IAC 2022

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

edited by John I Davies

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

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

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

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

The Congress was divided into these main subject areas -

A1. IAF/IAA SPACE LIFE SCIENCES SYMPOSIUM

A2. IAF MICROGRAVITY SCIENCES AND PROCESSES SYMPOSIUM

A3. IAF SPACE EXPLORATION SYMPOSIUM

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

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

A6. 20th IAA SYMPOSIUM ON SPACE DEBRIS

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

B1. IAF EARTH OBSERVATION SYMPOSIUM

B2. IAF SPACE COMMUNICATIONS AND NAVIGATION SYMPOSIUM

B3. IAF HUMAN SPACEFLIGHT SYMPOSIUM

B4. 29th IAA SYMPOSIUM ON SMALL SATELLITE MISSIONS

B5. IAF SYMPOSIUM ON INTEGRATED APPLICATIONS

B6. IAF SPACE OPERATIONS SYMPOSIUM

C1. IAF ASTRODYNAMICS SYMPOSIUM

C2. IAF MATERIALS AND STRUCTURES SYMPOSIUM

C3. IAF SPACE POWER SYMPOSIUM

C4. IAF SPACE PROPULSION SYMPOSIUM

D1. IAF SPACE SYSTEMS SYMPOSIUM

D2. IAF SPACE TRANSPORTATION SOLUTIONS AND INNOVATIONS SYMPOSIUM

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

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

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

D6. IAF SYMPOSIUM ON COMMERCIAL SPACEFLIGHT SAFETY ISSUES

E1. IAF SPACE EDUCATION AND OUTREACH SYMPOSIUM

E2. 50th STUDENT CONFERENCE

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

E4. 56th IAA HISTORY OF ASTRONAUTICS SYMPOSIUM

E5. 33rd IAA SYMPOSIUM ON SPACE AND SOCIETY

E6. IAF BUSINESS INNOVATION SYMPOSIUM

E7. IISL COLLOQUIUM ON THE LAW OF OUTER SPACE

E8. IAA MULTILINGUAL ASTRONAUTICAL TERMINOLOGY SYMPOSIUM

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

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

GTS. GLOBAL TECHNICAL SYMPOSIUM

LBA. LATE BREAKING ABSTRACTS

◀ The Reports

In this issue, sorted by IAC22 reference-

IAC22 reference	Title	Presenter	Institution	Country	P#
A.1.6.4.x73104	Space exploration of icy moons to determine their astrobiological potential	Athena Coustenis	Paris University	France	30
A.3.5.2.x71874	Exploration of Venus Using Bioinspired Flier, BREEZE	Mr Nicholas Noviasky	University at Buffalo	USA	28
A3.5.4.x70283	Feasibility study of a robotic space mission for searching trace of life on Europa	Mr. Mario Rizzi [1]	Politecnico di Torino	Italy	22
A4.2.7.x70624	SETI Space Telescope Mission Concepts Designed Around Upcoming Fully-Reusable Launch Vehicles	Mr Eric Michaud	MIT	USA	23
A5.4-D2.8.2.x72880	NASA Envisioned Future Priorities for In-Space Transportation	Mr John Dankanich	NASA	USA	41
A5.4-D2.8.4.x68378	Mission to Mars Using Space-Sourced Propellant	Dr Jan Thoemel	University of Luxembourg	Luxem-bourg	36
C2.3.8.x73418	Dynamic Stability of Flexible Lightsails for Interstellar Exploration	Dr Michael Kelzenberg	Caltech	USA	40
C3.4.1.x73419	Power for Interstellar Lightsails	Mason Peck et al	Cornell University	USA	32
D2.4.9.x67466	Interplanetary transfer network design and technology roadmap for a sustainable off-world human community	Mr Koldo Zuniga	Cranfield University	UK	26
D4.1.12.x70259	Advancements in Laser Propulsion for Relativistic Lightsail Missions	Mr Wesley Green	Breakthrough Initiatives, Starshot	USA	39
D4.3.1.x67635	KEYNOTE: Space Elevators as a Transformational Leap For Human movement off-planet	Dr Peter Swan	International Space Elevator Consortium	USA	34
D4.3.4.x69339	Space Elevator tether materials: An overview of the current candidates	Dr Adrian Nixon	Nixene Publishing	UK	37
D4.4.1.x70268	10%: The First 10 Years of the 100 Year Starship	Jason D Batt	100 Year Starship	USA	33
D4,4,4,x69452	Stella: Europe’s contribution to a NASA interstellar probe	Prof Stanislav Barabash	Swedish Institute of Space Physics	Sweden	44
D4.4.10.x73530	Stella science for interstellar probe	Prof Dr Robert F Wimmer-Schweingruber	University of Kiel	Germany	44
D4.4.11.x70087	The Pragmatic Interstellar Probe Study: The Evolutionary Journey of our Habitable Astrosphere	Dr Pontus Brandt	Johns Hopkins University Applied Physics Laboratory	USA	24
D4.4.5.x72336	Performance Map for Laser-Accelerated Sailcraft Missions	Dr Kevin Parkin	Parkin Research LLC	USA	25
D4.4.9.x69502	The Pragmatic Interstellar Probe Study: Results	Dr Ralph L McNutt, Jr	Johns Hopkins University Applied Physics Laboratory	USA	38

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◀ The Papers

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

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

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

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

Open paper: none found

Reported by: Adam Hibberd

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

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

The mission has 3 elements:

1) An orbiter

2) A lander

3) A probe for deep subsurface exploration

Here's the suggested instrumentation for the three components -

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

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

Goals:

