiliation	Country
A4,2,2,x62338 iafastro.directory/iac/paper/id/62338/abstract-pdf/IAC-21,A4,2,2,x62338.brief.pdf	“The readiness is all” - Understanding Post-Detection Dynamics through Live Action Role Play	Ms Kate Genevieve	University of Sussex	UK
Confirmed detection of extraterrestrial life has the potential to generate considerable societal upheaval and planning for post-detection scenarios should involve stakeholders from across human society, not just scientists and politicians. Collaborators (Genevieve, Dr Arik Kershenbaum - Cambridge U, Prof John Elliott - Leeds Beckett U, Ruth Catlow) developed and prototyped an online LiveAction Role Play (LARP) across video conferencing platforms that simulates a contact scenario for diverse groups of people. The presentation will showcase the post-detection LARP, techniques devised to share learning found through game-play aiming for an open source SETI experiment. Also consider issues of maintenance and creativity imagining post-detection that keeps pace with societal development and a final discussion of recent participatory experiments in the UKSRN (uksetiresearchnetwork.wordpress.com) Post-Detection group and others.				

Code & link	Paper title	Speaker	Affiliation	Country
A4,2,3,x64977 iafastro.directory/iac/paper/id/64977/abstract-pdf/IAC-21,A4,2,3,x64977.brief.pdf	Use of force against extra-terrestrial life	Matija Rencelj	European Space Policy Institute (ESPI)	Slovenia
This paper will analyse the legality of using force against extra-terrestrial life and potential mechanisms of assigning legal rights to extra-terrestrial life - based on current national and international law. Even though doing so might not be of immediate urgency it might help us better understand our role in the Universe.				

Code & link	Paper title	Speaker	Affiliation	Country
A4,2,5,x65530 iafastro.directory/iac/paper/id/65530/abstract-pdf/IAC-21,A4,2,5,x65530.brief.pdf	Other minds in the Universe?	Pauli Laine		Finland
The probability of the emergence of life is unknown - and of complex forms and into intelligence is even more unknown. We can see behaviour in many animal species that can be described as intelligent. We can program computers to behave like intelligent agents. But none of these are capable for (or interested in) interstellar communication. Our own interest arises from need to communicate within a small ancestor group. We do not know what possible evolutionary paths lead to intelligent society and technological culture - we have only one example. It is hard to imagine alternatives. Fermi's paradox questions any claim about how life would evolve to something that could be observable other than biochemically.				

Code & link	Paper title	Speaker	Affiliation	Country
A4,2,6,x66778 iafastro.directory/iac/paper/id/66778/abstract-pdf/IAC-21,A4,2,6,x66778.brief.pdf	On the necessary aspect of METI	Dr Carl DeVito	www.math.arizona.edu/~devito/	USA
Any message we send into space will be, to its recipients, a message from the past; perhaps from very far in the past. It is argued here that, because of this fact, any message we send should have a component that serves as a legacy of humanity; a component that says something about the nature of the intelligent, senescent ["sentient" ?] race that arose near a star in the Milky Way Galaxy. This should serve as at least a partial guide to us in preparing the content of our message.				

Code & link	Paper title	Speaker	Affiliation	Country
A4,2,7,x61738 iafastro.directory/iac/paper/id/61738/abstract-pdf/IAC-21,A4,2,7,x61738.brief.pdf	Astropolitcs and the Implications of Belonging to an Extraterrestrial Polity	Mclee Kerolle	Space Generation Advisory Council (SGAC)	USA
This paper will address the political implications regarding discovery that Earth belongs to an interstellar polity with several hundred extraterrestrial civilizations, questioning our anthropocentric assumptions and the expectation that more technically advanced civilizations will be more culturally and ethically advanced and would thus not harm human civilization. Are the five main space treaties of the UN consistent with the most famous post detection policy, the First SETI protocol of 1989? And what would the global impact on space law of the discovery of belonging to an interstellar polity have?				

Code & link	Paper title	Speaker	Affiliation	Country
A4,2,10,x65430 iafastro.directory/iac/paper/id/65430/abstract-pdf/IAC-21,A4,2,10,x65430.brief.pdf	Benedict XVI and SETI	Dr Paolo Musso	University of Insubria	Italy
Dr Musso wrote to Pope Emeritus Benedict XVI, asking his opinion about some theological issues related to extraterrestrial intelligent life - first of all of course whether it can exist from a Christian point of view. His reply in June 2014 was strictly personal but at the beginning of 2021 Dr Musso requested permission to include the letter as an appendix to a book in preparation. This was granted and here, for the first time , a former Pope has taken an open position to the possible existence of intelligent species other than humanity.				

Code & link	Paper title	Speaker	Affiliation	Country
A4,2,12,x61987 iafastro.directory/iac/paper/id/61987/abstract-pdf/IAC-21,A4,2,12,x61987.brief.pdf	Radio bridges of the future between Solar System and the nearest 100 stars	Dr Nicolò Antonietti	INAF - IRA	Italy
Co-author Claudio Maccone published *The Sun as a Gravitational Lens: Proposed Space Missions* in 1998. But radio bridges between the Sun and any nearby star may also be conceived. Space probes to the nearest stars could be placed behind the star of arrival and along the star-Sun line, thus allowing two gravitational lenses to work together resulting in a power-efficient permanent communication link. The paper studies radio bridges between the Sun and each of the nearest 100 stars, the basis for a Galactic Internet and human expansion to the stars.				

Code & link	Paper title	Speaker	Affiliation	Country
A4,2,18,x62033 iafastro.directory/iac/paper/id/62033/abstract-pdf/IAC-21,A4,2,18,x62033.brief.pdf	The need for a worldwide and international SETI Journal	Dr Claudio Maccone	International Academy of Astronautics (IAA) and Istituto Nazionale di Astrofisica (INAF)	Italy
Acta Astronautica, the official journal of the International Academy of Astronautics (IAA), has also been the preferred journal for SETI-related papers since 1971, when the IAA established the IAA SETI Committee. In 50 years, SETI research grew from a murky sub-field of Astronomy to a self-sufficient branch of science resting on Radio Astronomy, Optical and Cherenkov Astronomy, Astrobiology and the Social Sciences. In recent years SETI scientists have had their SETI Abstracts rejected by Acta Astronautica often without preliminary discussion with Acta Astronautica reviewers. Since SETI scientists now also come from the Social Sciences, concerning themselves with the social impact of SETI discovery and political leaders of the most advanced countries seem to be totally unprepared to face such a "SETI Crisis", this paper ponders the opportunities of establishing the first SETI Journal capable of preparing Humanity for Contact.				

Session: 24th IAA SYMPOSIUM ON HUMAN EXPLORATION OF THE SOLAR SYSTEM - session 4-D2.8 Space Transportation Solutions for Deep Space Missions

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Code & link	Paper title	Speaker	Affiliation	Country
A5,4-D2.8,1,x65969 iafastro.directory/iac/paper/id/65969/abstract-pdf/IAC-21,A5,4-D2.8,1,x65969.brief.pdf	Design optimisation and analysis of very high power transportation system to Mars	Dr Christie Maddock	University of Strathclyde	UK
Results of 2020 study through ESA to develop preliminary flight vehicle engineering model of a Very High Power Transportation System to Mars for a crewed return mission. Vehicle configuration study with numerical models for structural mass, radiation, propulsion, habitat and consumables, and structural analysis of the separation truss between the spacecraft, including crew habitat module, and nuclear engine. Requirements and assumptions: Earth-Mars one-way journey less than 90 days, minima 50 tons cargo and 3 crew, in-orbit manufacturing and re-fuelling assumed operational around both Earth and Mars. Launch and landing segments of the mission not considered. Two system configurations developed: higher-TRL nuclear thermal propulsion and ESA developed NTER (Nuclear Thermal Electric Rocket). Multi-objective optimisation solver used to examine trade-offs in mission and trajectory with vehicle design parameters including engine sizing, and gross and dry vehicle masses. For a cycler-based mission architecture, single and return legs were analysed independently and together, using continuous and on-off thrust models. Preliminary results show a single leg journey possible (eg 86.0 days for Earth to Mars for a 650.86 t vehicle). Trade-off between total transfer duration against vehicle mass for a 30 day stay on Mars showed total flight times ranging from 295 days (376.8 t out and 668.28 t return) to 541.7 days (111.7 t out and 272.21 t return).				

Session: IAF SYMPOSIUM ON ONGOING AND NEAR FUTURE SPACE ASTRONOMY AND SOLAR-SYSTEM SCIENCE MISSIONS - Technology Needs for Future Missions, Systems, and Instruments

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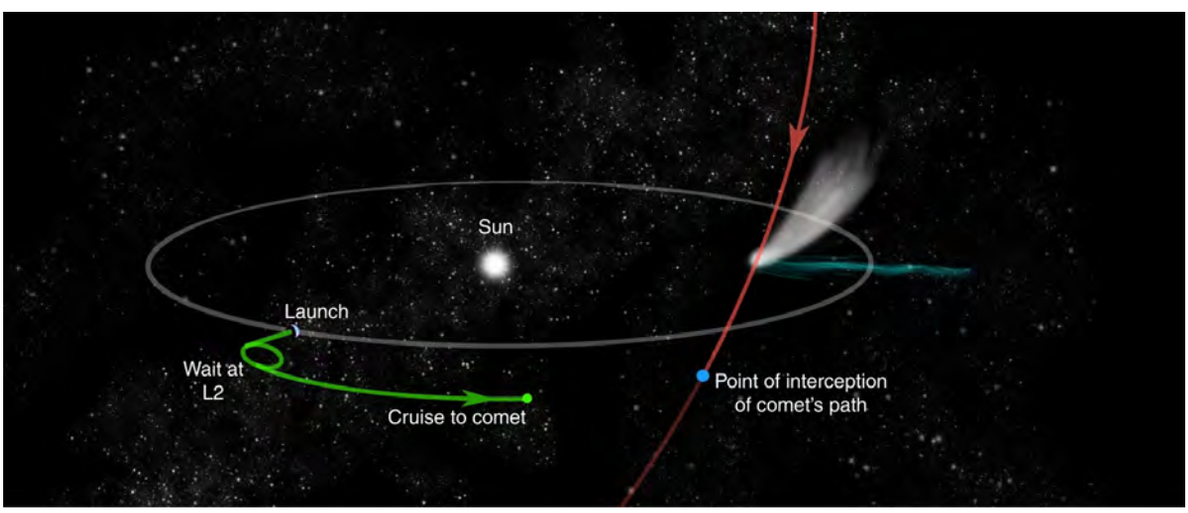
Code & link	Paper title	Speaker	Affiliation	Country
A7,3,2,x67120 iafastro.directory/iac/paper/id/67120/abstract-pdf/IAC-21,A7,3,2,x67120.brief.pdf	Comet Interceptor: A daring mission to a long period comet or an interstellar object	Dr Mohamed Ramy Elmaarry	Khalifa University of Science and Technology (KUST)	United Arab Emirates
Comet Interceptor is an upcoming European Space Agency (ESA)-led mission in partnership with the Japanese Space Agency (JAXA) planned for launch to Lagrange point L2 in 2029 to loiter until a suitable object is found[1]. The mission objective is to explore for the first time a long-period comet, preferably dynamically new and as such, are expected to be much less processed/evolved than comets that have come close to the Sun on multiple occasions. Alternatively, an interstellar object (ISO) with a trajectory that is feasible for Comet Interceptor would provide a chance to explore an ISO in close proximity for the first time. The paper will discuss the mission further, and provide updates on the state of its development..				



ESA Comet Interceptor - Launch, Loiter and Flyby.

Credit: Sketch of mission phases from *The European Space Agency's Comet Interceptor lies in wait* Colin Snodgrass & Geraint H Jones, Nature Communications 2019 www.nature.com/articles/s41467-019-13470-1.epdf.

Session: IAF SPACE COMMUNICATIONS AND NAVIGATION SYMPOSIUM

iafastro.directory/iac/browse/IAC-21/B2/

Code & link	Paper title	Speaker	Affiliation	Country
B2,5,4,x62574 iafastro.directory/iac/paper/id/62574/abstract-pdf/IAC-21,B2,5,4,x62574.brief.pdf	Gravitational lensing of sun for deep space communication	Ms Bhavana B Rao	Ramaiah Institute of Technology	India
Gravitational lensing by massive objects predicted by the General Theory of Relativity. The sun's mass allows a probe along any radial direction from the sun from 550 AU and beyond. This can be used for a link to an interstellar probe. This paper compares the bit error rate across interstellar distances with and without using the gravitational lens effect of the Sun and the possibility of building radio bridges from the solar system such that data could be transmitted from interstellar probes with minimum power.				

[1] See *News Feature: All Comets Great and Small* Principium 25 May 2019 for a summary of the Comet Interceptor mission.

