IAC 2022

72nd International Astronautical Congress 2022
The Interstellar Presentations - part 1

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 first 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 first of two reports on the Congress. The second will be in our next issue, Principium 40, in February 2023. Our reporters, for both reports, are Adam Hibberd, Al Jackson, Alan Cranston, 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

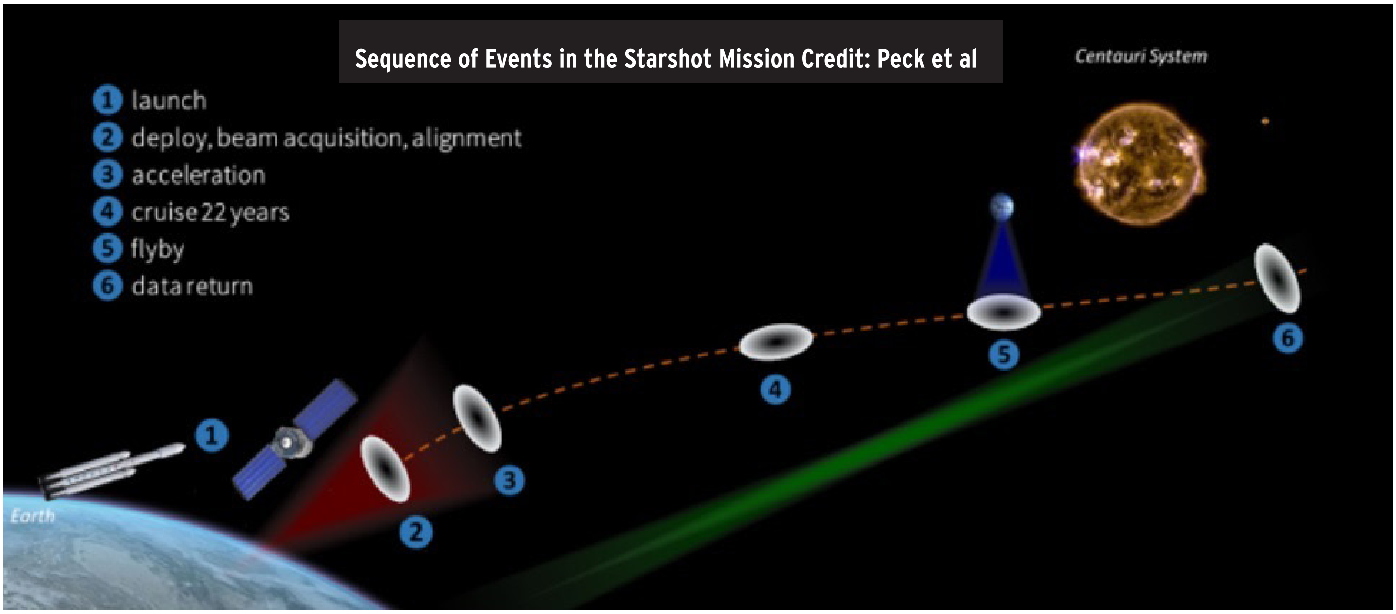
The Reports

In this issue-

More in our next issue.

◀ The Papers

IAF ref	title of talk/paper	presenter	institution	nation
C3,4,1,x73419	Power Requirements and Technologies for Gram-Scale Interstellar Spacecraft	Dr Mason Peck	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 title shown: *Power for Interstellar Lightsails*

IAF cited presentation/video: none cited

Open paper: none found

Reported by: John I Davies

Professor Peck's paper is co-authored by several core participants in Breakthrough Starshot, notably Dr Kevin Parkin (Systems Director, Breakthrough Starshot) and James Schalkwyk (Program Manager, Breakthrough Initiatives) – and contributors from Cornell, Princeton, UCSB, Arizona State and Howard Universities - also Caltech and NASA.

See also our summary in Principium 38 August 2022 page 37 (i4is.org/wp-content/uploads/2022/08/IAC-2022-Principium38-AW-2208290830-opt-3.pdf)

The paper identifies the three major technical elements of the baseline Starshot design now underway - the ground-based laser beamer, the lightsail's material and stability and the interstellar communications program element. To these it adds this fourth – onboard power (including energy storage) as part of the overall systems engineering approach (already exemplified in Parkin's earlier paper [1]). Studies now suggest that power and energy-storage technologies requiring concentrated mass are less viable than those that can be realised as distributed, low area-density masses and the current estimate of this mass-concentration limit is 90 mg. This precludes technologies that require dense components. Other issues identified include the requirements arising from the arrival propulsion needed to achieve a close pass of the target system, spindown from the interstellar configuration and possibility of an in-transit downlink to provide both reassurance and data to inform missions launched during the planned 20 year transit time (the base mission suggests a yearly re-orientation to achieve this). The team is studying in-transit power from both onboard (eg radioisotope thermal generator – RTG) or from interaction with the interstellar medium (ISM).