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

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

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

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

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

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

IAF cited paper: none available

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

Open paper: none found

Reported by: Adam Hibberd

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

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

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

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

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

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

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

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

Open paper: none found

Reported by: Al Jackson

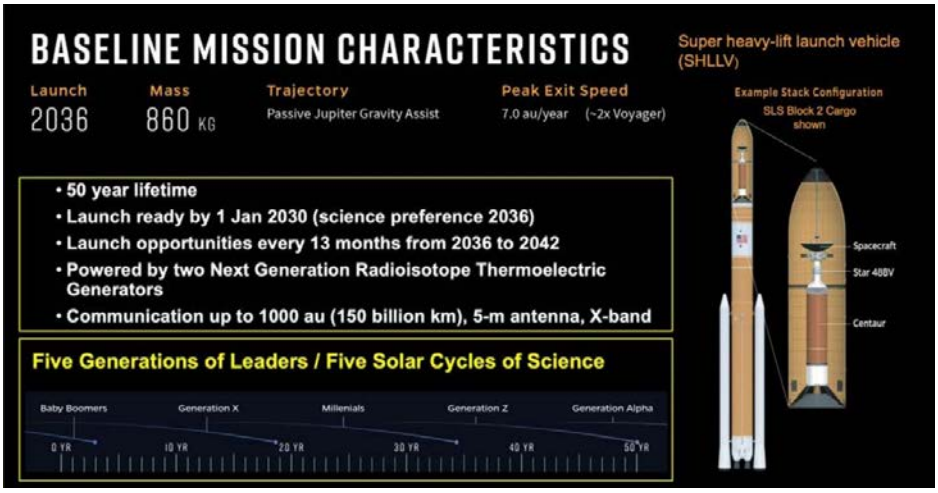
In 1987 JPL proposed a mission to send a nuclear powered spacecraft to 1,000 astronomical units (TAU). This would have been a dedicated unmanned probe to study 'near' interstellar space, quite apart from solar system probes like Voyager and New Horizons. There have been several detailed studies and proposed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

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

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

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

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



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

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

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

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

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

Open paper: none found

Reported by: Al Jackson

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

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

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

Table 1: System model constants

1.06 µm wavelength

60 000 km initial sail displacement from laser source

0.2 g m^{-2} areal density

10^{-8} spectral normal absorptance at 1.06 µm
70% spectral normal reflectance at 1.06 µm

625 K maximum temperature

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

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

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

\$50 kWh^{-1} storage cost (k_s)
\$0.1 kWh^{-1} grid energy cost (k_g)

100% grid to storage efficiency (η12)

50% storage to laser efficiency (η23)

70% transatmospheric propagation efficiency (η_a)

100 operations included in cost minimization (n_o)