Session: Joint Session on Advanced and Nuclear Power and Propulsion Systems

iafastro.directory/iac/browse/IAC-21/C3/5-C4.10/

Code & link	Paper title	Speaker	Affiliation	Country
C4,10-C3.5,1,x63502 iafastro.directory/iac/paper/id/63502/abstract-pdf/IAC-21,C4,10-C3.5,1,x63502.brief.pdf	Overview of Breakthrough Propulsion Research at TU Dresden	Prof Martin Tajmar	TU Dresden	Germany
Given the limitations of currently feasible means of propulsion to the stars, TU Dresden decided to establish a dedicated breakthrough propulsion group to investigate and test new ideas for propellantless propulsion with three main areas: Theory/model assessments, development of test equipment and experimental tests. Recently developing a suite of measurement devices including torsion thrust balances with nano-Newton resolution, a superconducting levitation thrust stand and a nano-gram weight balance, two thruster claims were tested in detail on different balances: the Mach-Effect thruster and the EMDrive, including a superconducting EMDrive and a laser-based variation. Also investigating complementary and fundamental theories such as claimed anomalous thrust of charged high-voltage capacitors, the influence of temperature on weight or consequences of scalar-tensor 5D gravity theories, which may lead to novel propulsion effects. The paper reviews current progress and summarises activities.				

Code & link	Paper title	Speaker	Affiliation	Country
C3,5-C4.10,2,x64835 iafastro.directory/iac/paper/id/64835/abstract-pdf/IAC-21,C3,5-C4.10,2,x64835.brief.pdf	Comparative Overview of NEP programs and concepts	Manuel La Rosa Betancourt	Neutron Star Systems UG	Germany
Human space exploration is at the dawn of a new era. Chemical propulsion will not be enough. Nuclear Electric Propulsion (NEP) is more cost-effective and sustainable for interplanetary voyages, combining the megawatt power of a nuclear reactor with the high specific impulse (Isp) of electric propulsion. This paper presents the geopolitical and technological considerations behind different NEP programs worldwide - the two major actors NASA and ROSCOSMOS and other interested space agencies such as CNSA, ESA and UKSA. Gridded Ion Thrusters (GIT) and Hall Effect Thrusters (HET) at low power levels (up to several kilowatts). Superconductor-based Readiness Enhanced Magnetoplasmadynamic Electric Propulsion (SUPREME) could be a better alternative for high power manned and cargo missions. Applied-Field Magnetoplasmadynamic (AF-MPD) Thrusters offer a range of operations wider than any other existing electric propulsion technology.				

Code & link	Paper title	Speaker	Affiliation	Country
C4,10-C3.5,3,x65105 iafastro.directory/iac/paper/id/65105/abstract-pdf/IAC-21,C4,10-C3.5,3,x65105.brief.pdf	A Cubesat Demonstrator of Quantized Inertia Propulsion	Dr Ryan Weed		USA
Results of effort to demonstrate a novel propellantless propulsion concept based on the theory of quantized inertia (QI), developed by Prof Michael McCulloch, University of Plymouth, UK [1]. QI theory predicts that a force can be generated in high-Q asymmetric electromagnetic cavities without the use of propellant. For interstellar propulsion, photon-based thrust efficiency is limited to approximately mN/MW. To enable human exploration of the outer solar system and the stars, engineers need a propellantless engine operating at much higher thrust efficiency (>100 N/MW) and an energy source providing high specific power(<10 kg/kW). In a Phase 1/II DARPA study, a 3U CubeSat thruster was designed to demonstrate an orbital inclination change under QI propulsion. A lab demonstration at USC Space Engineering Research Center with measurement of the thrust efficiency used a mechanically/electrically isolated/levitated platform in UHV, capable of micro-newton thrust measurements. Main technical challenges were manufacture/coating of the complex optical cavity shapes and isolating the thrust measurement from error sources. CubeSat design challenges included incorporation of unique QI cavity into CubeSat standard geometry, integration of medium power solid state laser, supporting power distribution and thermal design.				

[1] See the summary of McCulloch's talk at the second i4is *News Feature: Foundations of Interstellar Studies Workshop 2019* (FISW2) reported by Patrick Mahon in Principium 26 August 2019 page 12. For greater detail see the presentation *Quantised inertia, propellant-less thrust and interstellar travel* by Dr McCulloch video and slides available to i4is members at i4is.org/videos/fisw2/

Code & link	Paper title	Speaker	Affiliation	Country
C4,10-C3.5,5,x66797 iafastro.directory/iac/paper/id/66797/abstract-pdf/IAC-21,C4,10-C3.5,5,x66797.brief.pdf	Overview of the High Performance Centrifugal Nuclear Thermal Propulsion System	Jimmy Allen	Dynetics	USA

Space nuclear propulsion (SNP), and specifically nuclear thermal propulsion (NTP) and nuclear electric propulsion (NEP) show tremendous potential. High Performance NTP (HPNTP) systems can be defined as systems capable of providing ~20,000 N thrust at specific impulse >1300 s. This presentation will focus on one HPNTP concept, the Centrifugal Nuclear Thermal Rocket (CNTR) [1] enabling a relatively short (420 day) round-trip mission to Mars (including 6 weeks at Mars) at an acceptable advancement degree of difficulty (AD^2) [2].

CNTR uses a combination of flow geometry and centrifugal force to enable a high propellant exhaust temperature (~4000 K) while maintaining structural materials, moderators, and other components at 1000 K. The reactor comprises 19 fuel cylinders, each approximately 1 m in length and 0.1 m in diameter and partially filled with enriched metallic uranium fuel. The first experiment will demonstrate the feasibility of the flow geometry and the second experiment will demonstrate the required compatibility between the cylinder wall, the liquid metallic uranium fuel, and the propellant.

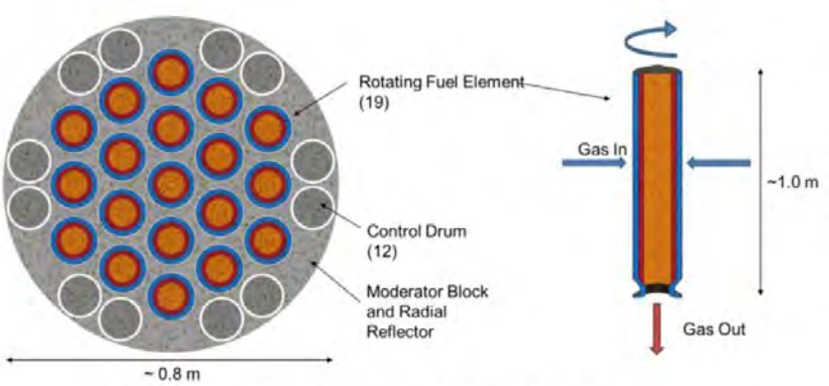


Fig. 1. Schematic of 19 cylinders CNTR

Schematic of 19 cylinders CNTR, Fig. 1 in Allen *et al*, *Overview of High-Performance Centrifugal Nuclear Thermal Rocket Propulsion System* [1]

Credit:Allen *et al*

Code & link	Paper title	Speaker	Affiliation	Country
C4,10-C3.5,11,x65142 iafastro.directory/iac/paper/id/65142/abstract-pdf/IAC-21,C4,10-C3.5,11,x65142.brief.pdf	Toward the Engineering Feasibility of the Centrifugal Nuclear Thermal Rocket	Prof Dr Dale Thomas	University of Alabama in Huntsville	USA

In the Centrifugal Nuclear Thermal Rocket, see above ref C4,10-C3.5,5,x66797, the propellant is heated directly by the reactor fuel. This can yield high specific impulse (1800 s) at high thrust but significant engineering challenges must be addressed to establish technical viability: Heat transfer between metallic liquid uranium and the propellant; Accommodation of startup and shutdown transients. Research is on analytical modelling and simulation of the two-phase heat transfer between the liquid metallic uranium fuel and gaseous propellant.

[1] *Overview of High-Performance Centrifugal Nuclear Thermal Rocket Propulsion System*, Jimmy Allen (Dynetics), Michael Johns & Mark Patterson (Southern Research), Michael Houts (NASA Marshall Space Flight Center), Florent Heidet (Argonne National Laboratory), Nicholas V Smith (Idaho National Laboratory), John E Foster (University of Michigan) - 2020 ANS Virtual Winter Meeting local.ans.org/ne/wp-content/uploads/2021/02/OverviewCNTR-ANS-Winter-2020-summary-paper.pdf

[2] See *Using the Advancement Degree of Difficulty (AD^2) as an input to Risk Management*, James W Bilbro 2008 apps.dtic.mil/sti/pdfs/ADA507591.pdf

Session: IAF SPACE PROPULSION SYMPOSIUM - Electric Propulsion

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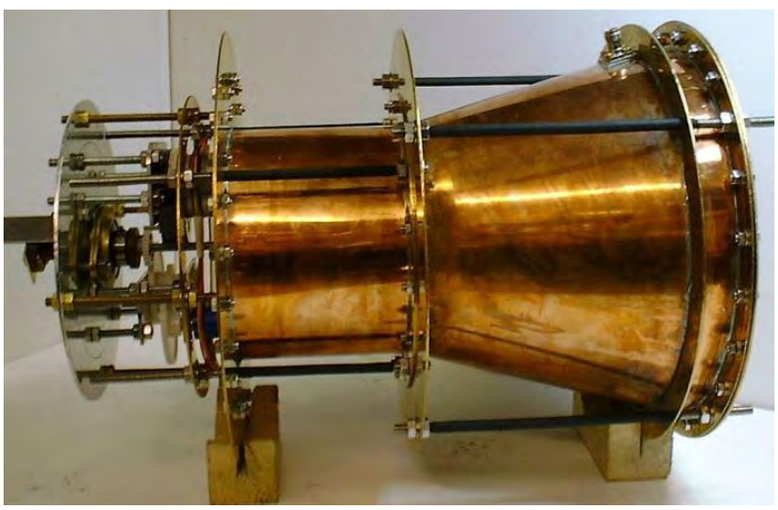
Code & link	Paper title	Speaker	Affiliation	Country
C4,5,2,x63347 iafastro.directory/iac/paper/id/63347/abstract-pdf/IAC-21,C4,5,2,x63347.brief.pdf?2021-03-31.07:18:11	A Superconducting EmDrive Thruster. Design, Performance and Application	Roger Shawyer	Satellite Propulsion Research Ltd	UK
Building on work described in a IAC20 paper [1, 2], the author advances that design to a superconducting version. Changes include a new material for the microwave cavity and a passive cooling system, Outline designs of inner and outer solar system missions, 90 kg and 120 kg, use solar power and isotope source power respectively. A specific thrust of 12.3 N/kW at operating temperature 77 K is expected.				



EmDrive Flight Thruster test
Credit: Satellite Propulsion Research Ltd
emdrive.com/

Code & link	Paper title	Speaker	Affiliation	Country
C4,6,7,x64788 iafastro.directory/iac/paper/id/64788/abstract-pdf/IAC-21,C4,6,7,x64788.brief.pdf	Progress in Research and Development of Superconductor-Based Applied-Field Magnetoplasmadynamic Technology	Marcus Collier-Wright	Neutron Star Systems UG	Germany
Applied-Field Magnetoplasmadynamic (AF-MPD) Thrusters have been widely-researched electric propulsion technologies, offering unique characteristics: propellant flexibility, throttleability, high specific impulse, high thrust density, and scalability but research diminished due to issues of electromagnet power consumption and thruster lifetime. There is now a renaissance in research in Germany, Italy, Japan, China, and Russia. Work at University of Stuttgart has achieved the most promising results to date, SUPREME [3], a 100 kW-class SX3 thruster, with thrust efficiencies as high as 62%. This paper reviews the latest advances in AF-MPD and HTS (high temperature superconductor) developments and presents the SUPREME design concept with technological roadmap, subsystem and system level developments and candidate flight missions.				

[1] *An EmDrive Thruster for Cubesats*, Roger Shawyer, IAC-20,C4,6,9,x56845 www.emdrive.com/IAC20paper.pdf

[2] EmDrive Fundamentals vimeo.com/501195339

[3] SUPerconductor based Readiness Enhanced Magnetoplasmadynamic Electric Propulsion thruster, https://www.neutronstar.systems/the-tech

Session: IAF SPACE PROPULSION SYMPOSIUM - New Missions Enabled by New Propulsion Technology and Systems

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Code & link	Paper title	Speaker	Affiliation	Country
C4,9,10,x61782 iafastro.directory/iac/paper/id/61782/abstract-pdf/IAC-21,C4,9,10,x61782.brief.pdf	The Comet Interceptor Mission - Making a case for Solar Electric Propulsion	Henrique Costa	GMV Innovating Solutions	Portugal
[see A7,3,2,x67120 above for more on Comet Interceptor] Analysis of a Solar Electric Propulsion (SEP) transfer for The Comet Interceptor Mission- possible encounter locations were parametrically defined and mapped according to the Δv required to reach them with SEP and compared results to available performance data for the Chemical Propulsion (CP) baseline system, establishing superiority of the SEP option in maximizing both payload mass and reachable locations. Concluded that SEP delivers trajectories requiring less propellant mass and allows savings of more than 125 kilogram for 50% of the comet encounter locations.				

Code & link	Paper title	Speaker	Affiliation	Country
C4,9,11,x61960 iafastro.directory/iac/paper/id/61960/abstract-pdf/IAC-21,C4,9,11,x61960.brief.pdf	Combining Electric sail propulsion and Magnetic propulsion to reduce the time involved in deep space exploration	Ms Zafera Amtul Khader	-	India
We can reduce the mission time of deep space exploration by combining electric and magnetic propulsion. A magnetic sail is more effective at higher velocities whereas an electric sail demonstrates superior performance at low speeds. For deceleration of an interstellar mission the most promising technology the magnetic sail - using the deflection of interstellar matter. Issues: thruster mass, propellant mass, variable specific impulse.				