[1] *The Breakthrough Starshot system model*, Kevin L G Parkin, Acta Astronautica Vol 152 November 2018 parkinresearch.com/wp-content/uploads/2018/07/starshotmodel.pdf
[2] This presumably implies an approach distance of less than 2-3 AU or equivalent for the target star since current missions beyond that use inboard RTG power

▶

Approaching the target star the craft re-orients to capture solar energy [2]. The paper states that the interstellar communications system is likely to require the most power from the power subsystem. It summarised a minimum-power case (large communications apertures) and a maximum-power case (more modest apertures) in a table.

Communications system power requirements Credit: Peck et al, *Computational requirements categorised by subsystem function*

Max energy use	Min energy use
3×105mW h	120 mW h
1×106 J total energy	400 J total energy
Small transmit aperture: 0.1 m	Medium transmit aperture: 1 m
Medium receive aperture:	200 m
Large receive aperture:	1000 m

The paper emphasises that - in contrast to traditional satellite design - where total cost arises from budgets for mass, power, and cost of subsystems, for interstellar sailcraft, the cost of the sailcraft mass and power is driven by the very large capital cost of the beamer which thence sets the mass of the sailcraft and thus the performance of each component and function. An ideal design would distribute all functions across the largest and most massive element, the sail. In any case at least 90% of the mass budget needs to be allocated to the sail.

Computation requirements might be optimised by networking in a swarm of vehicles but this early study concentrates on a single craft as a baseline case. Data storage volume is critical here since the fly through will be very brief, 0.2c = 1.4 AU/hr, so much data must be stored and transmitted after fly through – and that on a challenging downlink [1].

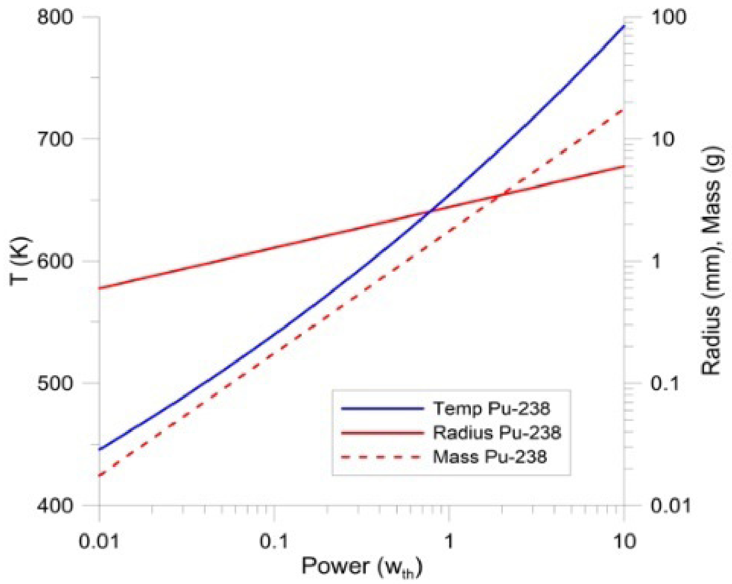
Extrapolating technology to 2040 they expect a storage energy cost of around 0.4 µJ/bit (microjoule/bit). Other power demands include imaging (at minimum to meet the "take a snapshot" requirement), guidance, navigation, and attitude control.

They make the point that a passively superconducting storage technology could use the naturally cold ISM. The technical challenge is mainly physical damage from ISM impact. Other possibilities such as chemical or alpha/betavoltaic power would require major advances to meet the requirement.

Can power be obtained from the environment? Ions and/or electrons from ISM impacts might be collected or current induced in an on-board conductor. This would naturally have the desirable property of even mass distribution. The temperature gradient between areas with ISM versus areas with minimal impact could be harnessed.

On board power from a tiny RTG might be feasible and is being studied in detail by Prof Philip Lubin's group at UCSD. This is, in principle, a scalable source but might still challenge the requirement for even mass distribution – and the scaling has limits as the team show in this diagram.