System model constants. Credit: Parkin

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

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

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

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Open paper: none found

Reported by: Graham Paterson

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

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

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

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

A prior example - American colonisation

Credit (caption and image): Zuniga et al

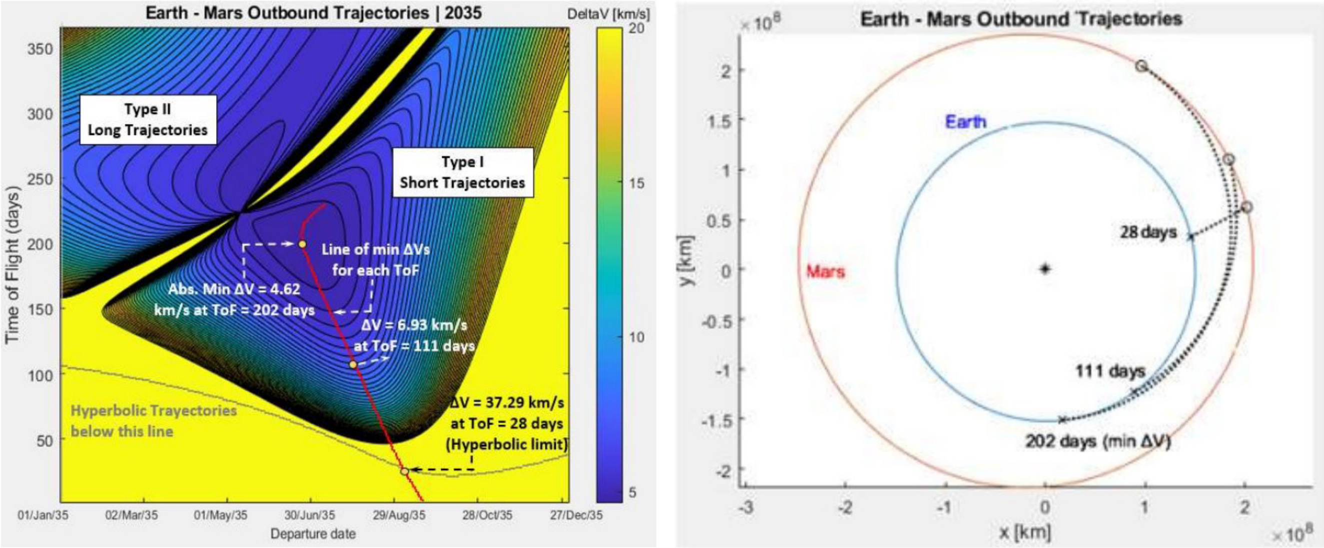
Refs are in the paper

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

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

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

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



Example "pork chop" plot and trajectories

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

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

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

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

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

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

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

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

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

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

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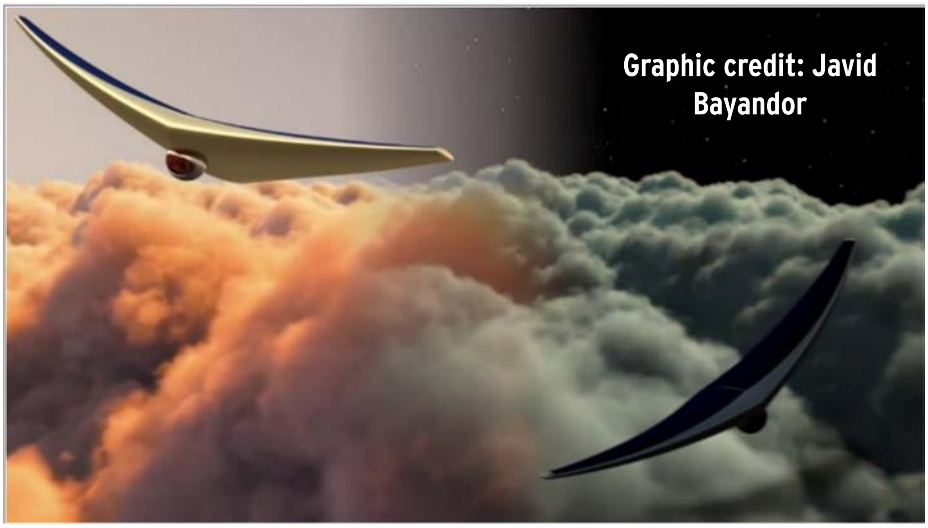
Open paper: none found

Reported by: Graham Paterson

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

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



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

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

The authors then report the science objectives as being

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

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

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

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

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

Web references:

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

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

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

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

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

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

Open paper: none found

Reported by: Graham Paterson

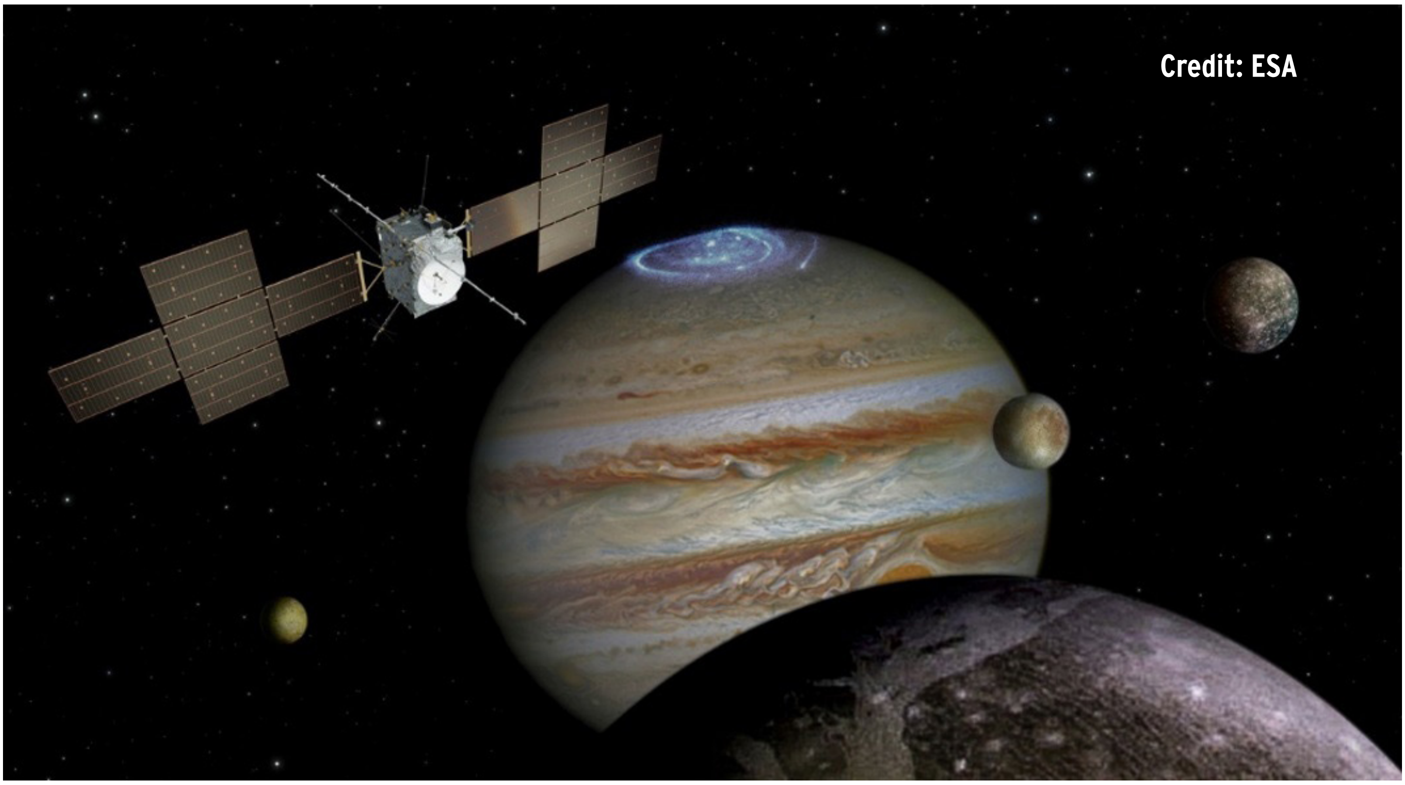
It has been known for some time that some of the icy moons of Jupiter and Saturn may harbour subsurface oceans, although up to 14 worlds in the solar system may have substantial oceans, including of course the Earth. The presence of liquid water on these bodies holds out promise of the tantalising prospect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