Code & link	Paper title	Speaker	Affiliation	Country
C4,9,12,x63409 iafastro.directory/iac/paper/id/63409/abstract-pdf/IAC-21,C4,9,12,x63409.brief.pdf	Optimization of interplanetary trajectory for direct fusion drive spacecraft	Prof Giancarlo Genta	Politecnico di Torino	Italy
Direct Fusion Drive (DFD) technology will allow fast and affordable interplanetary travel. To optimize the payload fraction, the thruster should operate in Variable Ejection Velocity (VEV) mode with low thrust interplanetary travel in three phases: first planetocentric, second heliocentric and third planetocentric - optimising thruster mass, propellant mass and variable specific impulse across the three phases. Using IRMA mission analysis code[1] an optimal solution for the duration of planetocentric phases and interplanetary phase, optimal starting and arrival dates can be chosen for any interplanetary journey. Examples of very fast Earth-Mars journeys are computed, showing that DFD allows affordable fast interplanetary travel.				

[1] *IRMA: a Graphical Tool for Interplanetary Mission Design*, Giancarlo Genta* and P Federica Maffione, 2018 www.matec-conferences.org/articles/matecconf/pdf/2018/69/matecconf_cscc2018_02049.pdf

Session: 19th IAA SYMPOSIUM ON VISIONS AND STRATEGIES FOR THE FUTURE - Innovative Concepts and Technologies

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Code & link	Paper title	Speaker	Affiliation	Country
D4,1,7,x66824 iafastro.directory/iac/paper/id/66824/abstract-pdf/IAC-21,D4,1,7,x66824.brief.pdf	An Interactive Model for Space Megastructure Construction	Ms Elizabeth Scott	Colorado School of Mines	USA
An interactive software model to explore the economic and technological conditions needed for the construction of space megastructures, including fuel depots, orbital habitats, space-based solar power satellites, and planetary sunshades intended to assess the technological and economic feasibility of space megastructure construction. Uses a time-driven state machine that virtually transforms various cislunar raw materials into useful resources and finished products, as well as modelling their transportation throughout cislunar space. The paper shows the model's architecture, demonstrates its use and presents preliminary results for time-, mass-, and cost-efficient construction of space megastructures.				

Code & link	Paper title	Speaker	Affiliation	Country
D4,1,14,x66313 iafastro.directory/iac/paper/id/66313/abstract-pdf/IAC-21,D4,1,14,x66313.brief.pdf	Selection of asteroids which are suitable for collision with Mars for the purpose of terraforming	Neelabh Menaria	Ramaiah Institute of Technology	India
To terraform Mars, methods are devised to augment temperature, water levels, atmospheric composition, and atmospheric pressure. No one approach was found that could tackle all of the requirements and a synergistic approach was taken. One of these approaches includes bombardment of planet from volatile rich asteroids. Importing volatiles is essential step for terraforming Mars since the abundance of nitrogen is currently too low to support Earth life. The paper also lists possible candidate asteroids with suitable mass, density, diameter, composition and other parameters.				

Session: 49th STUDENT CONFERENCE -

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Code & link	Paper title	Speaker	Affiliation	Country
E2,2,9,x65326 iafastro.directory/iac/paper/id/65326/abstract-pdf/IAC-21,E2,2,9,x65326.brief.pdf	A first step towards interstellar fusion propulsion	Mewantha Aurelio Kaluthantrige Don	University of Strathclyde	UK
This paper focuses on nuclear fusion processes. Inertial Electrostatic Confinement (IEC) is a method to obtain nuclear fusion reactions by means of strong electrical fields confining plasma. Two concentric spherical electrodes apply voltage to ionize the gas between them and accelerate the ions to initiate fusion. The electrical field geometry causes plasma to be ejected, as in common electrostatic propulsion systems. This paper shows the physics of an IEC by manufacturing and testing a small-scale plasma confining propulsion system and conceivably applying it to a 6U CubeSat. The work is at NASA Ames Research Center, Technological and Educational Nanosatellite department, lead by Marcus Murbach, Principal Investigator, Space Technology division.				

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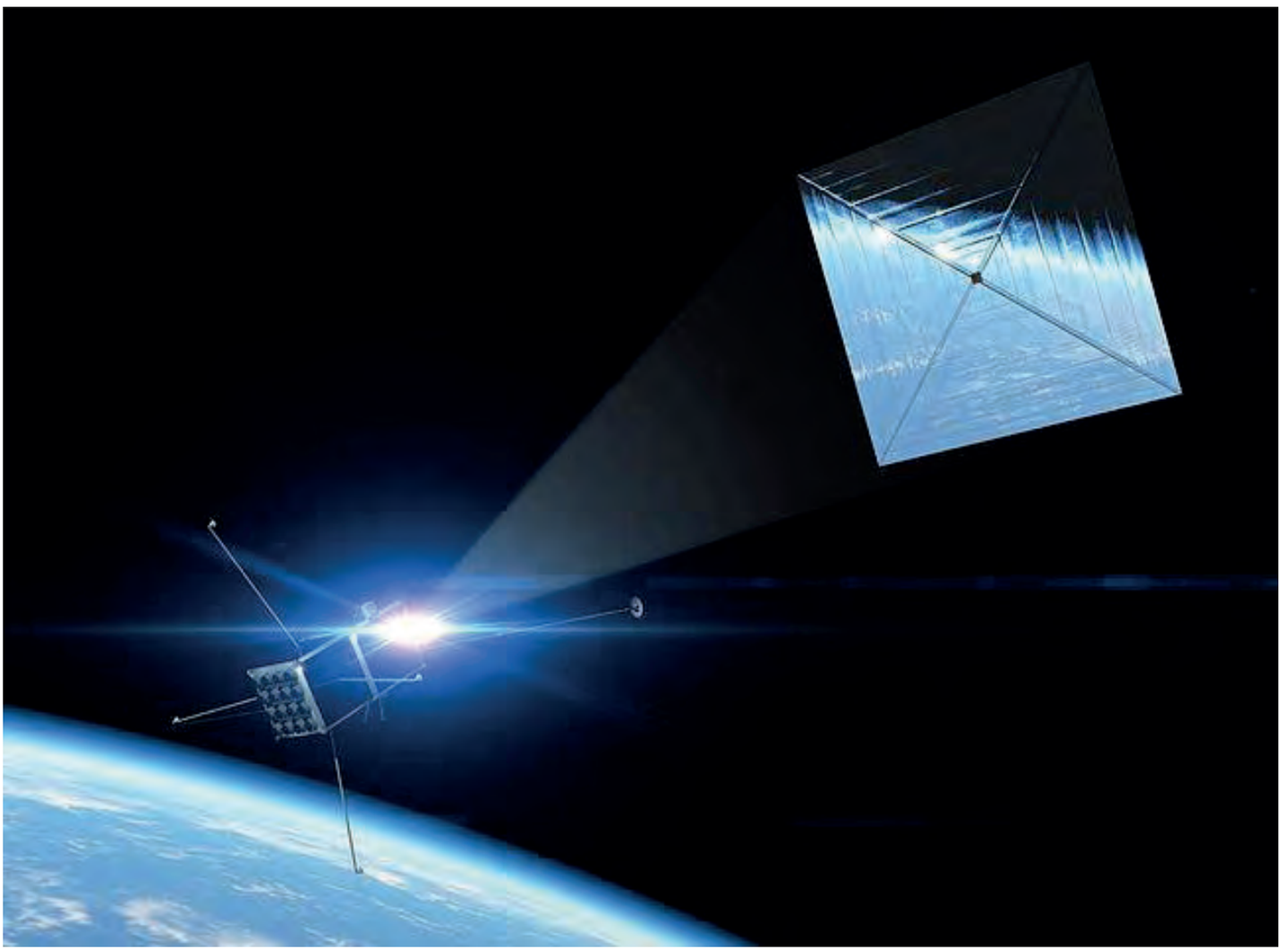

The Initiative for Interstellar Studies (i4is) has launched a membership scheme intended to build an active community of space enthusiasts whose sights are set firmly on the stars. We are an interstellar advocacy organisation which:

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

News Feature: Mission to 2014 UN271 using OITS

John I Davies

Comets are often the least "loyal" but sometimes the most spectacular members of the Solar System family. Their orbits often make them nearly interstellar objects. An unusually large one on a very eccentric orbit is therefore of special interest to i4is. Astronomical investigators recently discovered the largest comet yet known - it is the size of a respectable minor planet. Here John Davies reports on this intriguing object and the initial work on a possible mission to intercept it by Adam Hibberd of the i4is Project Lyra team. Adam's more detailed and recent work on this challenge, *2014 UN_{271} Spacecraft Missions*, is elsewhere in this issue. Many of the ideas here are Adam's - but please attribute any blunders to John. This article appeared as a Principium preprint for i4is members, announced in their 8 July Newsletter.

The Comet

C/2014 UN_{271} appears to be a very large Oort cloud comet. It was discovered by Pedro Bernardinelli and Gary Bernstein from archival images. Such a "throwback" discovery is not unusual. Much useful information is effectively buried in systematic astronomical observations and comet hunting detective work is not necessarily conducted by observational astronomers - either professional (as in the interstellar object 1I/'Oumuamua by Pan-STARRS team of the Institute for Astronomy at the University of Hawaii) or amateur (as in the interstellar object 2I/Borisov by Gennadiy Borisov). This new discovery has an orbit which shows it to be from the Oort cloud, the roughly spherical space surrounding the Solar System where many long period comets have their aphelion. Bernardinelli-Bernstein (named after its discoverers) has an orbital period in millions of years and a predicted aphelion so far out in the Oort cloud that it will be subject to perturbation by gravitational influences from beyond the Solar System. In fact its eccentricity is so close to one that it is very loosely bound to the Solar System and an unexpected perturbation might cause it to leave the solar system - though only after a few million years heading out again! BB will reach perihelion in 2031, coming no closer than Saturn which is 10 astronomical units away, ie 10 times further from the Sun than we are. All this is interesting from an astronomical point of view but not unusual.

What is unusual about BB is its size. Typically comets range up to a few tens of km in diameter - though they produce a coma which is much larger when warmed by the Sun. BB is at least 100 km across and may be 200 km. Dr Colin Snodgrass, at the University of Edinburgh and a member of the ESA Comet Interceptor team, has said “With a reasonable degree of certainty, it’s the biggest comet that we’ve ever seen”.