RTG - Temp, Radius, Mass vs Power
from Lubin 2021 - "The Path"



[1] See Principium 31, *The Interstellar Downlink*, i4is.org/wp-content/uploads/2021/08/The-Interstellar-Downlink-Principium31-print-2011291231-opt.pdf

They also considered energy from starlight, bioluminescence and microscale non-RTG nuclear though none look promising at this stage.

They suggest future research on power and energy storage across the most promising technologies they have identified, constrained by -

Requirements:

- Store >2 J
- Deliver >0.1 W
- >21 year lifetime
- Can be realised at <360 mg or 10% of the total

Additional guidelines that may influence solutions:

- Operates at <20 K
- Withstands > 10 GRad TID if face on or >200 rad TID if edge on
- Consistent with eventual sail structure design
- Consistent with flight mechanics (acceleration)

IAF ref	title of talk/paper	presenter	institution	nation
A3,4B,10,x70801	Mission architecture and spacecraft design for long-term contact studies of the interstellar asteroid 1I/Oumuamua	Dr Olga Bannova	University of Houston	USA

IAF abstract: iafastro.directory/iac/paper/id/70801/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A3/4B/manuscripts/IAC-22,A3,4B,10,x70801.pdf

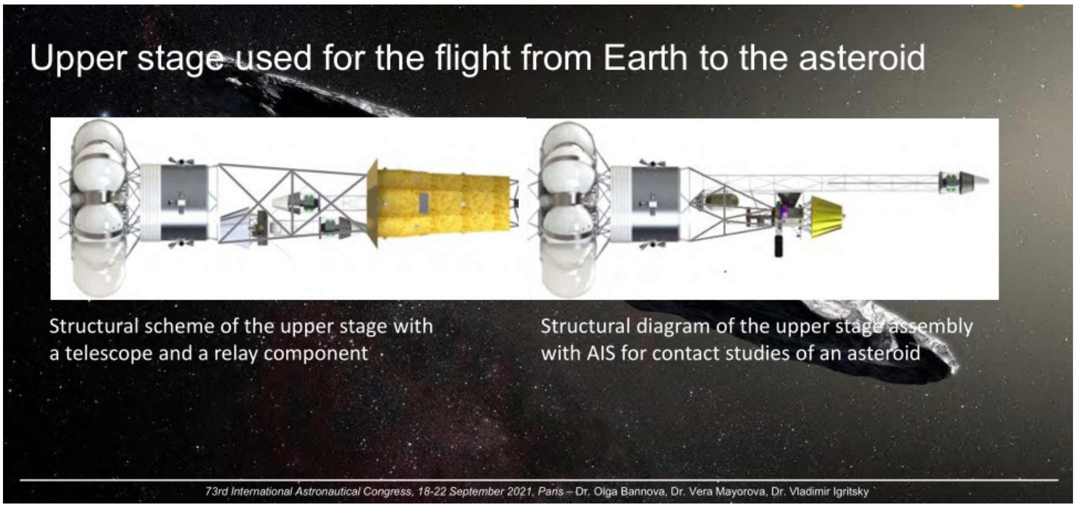
IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A3/4B/presentations/IAC-22,A3,4B,10,x70801.show.pdf

Open paper: none found

Other authors: Dr Vera Mayorova, Prof Vladimir Igritsky

Reported by: Adam Hibberd [1]

This is a report on a paper which is in itself a report on an explorative study to identify the architecture and systems necessary for what they term a ‘contact’ mission (ie rendezvous and robotic lander) to ‘Oumuamua, the first interstellar object to be discovered passing through our solar system. This study was performed by a team of international students from countries such as Russia, UK, USA, France and held at Bauman Moscow State Technical University.



The relay and telescope system and the AIS encounter vehicle. Credit: Bannova et al

[1] Adam has been the principal astrodynamicist for most of our i4is technical team papers under Project Lyra, a continuing programme investigating the interception and study of the interstellar object (ISO), 1I/'Oumuamua and of related ISOs and other challenging objects of interest.

Several spacecraft, each with different functions are envisaged -

Firstly a Space Telescope Spacecraft (STS) of mass 4.4 tons, in order to search for 'Oumuamua, with its consequential high positional dispersion as a result of the large proposed intercept distance.

Secondly a dedicated relay spacecraft, mass over 1.5 tons, would accompany the STS, presumably travelling along the same flight path as the STS and designed to convey STS data back to Earth with a High-gain antenna.