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

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

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

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



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

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

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

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

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

Websites:

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

Dragonfly: dragonfly.jhuapl.edu/

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

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

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

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

Open paper: none found

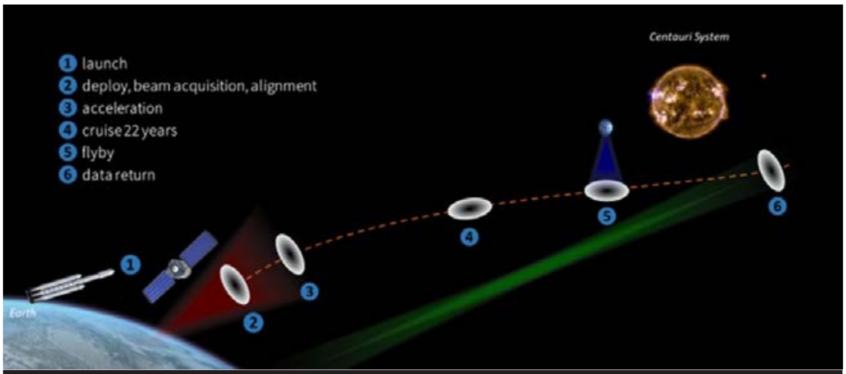
Reported by: Patrick Mahon

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

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

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

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



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

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

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

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

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

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

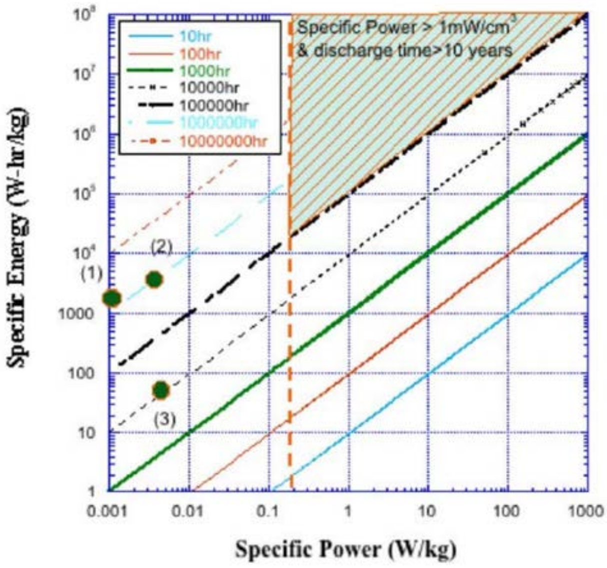
[1] Breakthrough Initiatives (2016), Starshot. breakthroughinitiatives.org/initiative/3

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

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

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

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



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

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

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

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

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

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

Reported by: Patrick Mahon

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

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

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

• Enabling safe and healthy space communities on the journey;

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

• Supporting the commercialisation of space exploration;

• Enabling vibrant in-system planetary development; and

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

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

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

• Set up a website (www.100YSS.org);

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

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

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

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

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

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

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

Plans for the next ten years include:

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

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

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

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

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

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

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

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

Open paper: none found

Reported by: John I Davies

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

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

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

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

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

ISEC Studies

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

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

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

9/19/22 8

www.isec.org

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

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

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

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

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

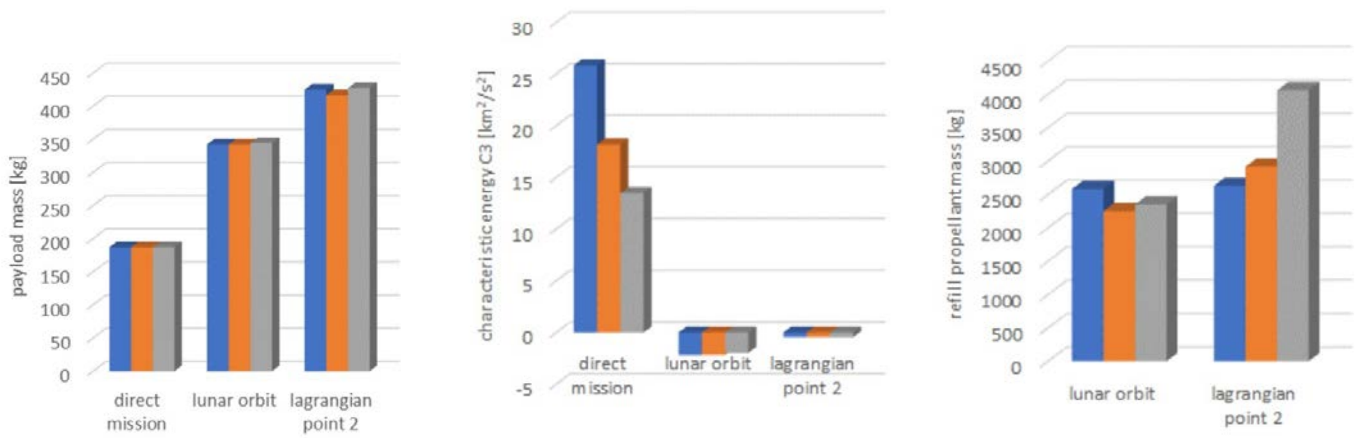
IAF cited presentation/video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A5/4-D2.8/presentations/IAC-22,A5,4-D2.8,4,x68378.show.pptx

Open paper: none found

Reported by: John I Davies

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

The results were striking -



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

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

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

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

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

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

Open paper: none found

Reported by: John I Davies

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

Some candidate materials mentioned in the paper -

- Graphene 130 GPa
- carbon nanotubes 200 GPa (theoretical) 77 GPa (in current practice)
- hexagonal boron nitride 100 GPa

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

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

[1] GPa = gigapascals. A pascal is 1 newton of force over one square metre. Since one one square metre is 100*100=10,000 square cm, 10 kilopascals is one newton per square cm, 10 megapascals is 1,000 newtons/cm^2 and 10 gigapascals is a million newtons/cm^2. So the usual materials for things like bridge suspension cables will not do!