A comet exploration pioneer

ESA image of Philae lander
Credit:ESA/ATG medialab

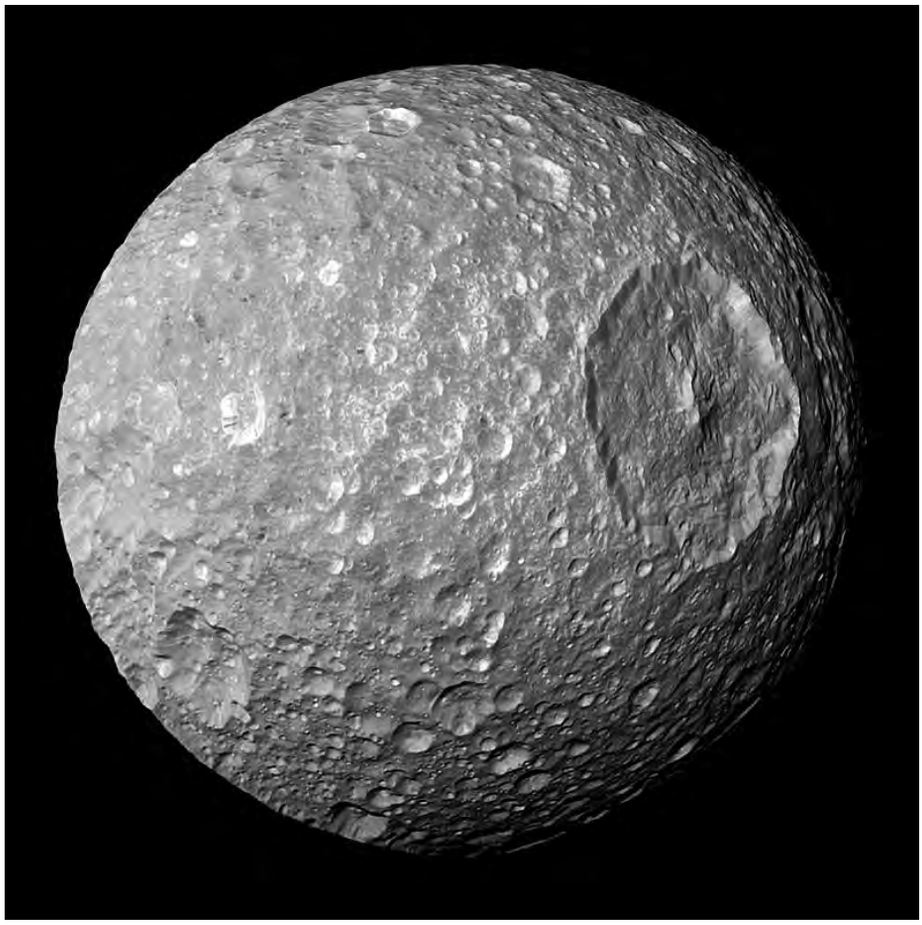
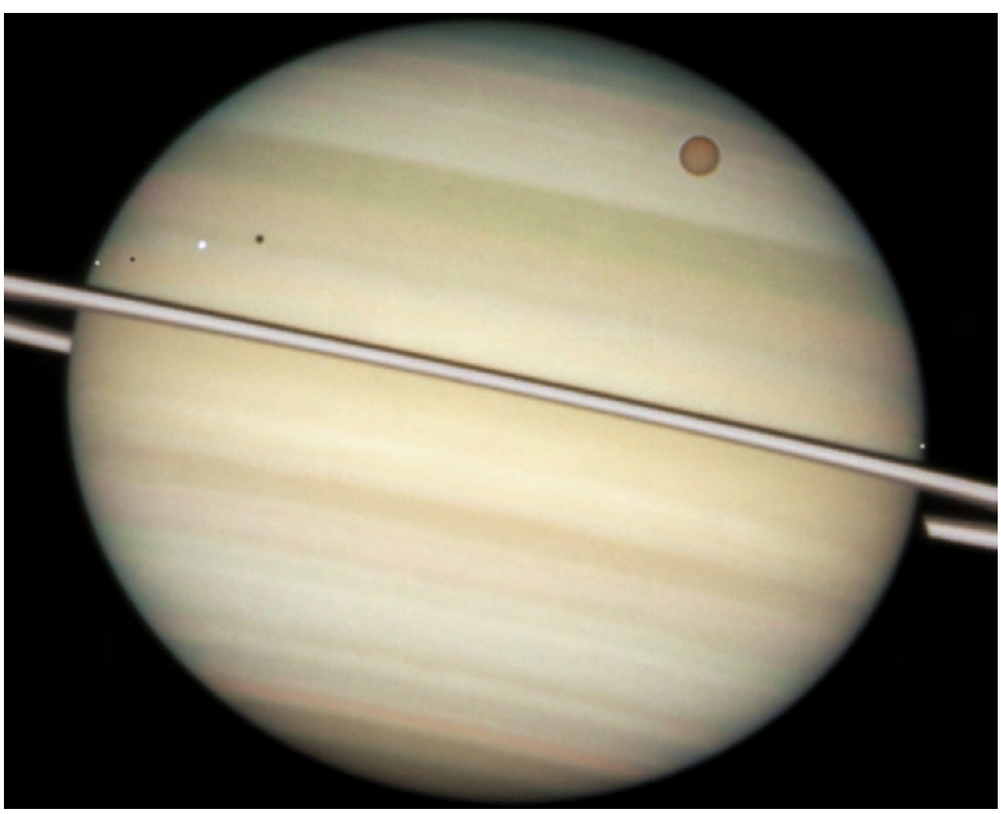


Image of Saturn's moon Mimas - from NASA spacecraft Cassini. Mimas is 396 km in diameter and its giant crater Herschel is 130 km across - giving an idea of the resolution which might be obtained by a probe to BB which is around 100-200 km in diameter.

Credit: NASA

A Mission

So should there be a mission to BB, presumably close to its perihelion at 10 AU? Telescopes cannot match orbiting probes even at Mars, about half an AU away at its closest, so in crude terms the argument for a probe is strong provided the results are desirable enough and the i4is Project Lyra team is already studying the possibility. Two contrasting images from Saturn, at the same 10 AU distance, suggest the case for a probe. Images are only part of the science to be gathered, of course, but they make the point.



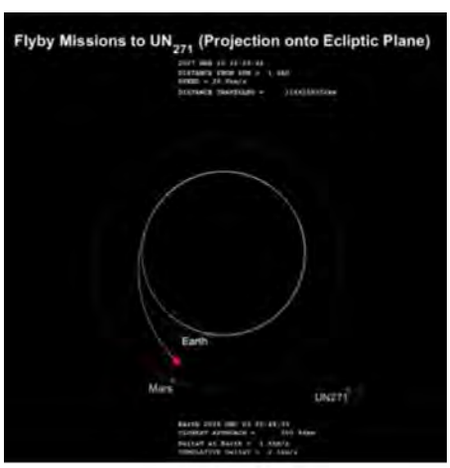
Contrasting with the Cassini image of Mimas here is what the Hubble telescope sees from its low Earth orbit. The image captures four moons of Saturn, 10 AU out from the Sun, which is as close as BB will be at perihelion. The ESA caption says "The giant orange moon Titan - larger than the planet Mercury - can be seen at upper right. The white icy moons that are much closer to Saturn, hence much closer to the ring plane in this view, are, from left to right: Enceladus, Dione, and Mimas." and "Hubble can see details as small as 300 kilometres across on Saturn." sci.esa.int/web/hubble/-/44464-quadruple-saturn-moon-transit-snapped-by-hubble

Credit: ESA/Hubble

Here is an early mission suggestion from Adam Hibberd, using his Optimum Interplanetary Trajectory Software (OITS) [1] and a combination of NOMAD and MIDACO-Solver [2]. This initial mission profile is -

Number	Encounter	Date	Sun Distance (AU)	Arrival Velocity (kms^{-1})	Departure Velocity (kms^{-1})	ΔV (kms^{-1})	Cumulative /W (kms^{-1})	Periapsis (km)
1	EARTH	2025 DEC 25	0.984	0.000	0.118	0.118	0.118	N/A
2	DSM @1.0AU	2026 JUN 03	1	29.670	29.679	0.543	0.661	N/A
3	EARTH	2026 DEC 03	0.986	0.443	5.727	1.392	2.053	200.8
4	MARS	2027 APR 18	1.656	10.279	10.279	0.000	2.053	206.1
5	EARTH	2028 OCT 03	1	8.816	12.119	2.269	4.322	200
6	2014 UN271	2033 AUG 06	11.952	12.658	12.658	0.000	4.322	N/A

After Earth departure with a velocity change (ΔV) 0.188 km/second (ie 188 metres per second - a modest 420 miles per hour) the probe to BB would execute a deep space manoeuvre (DSM) with ΔV 0.543 km/sec, a bigger push, to bring it back to Earth for a slingshot manoeuvre, rocket assisted by 1.392 km/sec. Mars would provide a "free" slingshot, no rocket assisted ΔV, to bring the probe back to Earth for a final slingshot manoeuvre, rocket assisted by 2.269 km/sec. Leaving on Christmas Day 2025 would enable a flyby of BB on 6 August 2033 at 12.658 km/sec. Adam has produced an animation of this proposal.



Animation of mission candidate using Mars gravitational assist - drive.google.com/file/d/1hMg1a848PblvBle0N08ie3d-BAdt-Olg/view

The apparent close proximity of C/2014 UN_{271} to Mars and its slow apparent motion is simply because this is a 2D projection onto the ecliptic. UN_{271} will cross the ecliptic almost vertically and probe would flyby as this happens.

The probe could clearly perform useful observations from well before to well after the encounter but it's worth noting that at 12.658 km/sec a distance of a 100 km diameter would take 100/12.658 = 7.9 seconds so much would need to be done in a relatively short time. The probe could, of course, release an impactor and, even without further rocketry, a 1 kg impactor would yield 160,000 kjoules[3] or about the equivalent of about 38 grams of TNT. The possible effect on a 100 km "dirty snowball" is clearly a "matter for further study".

Other considerations include the possibility of a rendezvous with BB, which would allow much more detailed investigation - more about that below. For a flyby, the best arrival time of the probe is when BB intersects the ecliptic around August 6th 2033 as in the mission profile above. By definition all of Earth's velocity is in the ecliptic plane and since the probe would be launched from Earth, to make optimal use of this velocity which it has been given by Earth, its trajectory would 'prefer' also to be in the ecliptic. Any deviation from that plane along its interplanetary trajectory would require an extra ΔV component out of the ecliptic, which would use up more fuel - and, of course, the "tyranny" of Tsiolkovsky's equation reminds us that all fuel to be used later has to be accelerated by fuel used earlier - except where you can steal momentum from a handy object which can spare it, such as Earth or Mars in our example. Thus Adam is finding that nearly all the good flyby trajectories arrive at BB around 2033 August 6th.

[1] See - *How to reach Interstellar Visitors, Optimum Interplanetary Trajectory Software* - in Principium Issue 27 November 2019.

[2] NOMAD - A blackbox optimization software (www.gerad.ca/nomad/) to get the general solution followed by MIDACO-Solver (Mixed Integer Distributed Ant Colony Optimization www.midaco-solver.com).

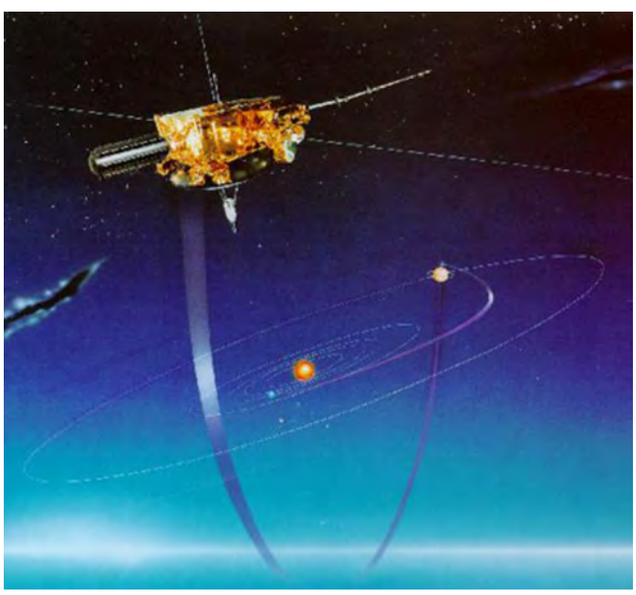
[3] Kinetic energy = $1/2mv^2$ =0.5*1*12,658² = 160,224,964 = 160,225 kjoules.

Is a rendezvous practical?

If our probe could rendezvous with BB the science rewards would be considerable! The opportunities for investigation can be imagined by the example of the Rosetta mission [1] to the comet 67P/Churyumov-Gerasimenko. The approach, orbit and subsequent landing of the subprobe Philae will not be forgotten by those who followed it in 2014.

For a rendezvous with BB the probe must apply ΔV on arrival to match its velocity with BB. Unfortunately when BB intersects the ecliptic the arriving probe velocity will be almost 90 degrees to that of BB meaning a massive change in its velocity. This is because the inclination of BB's orbit is over 90 degrees to the ecliptic. In other words it's flying through the ecliptic almost perpendicular to the plane of rotation of the Solar System. Thus for a rendezvous, the probe should aim to arrive at BB long after it has passed through the ecliptic so that the relative velocity of the probe and BB is at a much lower angle, allowing a much easier rendezvous manoeuvre. Although a gravity assist can also be used to divert a probe out of the ecliptic [2] the rendezvous challenge remains much more daunting than a flyby mission.

A rendezvous is also much more complex in terms of instrumentation, possibly including a lander like Philae, as well as a major challenge in terms of additional ΔV - even if Tsiolkovsky can be dodged using gravitational assistance!



Example of an out-of-ecliptic mission, visualisation of the unique orbit of the ESA Ulysses probe.

Credit ESA www.esa.int/Science_Exploration/Space_Science/Ulysses_overview

What next?

The team are looking at a range of potential missions and in much more detail than the above initial calculation and, of course, the science implications of such a mission. One unknown factor is the prevalence of such very large comets which, like the ISO 1I/'Oumuamua, cannot be confidently predicted from a single instance. Comet impacts are major concern for Earth defence and the existence of comets of this size, and possibly larger, makes the case for investigation even stronger, if only to inform future detection and countermeasures.

[1] www.esa.int/Enabling_Support/Operations/Rosetta

[2] Note the examples of the NASA Voyager 1 (35 degrees out of the ecliptic) and ESA Ulysses (80 degrees). See - T Franc, The Gravitational Assist, WDS 2011 - Proceedings of Contributed Papers, www.mff.cuni.cz/veda/konference/wds/proc/pdf11/WDS11_309_f12_Franc.pdf

2014 UN_{271} Spacecraft Missions

Adam Hibberd

Following his practical treatment of missions to interstellar objects. *Practicalities and Difficulties of a Mission to 'Oumuamua* in our last issue, Principium 33, Adam Hibberd here shows us how to reach another intriguing visitor to our solar system neighbourhood, C/2014 UN_{271} (Bernardinelli-Bernstein). This is, on good authority, the largest comet we have yet seen. More about the Bernardinelli-Bernstein (BB) comet and earlier thoughts on a mission in *Mission to 2014 UN271 using OITS*, a News Feature by John Davies published earlier in the members area of the i4is website and now elsewhere in this issue of Principium.

All images in this article are credit Adam Hibberd.

1 Flyby Missions

Flyby missions to UN_{271}, ie missions which approach and depart the objective without any significant correction to match velocities with the target, may be achieved by direct transfer from Earth to UN_{271} or using a combination of powered or unpowered gravitational assists. Normally we seek to minimize fuel usage and so maximize the useful payload mass. This general aim, which would in practice have to be studied in detail on a specific mission-by-mission basis, can nevertheless be addressed in a generic sense by various methods and adopting different assumptions.