Thirdly an Automatic Interplanetary Station (AIS) would be required and would possess Xenon ion thrusters to slow the spacecraft down for a rendezvous with 'Oumuamua.

Close to 'Oumuamua a Space Net System would be utilised, and would encapsulate 'Oumuamua, allowing a spider robot lander to gain a good purchase on 'Oumuamua which would in turn enable activities such as drilling to be undertaken.

With a launch in 2026 and a Gravitational Assist of Jupiter, this is clearly a mission which is unlikely to be realised (the near-term launch and the lack of funding resources being the major factors for this).

Nevertheless, it is an ambitious and meticulously planned mission which no-doubt stretched the imagination and technical abilities of the students to the limit.

IAF ref	title of talk/paper	presenter	institution	nation
A4,1,12,x72537	Upper bounds on technoemission rates from 60 years of silence	Claudio Grimaldi	Ecole Polytechnique Fédérale de Lausanne	Switzerland / Italy

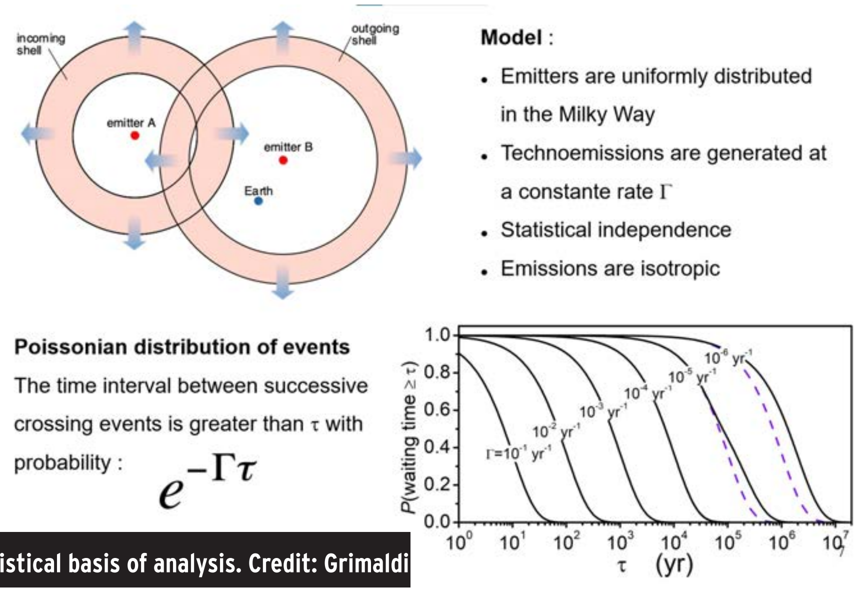
IAF abstract: iafastro.directory/iac/paper/id/72537/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A4/1/manuscripts/IAC-22,A4,1,12,x72537.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A4/1/presentations/IAC-22,A4,1,12,x72537.show.pptx

Open paper: none found

Reported by: John I Davies



Statistical basis of analysis. Credit: Grimaldi

No electromagnetic technosignatures have been detected in the 60 year history of SETI so far. Dr Grimaldi asserts that this must mean that we have incomplete sampling of the search space or that we cannot detect them because the Earth has been located during the entire history of SETI in a region of space not covered by artificial extraterrestrial emissions. Assuming a constant rate of transmissions he has derived probabilistic upper bounds and in the case of isotropic emissions, finds a 5% probability that there are more than one to five emissions per century that are generated across the entire Milky Way and shows that higher emission rates can only be derived if we assume that a significant fraction of all technoemissions are anisotropic – in randomly oriented narrow beams.

He produces an intermediate result which is independent of the average longevity of the emissions. His conclusion is guarded but pessimistic. Maybe the first of Clarke's twin hypotheses [1] is, in fact the case.

[1] "Two possibilities exist: Either we are alone in the Universe or we are not. Both are equally terrifying."

IAF ref	title of talk/paper	presenter	institution	nation
A4,1,10,x72939	Extragalactic SETI	Prof Mike Garrett	University of Manchester	UK

IAF abstract: iafastro.directory/iac/paper/id/72939/summary/

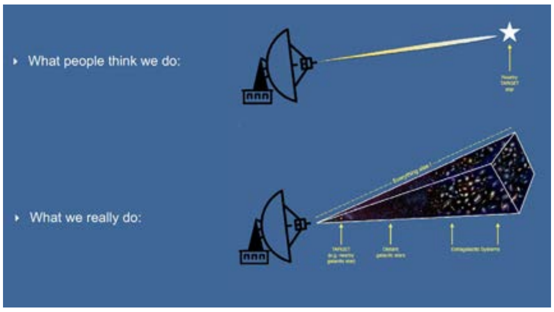
IAF cited paper: none given

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A4/1/manuscripts/IAC-22,A4,1,10,x72939.pdf

Open paper: arxiv.org/abs/2209.08147 *Constraints on extragalactic transmitters via Breakthrough Listen*, Garrett & Siemion, Sep 2022 – note this paper has also provided input to this report.