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

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

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

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

Open paper: none found

Reported by: John I Davies

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

The paper sets out three Science Questions -

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

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

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

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

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

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

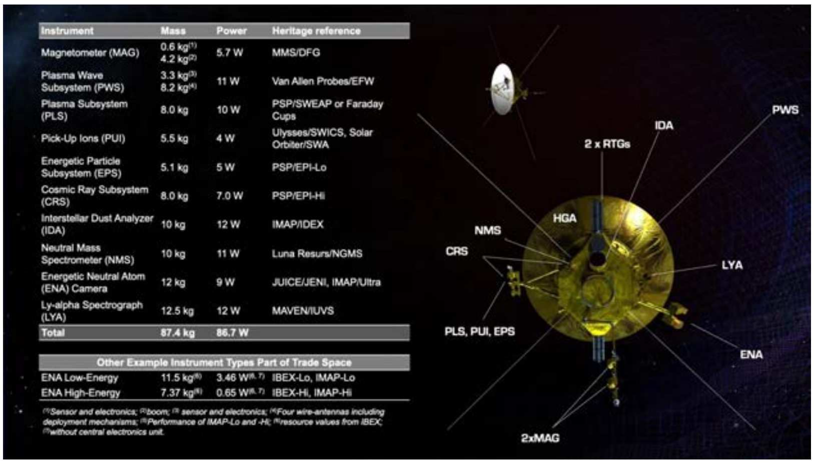


Figure 3: Example baseline spacecraft design including the 5-m HGA, two RTGs, magnetometer booms, four spin-plane PWS wire antennas, charged particle suite and ENA camera on pedestals and body mounted instruments graphene production line
Credit (caption and image): Brandt / JVU-APL