1.1 Direct Transfer

In this section we assume a direct transfer to UN_{271} and that we wish to minimize the Hyperbolic Excess Speed at Earth, designated V_∞. Generally, in preliminary mission design of the kind adopted here, the task is to minimize some metric of the interplanetary trajectory, usually ΔV, the definition of this depending on the precise context. For the moment we shall assume $\Delta V = V_\infty$.

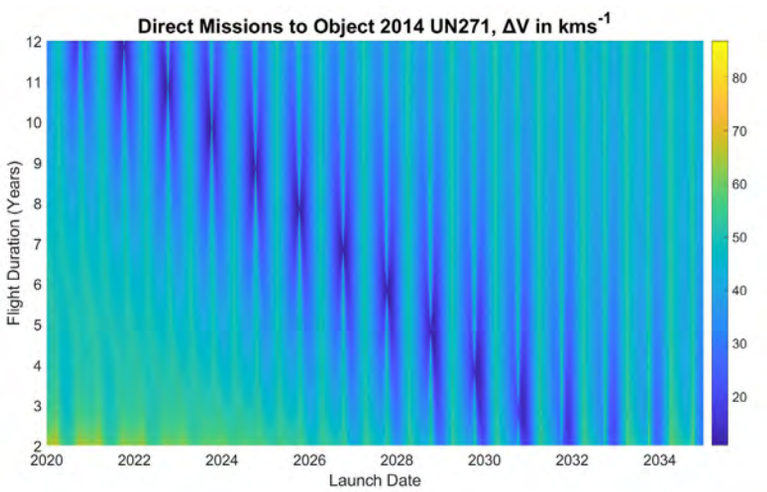
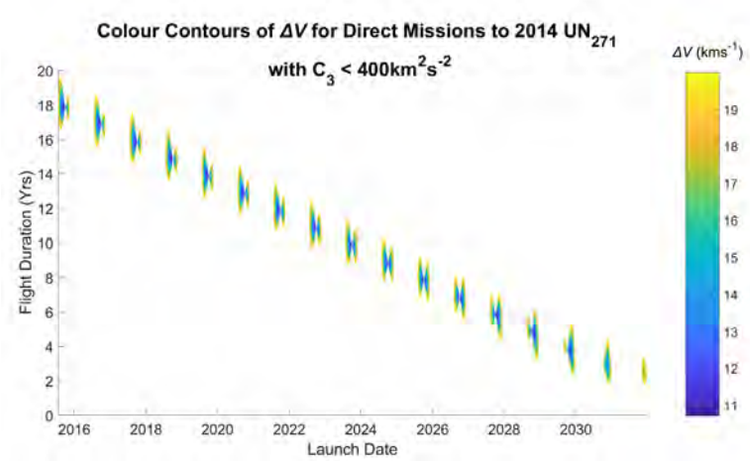


Figure 1: Direct trajectories, launch date versus flight duration, colour coded by ΔV see scale to right.

Figure 1 is a colour contour plot of direct trajectories, with two independent variables – on the x-axis are launch dates between 2020 and 2035 and on the y-axis are overall flight durations in years. The darker and bluer the colours, the lower the ΔV. We see in this contour plot the yearly patterns resulting from the Earth occupying yearly sweet spots in its orbit with respect to UN_{271}, at which points the relative alignment of the two bodies are particularly propitious for missions.



In Figure 2 we take Figure 1 results and filter out any trajectories for which the characteristic energy required at Earth, C_3 [1] is too large, specifically $C_3 > 400$ km²/s². (Note $C_3 = V_\infty^2$.)

Figure 2: Direct trajectories showing feasible characteristic energies only, launch date versus flight duration, colour coded by ΔV see scale to right.

Observe in Figure 2 that there are limited areas of realistic viability for direct flyby missions and they tend to follow a diagonal arrangement on the graph. In fact as we progress from year to year, the feasible flight durations reduce by

[1] **Characteristic Energy**. Earth departure energy (km2/s2), equal to the square of the departure excess velocity - see *NASA/TM—2010-216764 Interplanetary Mission Design Handbook:Earth-to-Mars Mission Opportunities 2026 to 2045 Glenn Research Center 2010* (ntrs.nasa.gov/api/citations/20100037210/downloads/20100037210.pdf). For example, the SpaceX Falcon Heavy, can achieve the C3 of 50.5 km²/s²

almost precisely one year, from which we can infer that there is an optimal arrival date at the object UN_{271}. Perhaps as one might expect, this date corresponds to when the comet reaches its Ascending Node [1] with respect to the ecliptic plane, a point at which a spacecraft sent from Earth would 'prefer' to intercept UN_{271}, as it can then use Earth's own planar velocity optimally to arrive at the target.

Numerical data on this is provided in Table 1 which gives a summary of the optimal launch scenarios displayed visually in Figure 2. Thus for launches between 2022 and 2027 inclusive, the optimal arrival date turns out to be 6 August 2033. For a launch date 2029 and beyond, there is simply insufficient time to intercept UN_{271} at its Ascending Node and the corresponding ΔVs increase.

Table 1 Optimal launch scenarios at feasible characteristic energies

Launch Date	Arrival Date	Flight Duration (Days)	Flight Duration (Years)	ΔV at Earth (km/s)	C_3 at Earth (km^2/s^2)	Arrival Velocity (km/s)	Phase Angle (deg) [2]
24 SEP 2022	06 AUG 2033	3969	10.87	10.77	115.92	13.74	114.89
27 SEP 2023	06 AUG 2033	3601	9.86	10.73	115.07	13.44	112.05
29 SEP 2024	06 AUG 2033	3233	8.85	10.70	114.43	13.13	108.47
02 OCT 2025	06 AUG 2033	2865	7.84	10.69	114.22	12.83	103.83
07 OCT 2026	06 AUG 2033	2495	6.83	10.72	114.87	12.57	97.64
13 OCT 2027	06 AUG 2033	2124	5.82	10.83	117.32	12.46	89.21
20 OCT 2028	07 AUG 2033	1752	4.80	11.13	123.85	12.77	77.66
31 OCT 2029	19 AUG 2033	1388	3.80	11.86	140.72	14.07	62.72
13 NOV 2030	25 OCT 2033	1077	2.95	13.63	185.82	17.02	47.38
26 NOV 2031	12 MAY 2034	898	2.46	17.06	290.97	20.46	37.01
03 DEC 2032	27 MAR 2035	844	2.31	21.71	471.15	22.56	31.31

1.2 Indirect Transfer

By contrast, an indirect transfer uses some combination of unpowered (without spacecraft thrust) or powered (with spacecraft thrust) Gravitational Assists (GAs) at one or more of the inner planets Venus, Earth and Mars, or the gas giant Jupiter.

1.2.1 Using Jupiter

By using Jupiter's mass, a combined Jupiter GA and Jupiter Oberth manoeuvre (in other words a powered GA) can be attempted as a possible strategy by which overall mission ΔV can be reduced compared to the direct case (Section 1.1). In this context, we define here the overall mission ΔV as the sum of V_∞ at Earth and the impulsive change in velocity required at perijove [3] to intercept and flyby UN_{271}.

We may inquire as to whether we can produce a colour contour plot for the mission here, ie using a Jupiter encounter, similar to that provided for the direct case in Section 1.1. The context here is more complicated in that there are two legs which combine to make the overall mission duration, the leg from Earth to Jupiter and that from Jupiter to UN_{271}.

[1] The **Ascending Node** is the point in an orbit at which the trajectory passes from below to above the reference plane. In this case the reference plane is the ecliptic, the plane of reference for the Solar System. Most planets orbit close to the ecliptic so we see the Solar System as more-or-less flat with just about all the angular momentum of the major bodies concentrated in the ecliptic. Comets from the Oort cloud, which is roughly spherical, are a major exception to this Solar System "traffic law"!

[2] **Phase Angle.** The angle between two lines subtended at the target body, the approach vector of the probe and the line between the Sun and the target body.

[3] **Perijove.** Closest approach to Jupiter. Corresponding to perihelion for the Sun and perigee for Earth.

However if we choose the optimal ratio of times for these legs (in terms of minimizing the previously defined ΔV) then we can construct a plot of the kind we are after. Thus refer to Figure 3.

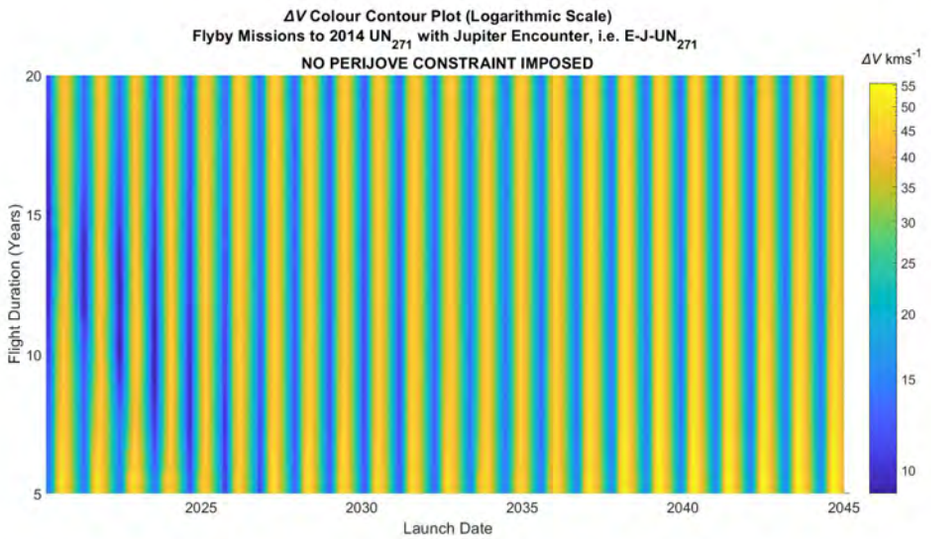


Figure 3: Indirect trajectories using Jupiter's mass with colour coded logarithmic ΔV scale.

Please note in Figure 3 the following:

1. There is no constraint on the minimum perijove altitude which the spacecraft can follow, thus this altitude may indeed be negative, obviously making the trajectory impossible to achieve in practice.

2. A logarithmic scale for ΔV is provided because of the large range of values this parameter can take.

3. There is no constraint on the perihelion distance along the interplanetary trajectory, ie from the Earth to Jupiter leg or the Jupiter to UN_{271} leg.

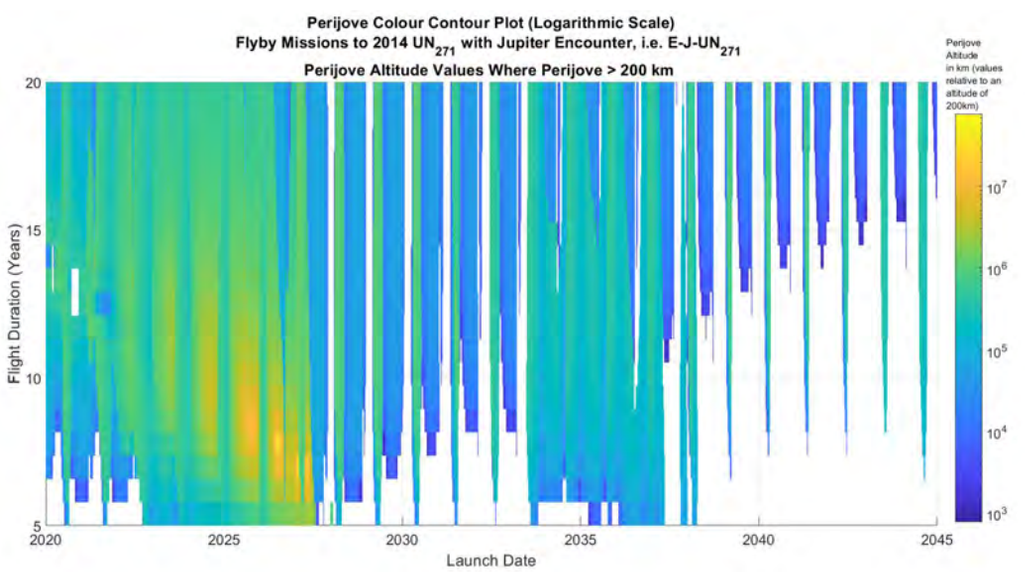


Figure 4: Avoiding bumping in to Jupiter! Colour codes vs reference altitude of 200km

To address first point (1), refer to Figure 4 which shows the perijove altitudes with respect to a reference altitude of 200 km. Again, due to the wide range of perijove altitudes required (a range of several orders of magnitude), a logarithmic scale is utilised. The white areas or gaps in this plot are where the perijove altitudes < 200 km have been removed.

Figure 5 takes the white areas in Figure 4 and removes them from Figure 3 and further neglects all trajectories for which the perihelion is < 0.5 AU. Figure 5 therefore represents feasible missions in terms of interplanetary trajectories and the orbital mechanics of the Jupiter encounter. Observe that there are two regions of general feasibility from around 2020 to 2027 and then again from 2034 to 2037. In both regions there exist gaps of infeasibility but more importantly, also regions of low ΔV.