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

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

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

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

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

Open paper: none found

Reported by: Dan Fries

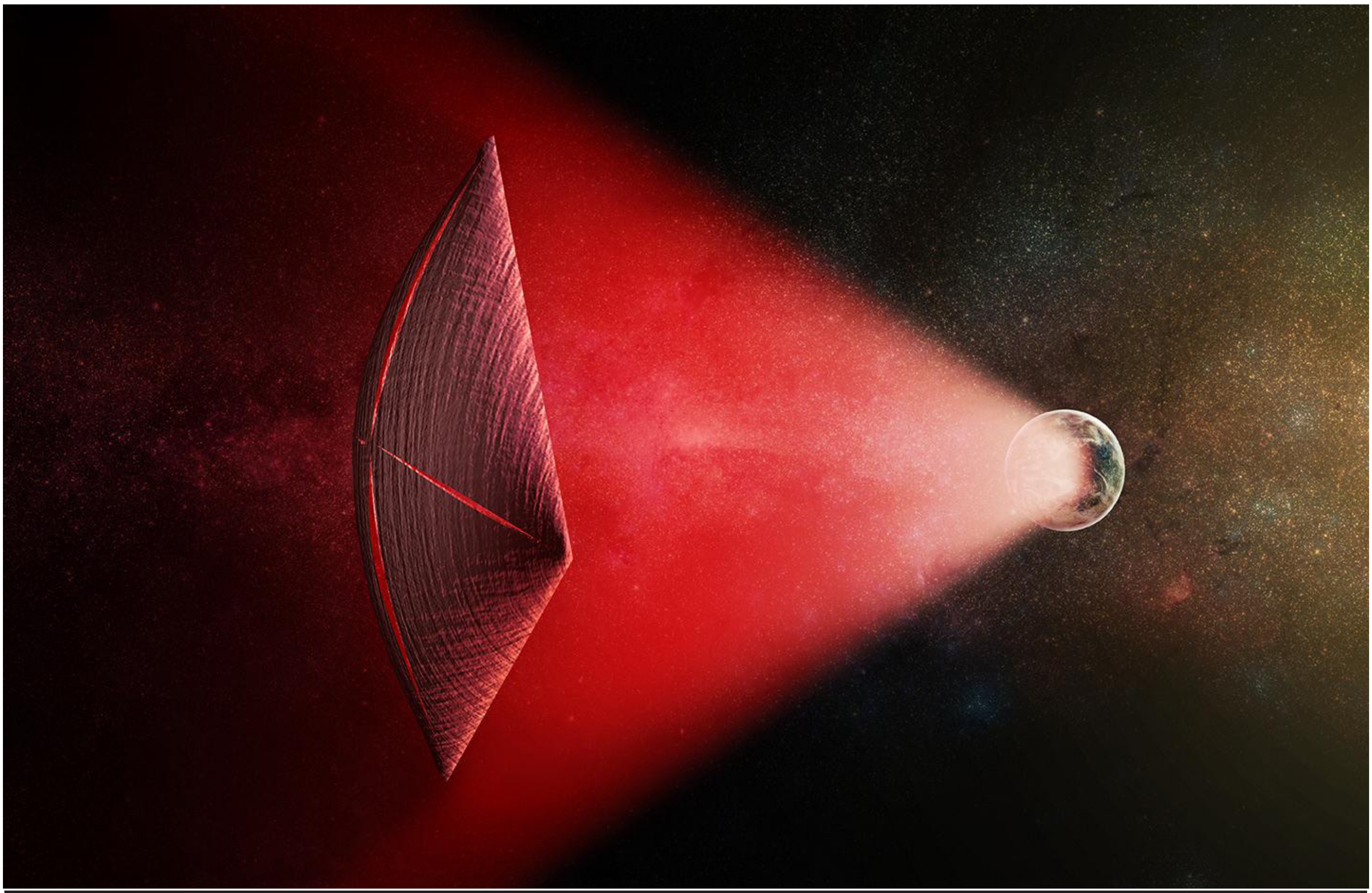


Figure 1: Artistic rendering of the Breakthrough Starshot ligthsaiil illuminated by laser light from earth. Credit: M. Weiss/CfA and www.universetoday.com/151478/sending-a-spacecraft-to-another-star-will-require-a-million-lasers-working-together/L

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

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

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

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

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

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

IAF cited paper: none available

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

Open paper: none found

Reported by: Dr Dan Fries

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

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

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

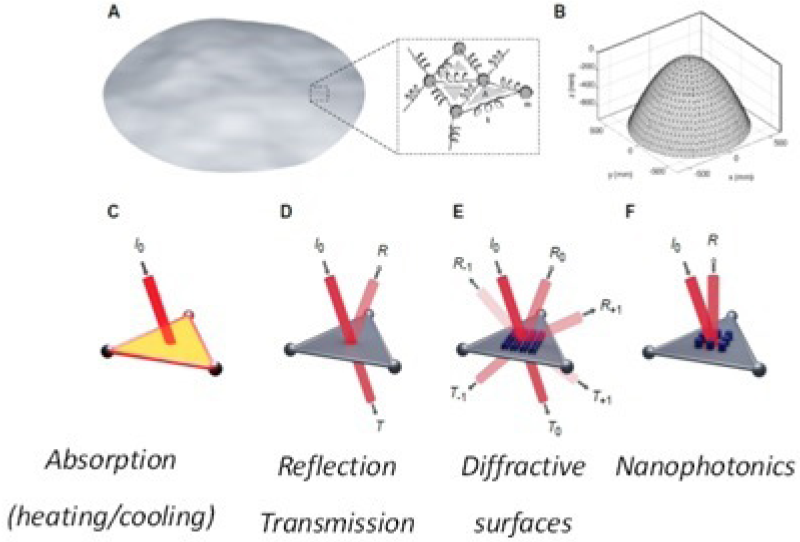


Figure 1: Image from the presentation, showing a schematic of the FEM thin sail membrane and different responses of the sail material to incident radiation.

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

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

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

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

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

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

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

Open paper: none found

Reported by: Dr Dan Fries

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

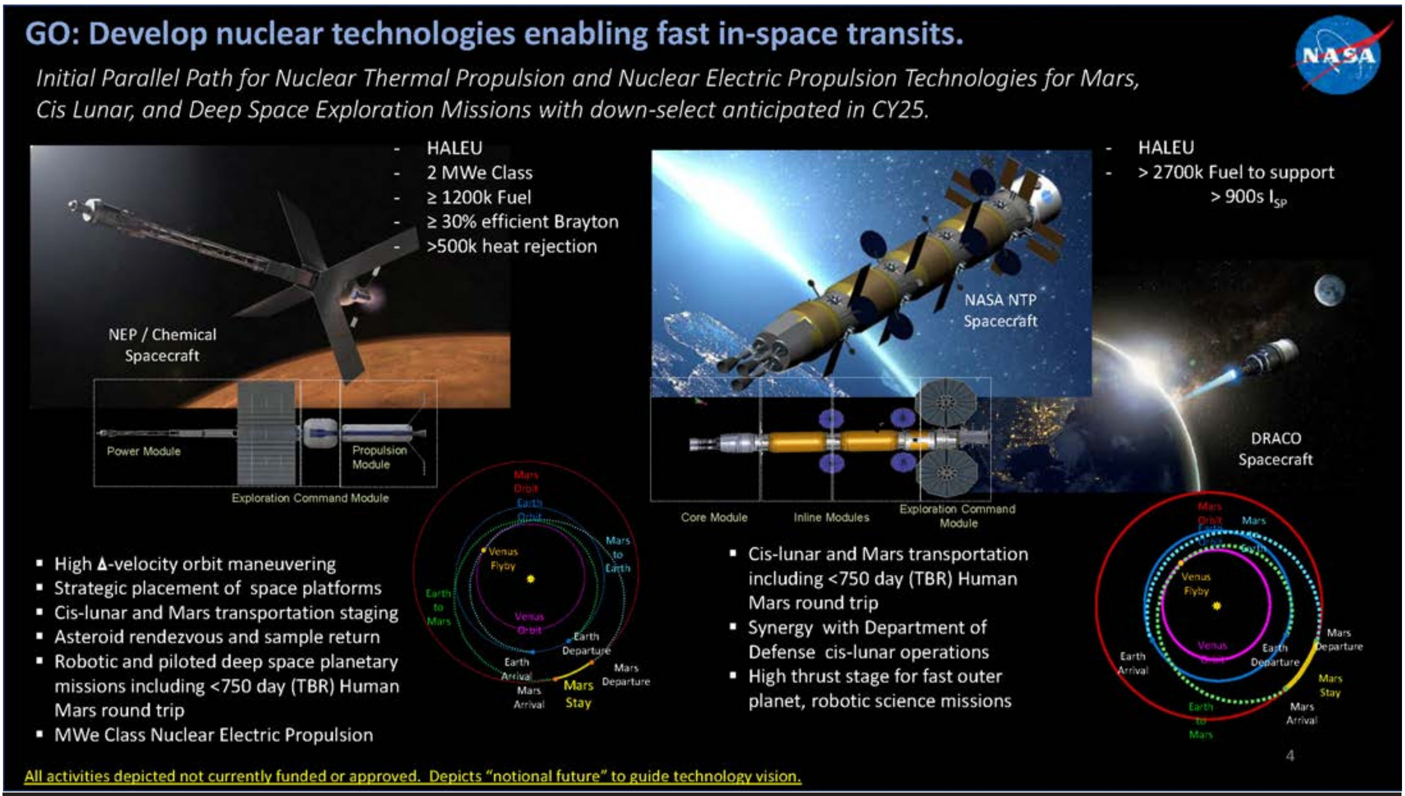


Figure 1: Example of a NASA nuclear electric/chemical spacecraft concept (left), and a nuclear thermal concept (right).

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

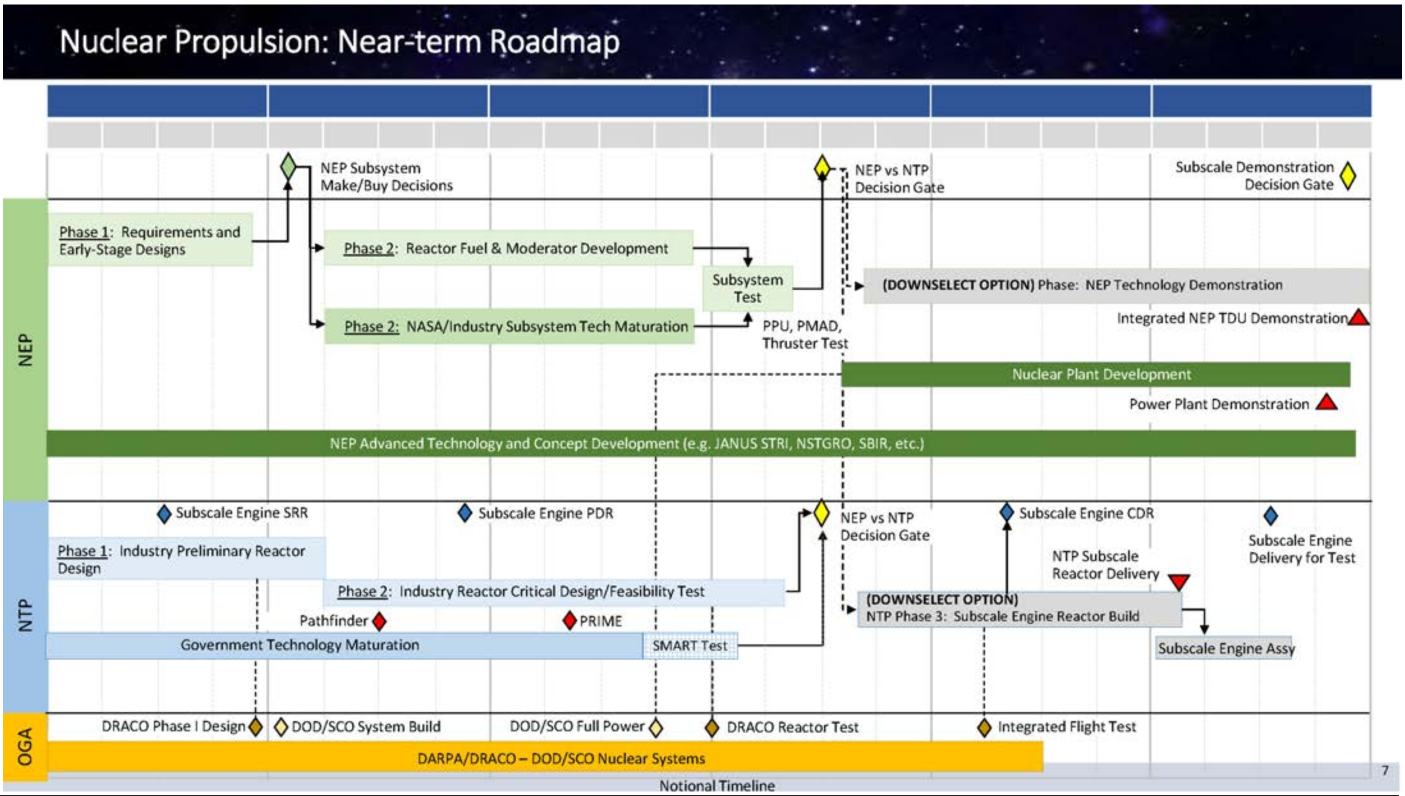


Figure 2: Roadmap for the near-term development of nuclear propulsion options.