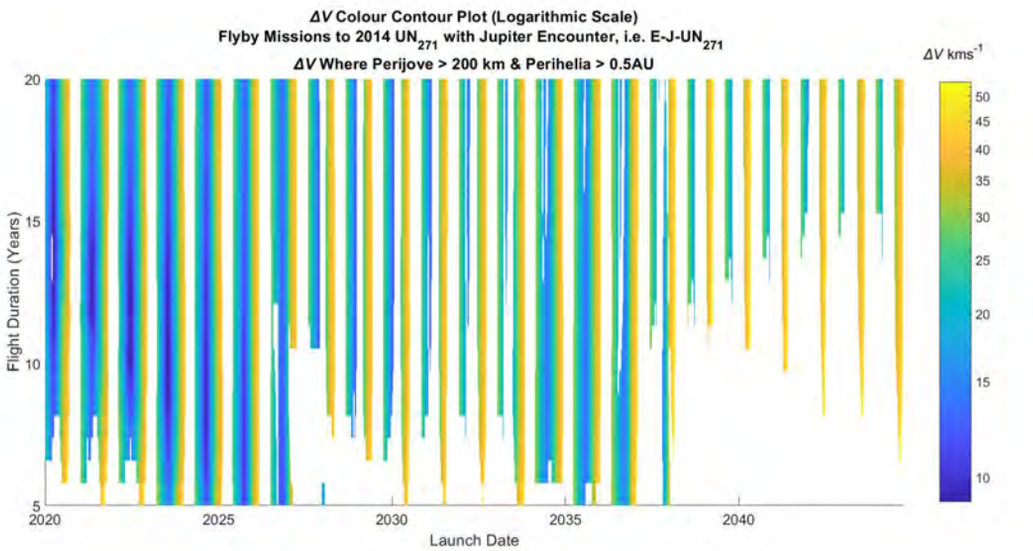


Figure 5: Feasible missions in terms of interplanetary trajectories and the orbital mechanics of the Jupiter encounter.

For an example trajectory involving launch in the year 2022, the minimal ΔV trajectory involves a launch on 21 JUN 2022, the ΔV is 8.9 km/s (all of which is V_∞) and the arrival speed relative to UN_{271} is 14.5 km/s, with a perijove altitude of 660,286 km. This can be compared to the New Horizons spacecraft where V_∞ = 12.6 km/s, perijove altitude was 2,300,000 km and the arrival speed was 13.8 km/s.

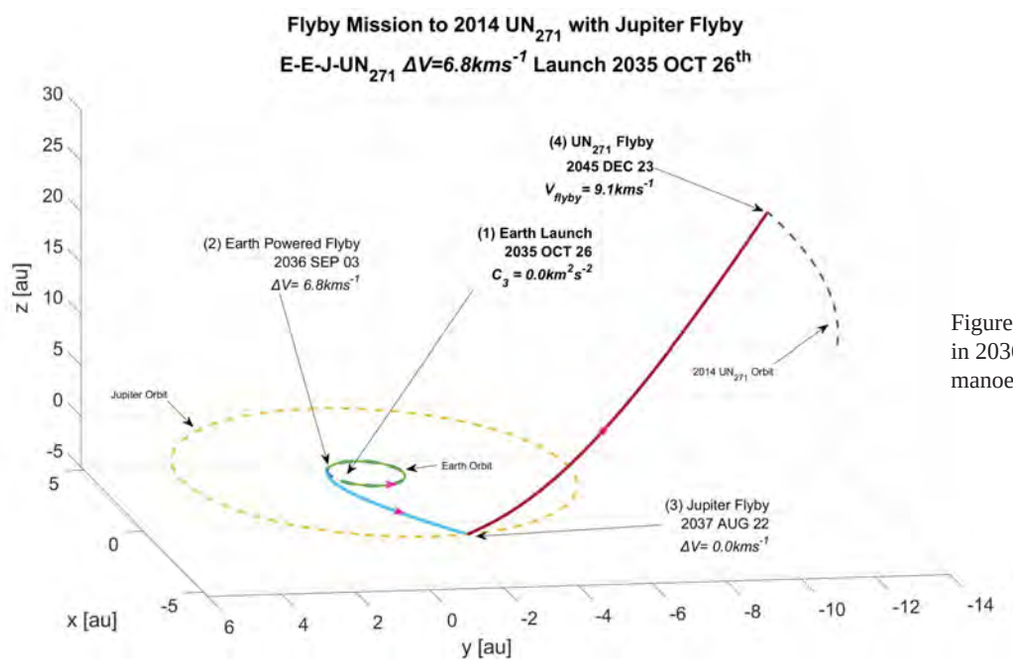


Figure 6: trajectory for a launch in 2036 with one year leveraging manoeuvre.

If we home in on the second of these intervals, 2034 to 2037, specifically a launch in 2036 and furthermore precede the trajectory from Earth to Jupiter by a one year leveraging manoeuvre with a 1:1 Earth resonance [1] we find the trajectory shown in Figure 6. This leveraging has the benefit of significantly reducing the C_3 at Earth launch, in fact to zero.

In addition it would seem the overall ΔV is reduced, however this is partly as a result of the definition of ΔV we have used. Clearly a C_3 = 0.0 km^2/s^2 ignores the contribution to the ΔV required by the launch vehicle in question.

[1] Orbital resonance - hosting.astro.cornell.edu/academics/courses/astro6570/orbital_resonances.pdf

1.2.2 Using the Inner Planets

Various combinations of inner planets were tried and there can be no guarantee with OITS as to whether a global optimum is reached, in terms of both (a) finding an optimal solution trajectory in a user-specified sequence of planetary encounters, and (b) finding the globally optimum sequence of encounters.

In the case of (b), it is the responsibility of the user to specify to OITS the precise combination and sequence of encounters to adopt and it is therefore a question of trying many such combinations, running OITS many times, and concentrating on those which are the best in terms of minimizing ΔV. Table 2 provides a summary of the results. Note a preceding one year leveraging manoeuvre, with a launch one year before the optimal launch dates provided would generally serve to reduce the overall ΔV for the trajectories and also to reduce the C_3 needed at Earth to 0.0 km^2/s^2.

The lowest ΔV of 5.54 km/s in Table 2 corresponds to the sequence E-Vr-V-E-UN_{271} (with the Venus-Venus segment incorporating a Deep Space Manoeuvre at a 2:1 resonance with Venus, ie at 1.57 AU). The launch is 2028 MAR 10, and arrival at UN_{271} is on 2033 OCT 18.

Table 2. Minimum ΔV trajectories from multiple OITS runs.

Trajectory (r=resonance)	Aphelia for Resonances and heliocentric distance of DSM (AU)	Launch Date	Arrival Date	Total ΔV (km/s)	C_3 (km^2/s^2)	Approach Velocity (km/s)	Arrival Helio-centric Distance (AU)	In-flight ΔV (km/s)	Phase Angle (deg)
E-Vr-V-E-UN_{271}	1.57	2028 MAR 10	2033 OCT 18	5.53	10.35	13.5	12.11	2.32	114.89
E-V-Er-E-UN_{271}	2.20	2026 AUG 06	2033 SEP 09	6.42	12.6	14.01	12.02	2.87	116.01
E-Vr-Vr-V-UN_{271}	1.57, 2.92	2025 JAN 07	2033 NOV 12	6.50	13.7	12.5	12.16	2.8	103.90
E-Vr-Vr-V-UN_{271}	1.57, 2.28	2025 JAN 11	2033 NOV 11	7.04	13.63	12.2	12.16	3.34	95.68
E-Vr-V-M-V-UN_{271}	1.57	2025 FEB 04	2033 OCT 15	7.23	13.9	11.97	12.1	3.5	89.60
E-Vr-V-UN_{271}	2.28	2025 MAR 03	2033 NOV 11	7.31	15.8	12.23	12.16	3.34	83.14
E-Vr-V-M-DSM-V-UN_{271}	1.57, DSM = 2.28	2025 FEB 08	2033 NOV 25	7.52	14.34	11.97	12.19	3.73	95.13
E-Vr-V-UN_{271}	1.57	2025 MAR 12	2033 NOV 03	7.81	17.38	12.38	12.16	3.64	101.32
E-M-E-UN_{271}	N/A	2026 NOV 26	2033 AUG 07	7.83	30.48	12.65	11.9	2.31	102.16
E-Vr-V-M-DSM-V-UN_{271}	1.57, DSM = 2.92	2025 MAR 18	2033 NOV 27	9.86	35.26	12.57	12.19	3.92	103.17
E-Vr-V-E-DSM-V-UN_{271}	1.57, DSM = 2.28	2025 JAN 02	2033 OCT 03	10.32	8.4	12.22	12.07	7.42	96.96

2 Rendezvous Missions

Unlike flyby missions, covered in Section 1, rendezvous missions involve an application of thrust as the target is approached to match velocities with it.

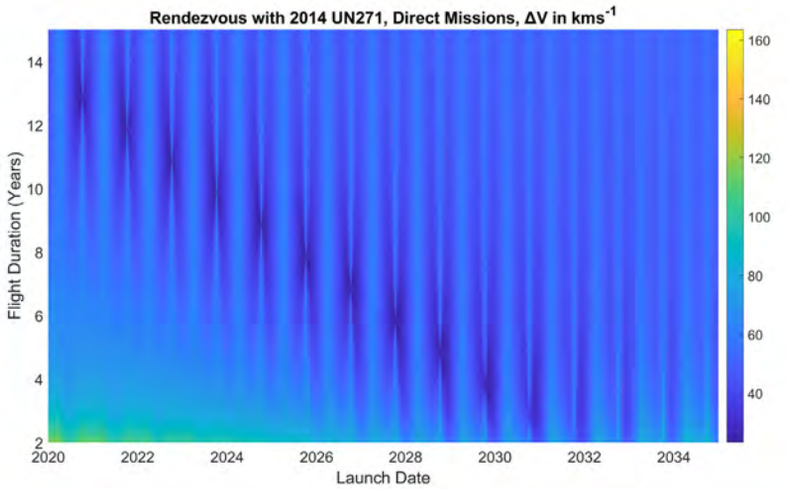


Figure 7: Direct Transfer, launch date versus flight duration,. Adding ΔV at the target to achieve rendezvous.

Colour coded by ΔV see scale to right.The darker and bluer the colours, the lower the ΔV.

Note ΔV always exceeds 20.0 km/s.

Compare Figure 1 in Section 1.1 which shows the flyby case.

2.1 Direct Transfer

A colour contour plot is provided in Figure 7 which is analogous to Figure 1 in Section 1.1, but in addition to the V_∞ needed at Earth, has an extra ΔV at the target, UN_{271}, in order to rendezvous with it. The main conclusion which can be drawn from this, is that the total ΔV required for this is much larger, and in fact always exceeds 20.0 km/s.

2.2 Indirect Transfer

2.2.1 Using Jupiter

Analogous contour plots to those used for the flyby case provided in Section 1.2.1 can be constructed for the rendezvous case and are provided in Figures 8 to 10.

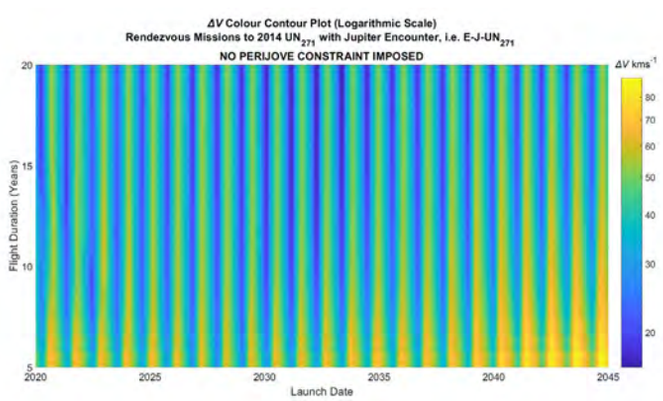


Figure 8: Theoretical optimal launch dates for a rendezvous mission with a single Jupiter encounter.

From Figure 8, we can observe that the theoretical optimal launch dates for a rendezvous mission with a single Jupiter encounter (without filtering out negative perijove altitudes) are around 2030 to 2034 and with flight durations around 14-15 years.

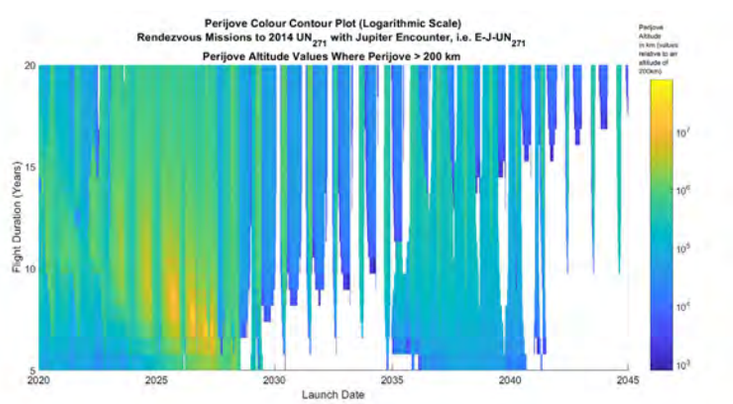


Figure 9: Rendezvous mission with a single Jupiter encounter and limited perijove.