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

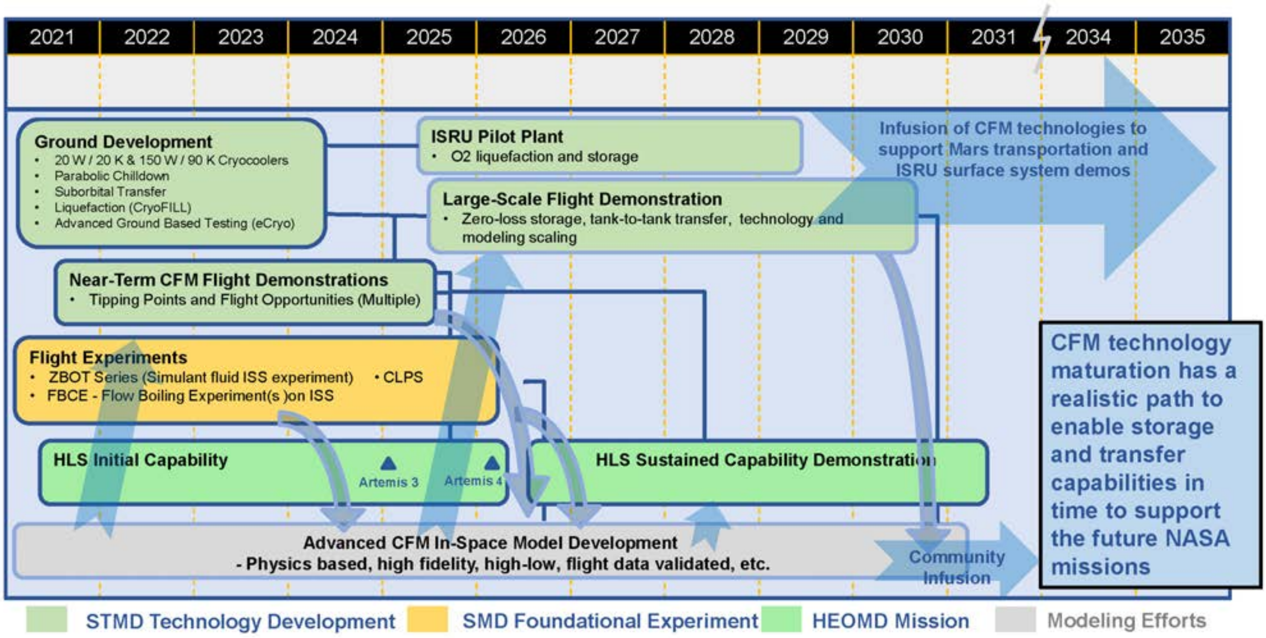


Figure 3: Roadmap for the near-term development of CFM capabilities.

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

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

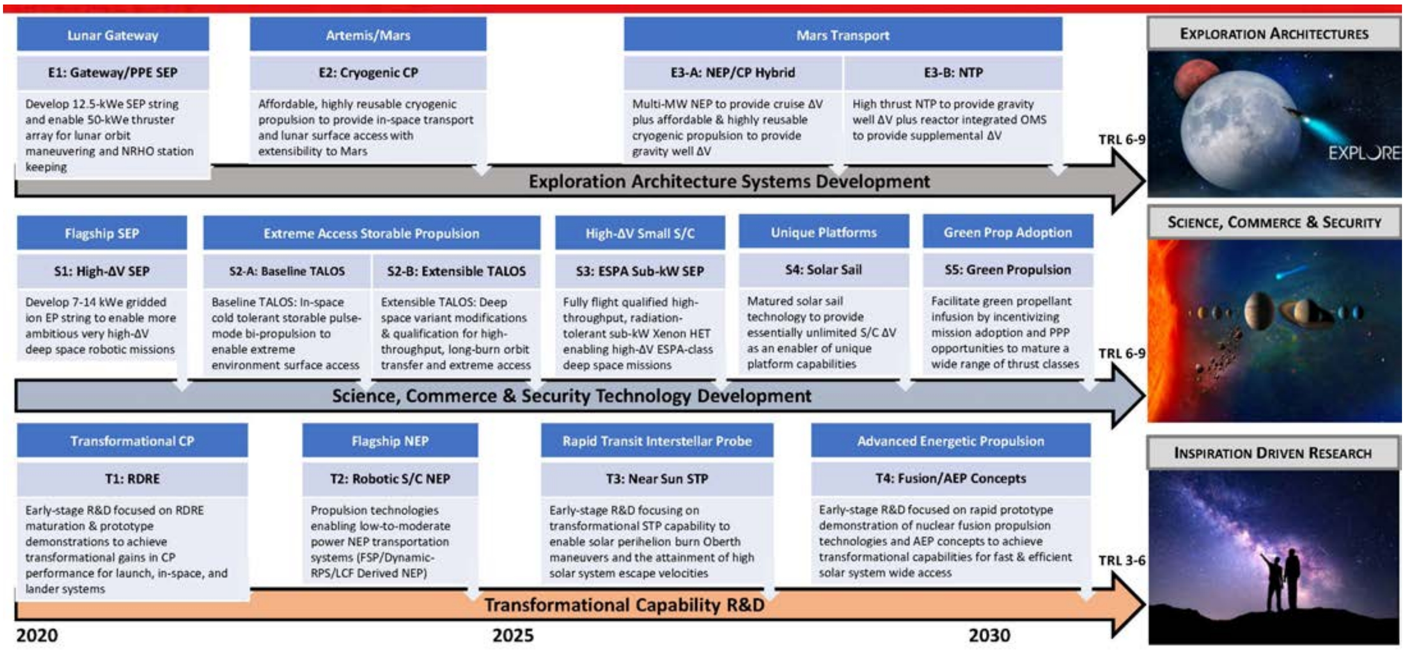


Figure 4: Roadmap for the near-term development of advanced propulsion concepts

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

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

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

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

Open paper: none found

Reported by: John I Davies

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

• What is the composition of the local interstellar medium?

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

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

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

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

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

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

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

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

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

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

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

Open paper: none found

Reported by: John I Davies

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

• Core: Provision of European scientific instruments;

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

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

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

The proposed instruments are -

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

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

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

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

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

The instruments proposed are -

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

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

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

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

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

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

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

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

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

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