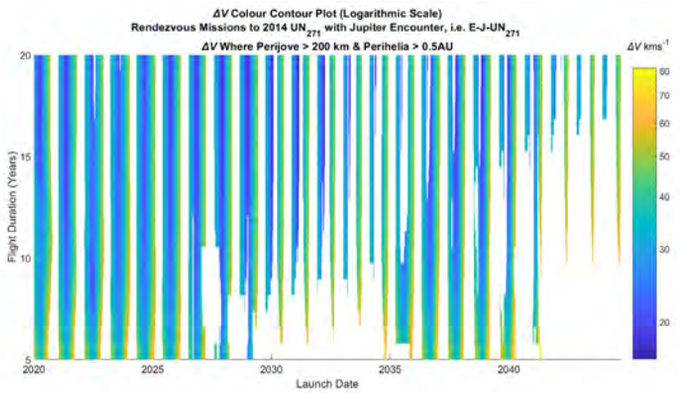


Figure 10:. Feasible trajectories for rendezvous via Jupiter with limited perihelion and perijove.

From Figure 10 we can see that when we remove negative perijove altitudes and low perihelia, most of the landscape for the region 2030 to 2034 is removed and is in fact infeasible.

However there are also regions of feasibility and to take a case in point, we assume a launch in 2032 and flight duration 14 years from Figure 10 and precede it by an Earth leveraging manoeuvre with 1:1 resonance (to make the launch one year earlier) and we get the trajectory shown in Figure 11.

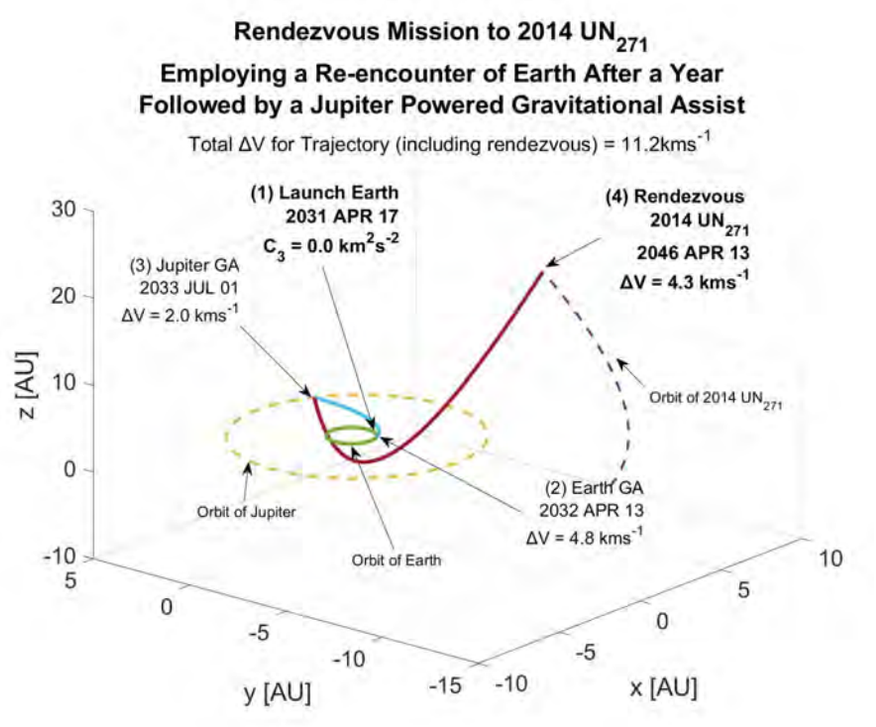


Figure 11: Selected trajectory for launch in 2032 and flight duration 14 years.

Note that the optimal Rendezvous point is not in the ecliptic plane, contrary to what was observed for direct missions.

The reasons for this are:

• An intercept with UN_{271} in the ecliptic plane would inevitably mean that the angle between approach velocity of the spacecraft and the velocity of UN_{271} would be around 90°. This is because the orbital inclination of UN_{271} is just over 90° which means on crossing the ecliptic its velocity will primarily be along the heliocentric z-axis direction.

• The magnitude of the velocity of UN_{271} reduces as it becomes further displaced from the ecliptic plane making the change in velocity of the spacecraft more manageable.

About The Author

Adam Hibberd was educated at a state school, Stoke Park Comprehensive School and Community College, in Coventry and attended the University of Keele, gaining a joint honours degree in physics and maths. He worked in the '90s as a software engineer on the on-board flight program for the European Ariane 4 launch vehicle - including the production, maintenance, real-time testing and post-flight analysis, his expertise being the guidance algorithm. He is also a pianist and composer and, as a member of musical trio 'Superheroes Dream', produced a vinyl under the Coventry Tin Angel Record Label. More about *Adam's Music and Space Research* - adamhibberd.com.

Adam developed his Optimum Interplanetary Trajectory Software, 'OITS' in 2017 as a personal challenge to learn the MATLAB programming environment and language. He then used it to investigate missions to interstellar objects (the work being published in Acta Astronautica) and is now a research volunteer for i4is.

The i4is Members' Page

The i4is membership scheme launched in December 2018 and we are now adding new members-only material to the website regularly. Membership of i4is draws together all who aspire to an interstellar future for humanity. Your contribution, together with the voluntary work of our team and their donation of their own expenses helps us to take the vital early steps toward that goal.

You need to login with your i4is identity to access members' content. If you are not yet a member you can sign up via - i4is.org/membership - or simply find out more about membership. We'll keep you up to date as we add to this content, both in the next issue of Principium and in our members' email newsletter.

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2021 Third Series

8th June — Adam Hibberd — Guidance of the Ariane 4 launch vehicle

15th June — Rob Swinney — New Limitless Space Institute Course — Open

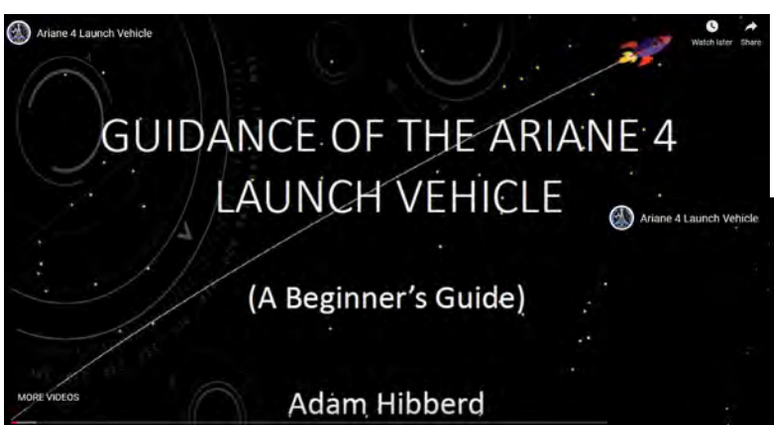
22nd June — John Davies — Visions of our Interstellar Future

29th June — Terry Regan — Scratch Modelling Conventional and Interstellar Spacecraft

6th July — Frederic Schoutetens — Optimisation of Photon-Sail Trajectories in Alpha Centauri using Evolutionary Neurocontrol

13th July — Satinder Shergill — The Role of In-Space Resource Utilisation (ISRU) as an Enabler for Human Expansion into the Solar System and Beyond

20th July — Robert Kennedy III — Humanity's Power Basis for Starfaring



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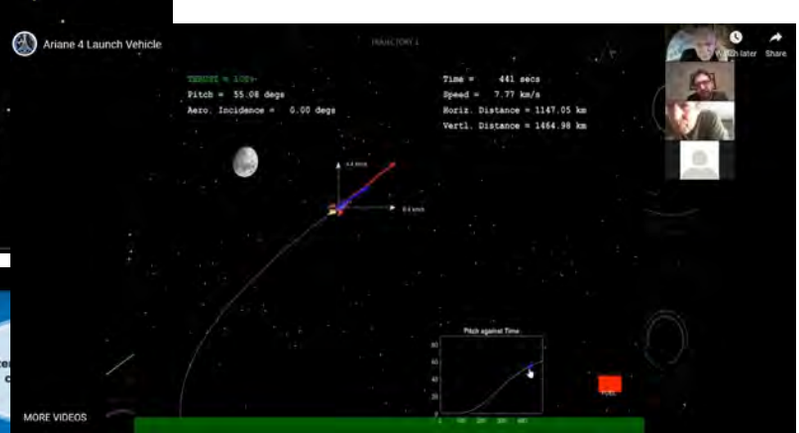

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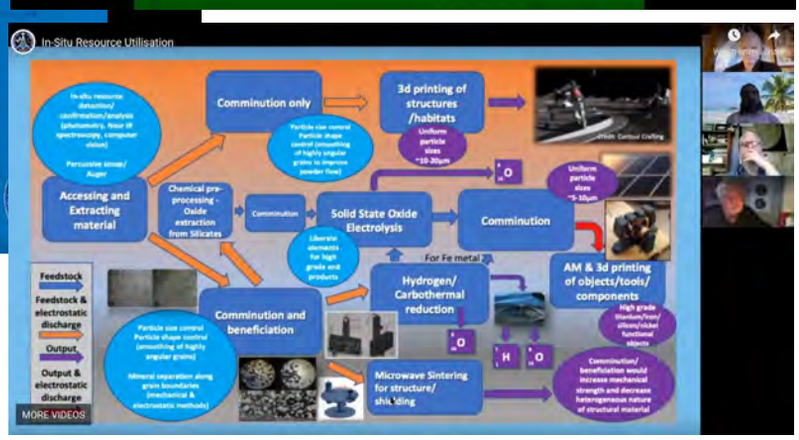

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26th January — John Davies — The Interstellar Downlink — Open

2nd February — Olivia Borgue — Advanced Propulsion 2 (Nuclear etc)

9th February — Adam Hibberd — 'Optimum Interplanetary Trajectory Software', from Interplanetary to Interstellar

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23th February — Dan Fries — Interstellar Travel using Einsteinian Physics — Open

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10th November — Dr Andreas Hein — Worldship Design

17th November — Dan Fries — An Introduction to Advanced Propulsion

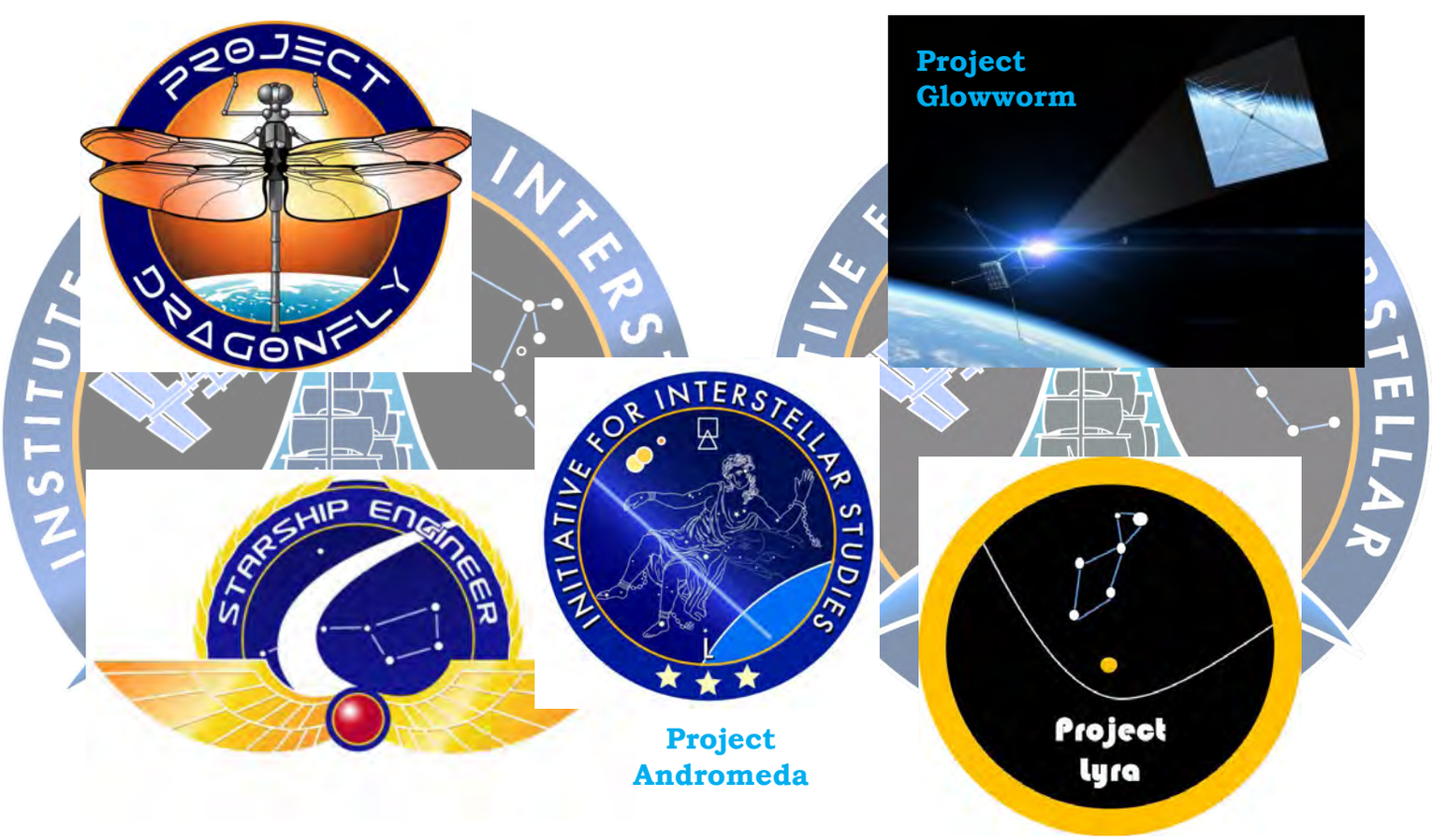
24th November — Robert Swinney — Interstellar Precursor Missions

1st December — Patrick Mahon — Science Fiction Interstellar Starships — Open

Members' Newsletter

i4is members have received this Members Newsletter since our last Principium issue -

Newsletter: Interstellar Studies Summer Course, and lots of new videos - 08/07/2021
i4is.org/newsletter-interstellar-studies-summer-course-and-lots-of-new-videos/



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Our membership is growing worldwide but we can do better with your help. Our project logos show some of what we have done and are still doing - and there is more to come.

We repeat ourselves here but if you would like to help you can find all the ideas from last time at -

i4is.org/wp-content/uploads/2021/05/The-i4is-Members-Page-Principium33-print-2105280923opt.pdf

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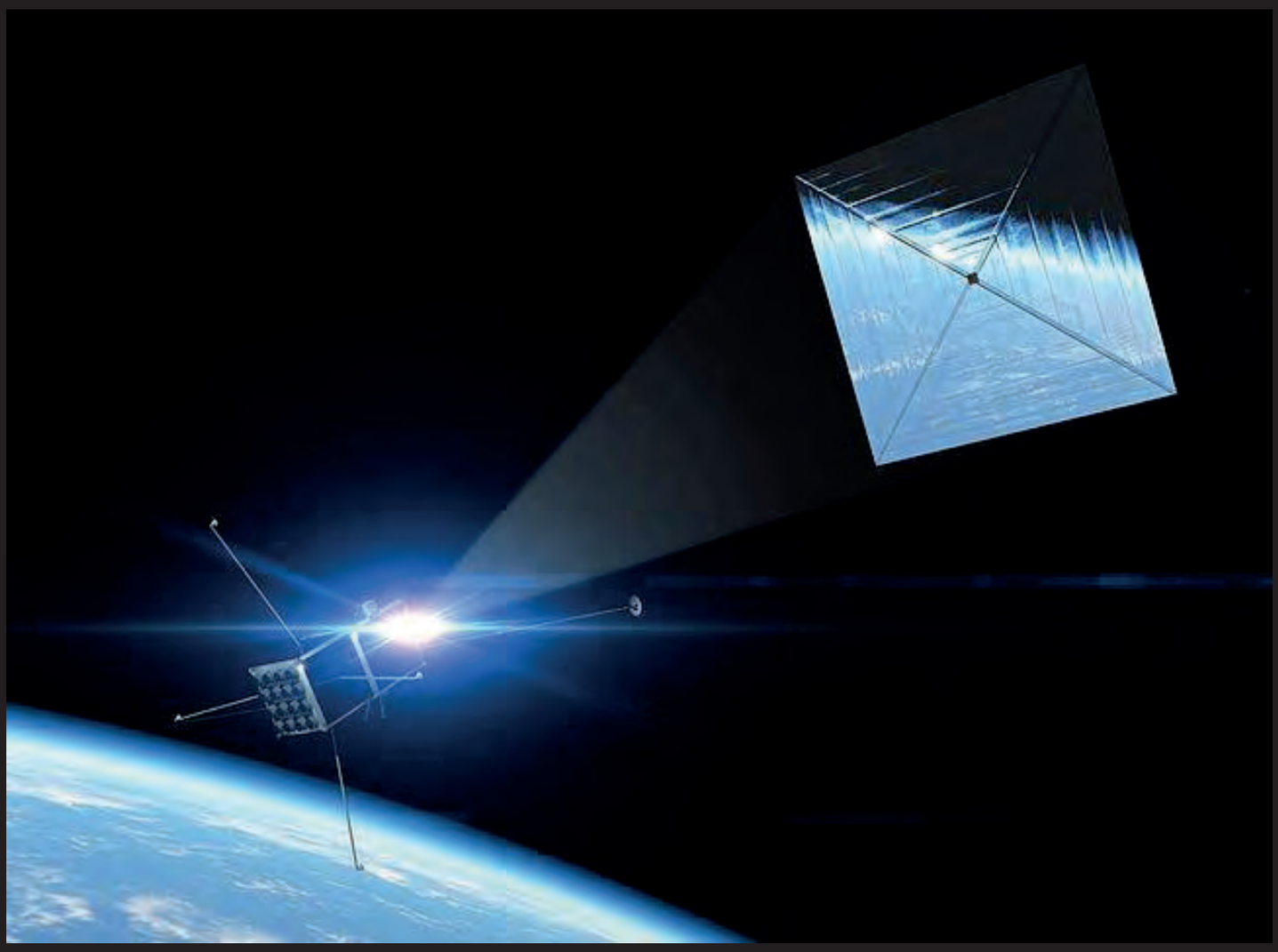

The Initiative for Interstellar Studies (i4is) has launched a membership scheme intended to build an active community of space enthusiasts whose sights are set firmly on the stars. We are an interstellar advocacy organisation which:

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> **"Every revolutionary idea seems to evoke three stages of reaction.**
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> **(1) It's completely impossible.**
> **(2) It's possible, but it's not worth doing.**
> **(3) I said it was a good idea all along."**
>
> **Arthur C Clarke**

i4is formed in 2012. Nine years on, we're making great strides in our technical research, education and outreach programmes. We are a growing community of enthusiasts who are passionate about taking the first steps on the path toward travel beyond our solar system. Our ambitions are sky high, but to achieve them we need your support.

The best way you can support our mission is to become a subscribing member. If you want to, and have the time, we would love you to get actively involved with our projects. But we appreciate that not everyone who shares our interstellar vision can do this. Becoming a member is a great way to show your support and help us expand our activities.

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- The role of In-Space Resource Utilisation (ISRU) as an enabler of human expansion;
- Optimising solar sail trajectories to Alpha Centauri using evolutionary neurocontrol;
- Guidance of the Ariane 4 launch vehicle; and
- Visions of our interstellar future.

Our most recent newsletter gave members early information on, and the opportunity to register for, a summer course on 'Human Exploration of the Far Solar System and on to the Stars', which was successfully delivered by i4is on behalf of Limitless Space Institute last month.

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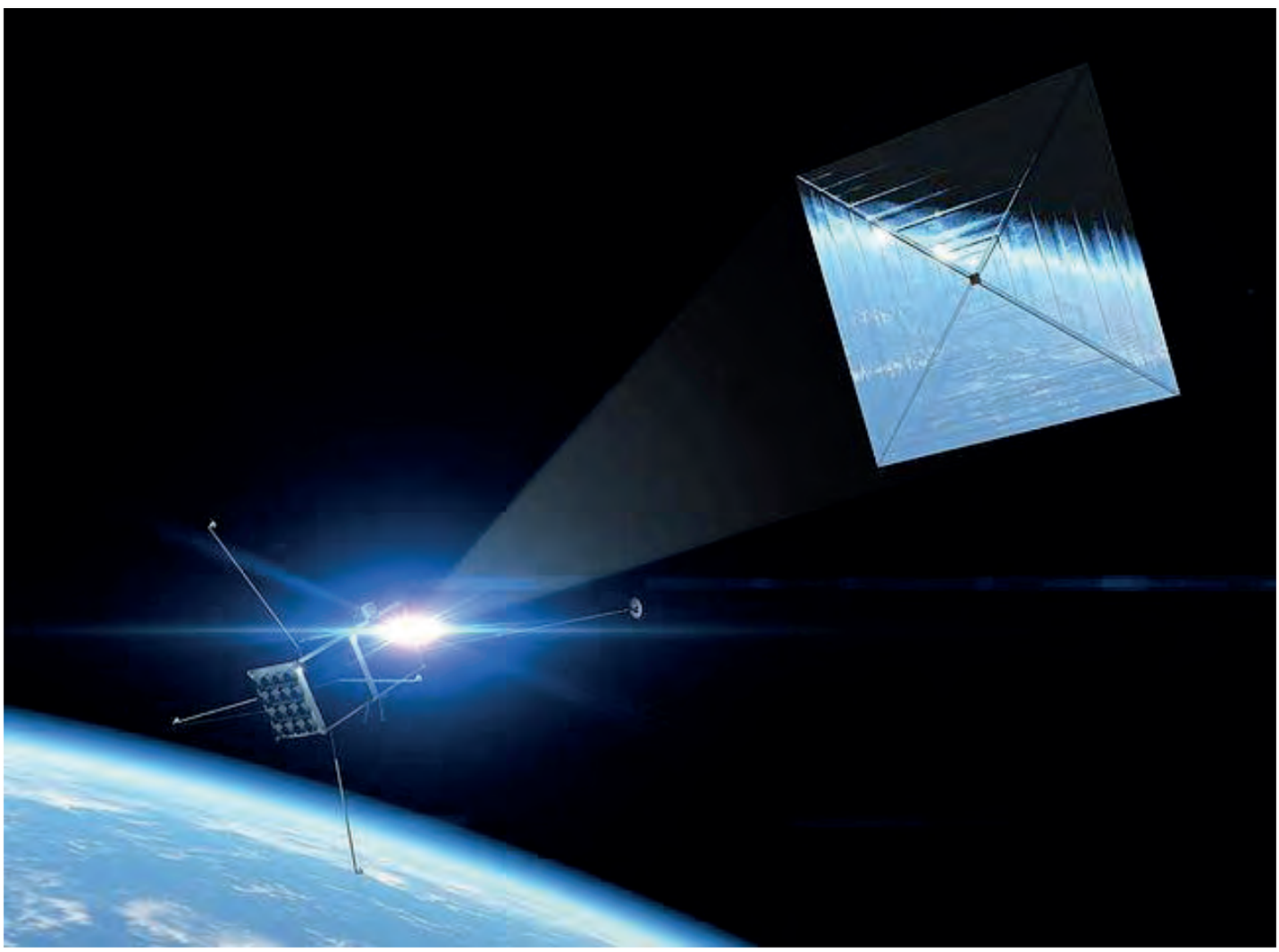
JOIN I4IS ON A JOURNEY TO THE STARS!

Do you think humanity should aim for the stars?

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



The 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.

Join us and get:

- early access to select Principium articles before publicly released;
- member exclusive email newsletters featuring significant interstellar news;
- access to our growing catalogue of videos;
- participate in livestreams of i4is events and activities;
- download and read our annual report.

To find out more, see www.i4is.org/membership
90% discount for full time students!

NEXT ISSUE

Interstellar Downlink Communications
Icarus Firefly downlink and BIS Daedalus downlink
The downlink from swarming micro-probes

Conference reports:
Interstellar at the *72nd International Astronautical Congress, Dubai, October*
IRG 7th Interstellar Symposium, Tucson, September

Course report: first running of -
***Human Exploration of the Far Solar System and on to the Stars* -**
- by i4is for the Limitless Space Institute

Cover Images

Our cover images have a common thread this time - obstructions to our ambitions in space.

Front Cover

Our front cover image is the star system LL Orionis showing its "solar wind" colliding with the interstellar medium (ISM) - reminding us that interstellar space is a fine vacuum but not a perfect one. LL Orionis is a young and active star emitting a relatively powerful outward flux of particles, the equivalent of the solar wind emitted by our own star, the Sun. The "bow shock" this produces was captured by the Hubble space telescope back in 1995. The ISM is one of the major obstacles which fast interstellar spacecraft must face if travelling at substantial fractions of the speed of light. Both the fusion propelled studies, Daedalus and Icarus, and the laser propelled proposals, i4is Dragonfly/Andromeda and Breakthrough Starshot, have had to confront this battering by the ISM.

The image was NASA Astronomy Picture of the Day 22 May 2016 apod.nasa.gov/apod/ap160522.html.

Back Cover

Our rear cover image is a visualisation by the European Space Agency of the scale of the space debris problem around Earth. If we do not deal with this, both by preventing further debris and by disposing of existing debris, then access to space from Earth will be curtailed. The extreme form of this catastrophe was imagined in the film *Gravity* with the demise of the International Space Station. A brilliant film which nevertheless had lots of implausible Hollywood gloss. But the problem it highlights, that space debris can "self replicate" by collision, is real. And if we don't solve the space debris problem then it will be increasingly difficult to get off Earth, or to the rest of the Solar System and the stars.

The image is a shot from ESA's latest space debris movie: *Time to Act* www.esa.int/ESA_Multimedia/Videos/2021/04/Time_to_Act.

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.

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

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Front cover: LL Orionis "bow shock"
Credit: NASA

Back cover: Visualisation of the scale of the space debris problem around Earth
Credit: ESA

i4is.org

Scientia ad sidera
Knowledge to the stars