Reported by: John I Davies

Prof Garrett starts with a “reality check” on the scope of Breakthrough Listen [1].



He looks at nearby galaxies and is particularly interested in “exotica” including interacting galaxies and star forming regions, galaxy clusters, active galactic nuclei (AGN), radio loud galaxies and useful gravitational lenses. The Breakthrough Listen survey has a Full Width Half Maximum (FWHM) is 8.4 minutes of arc (60 minutes in a degree) and the Aladin New Edition shows 143,024 extragalactic objects within that field of view.

This includes –

- 17,810 point sources,
- 28,405 galaxies,
- 87,841 Infrared sources,
- 44 QSOs,
- 8,016 Ultraviolet sources,
- 401 X-ray sources,
- 398 radio sources,
- 11 Absorption line systems,
- 5 Gamma ray sources,
- 53 Galaxy cluster members, 33 galaxy groups, 6 galaxy pairs and 1 galaxy triple,
- Two gravitational lens systems.

- a daunting selection!

Prof Garrett cited the Garrett & Siemion (paper cited and linked above - open access) – which is due for publication in the Monthly Notices of the Royal Astronomical Society.

He concluded by pointing out that –

- SETI observations in the radio, sample a wide range of different cosmic objects.
- It’s time to take this into account (eg via Gaia & updated galactic models) to improve the constraints we place on the prevalence of extraterrestrial transmitters in the Milky Way.
- Observations of nearby mass concentrations eg galaxies, galaxy groups and galaxy clusters encompass many potential sites for ETI.
- Every line-of-sight contains “exotica”, both near and far…!

More in the Garrett & Siemion paper *Constraints on extragalactic transmitters via Breakthrough Listen*, cited above.

[1] Warden et al *Breakthrough Listen – A new search for life in the universe*, Acta Astronautica, V139, Oct 2017

IAF ref	title of talk/paper	presenter	institution	nation
A4,1,8, x73676	SETI India: A search for techno-signatures from extraterrestrial life using uGMRT.	Mr Arun Muraleedharan	Amity University Mumbai	India

IAF abstract: iafastro.directory/iac/paper/id/73676/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A4/1/manuscripts/IAC-22,A4,1,8,x73676.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A4/1/presentations/IAC-22,A4,1,8,x73676.show.pdf

Open paper: none found

Reported by: John I Davies

The Upgraded Giant Metrewave Radio Telescope (uGMRT - www.ncra.tifr.res.in/ncra/gmrt) permits SETI coverage frequencies from 300 to 700 MHz, which are currently less explored. The instrument comprises 30 steerable 45 metre parabolic antennas covering both celestial hemispheres down to −53° declination.

The paper explains the SETI processing pipelines -

- and plans for their future development.

The pipeline has now been tested using pulsar data and by signal injections for drifting narrowband signals with signals from artificial broadband using existing SETI software tools. They plan searching for wide-band signals with embedded modulations, a signal class which has not yet been comprehensively searched.

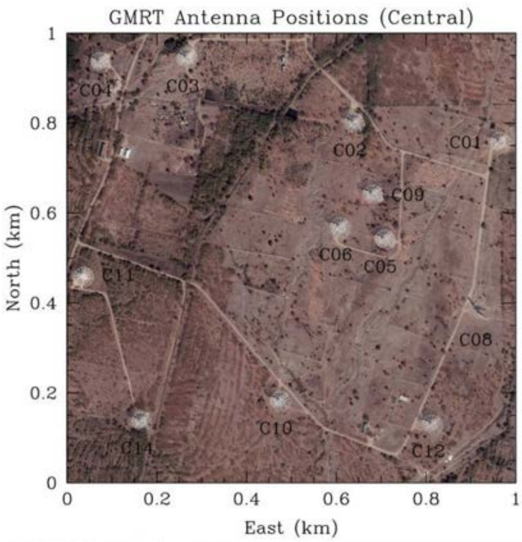
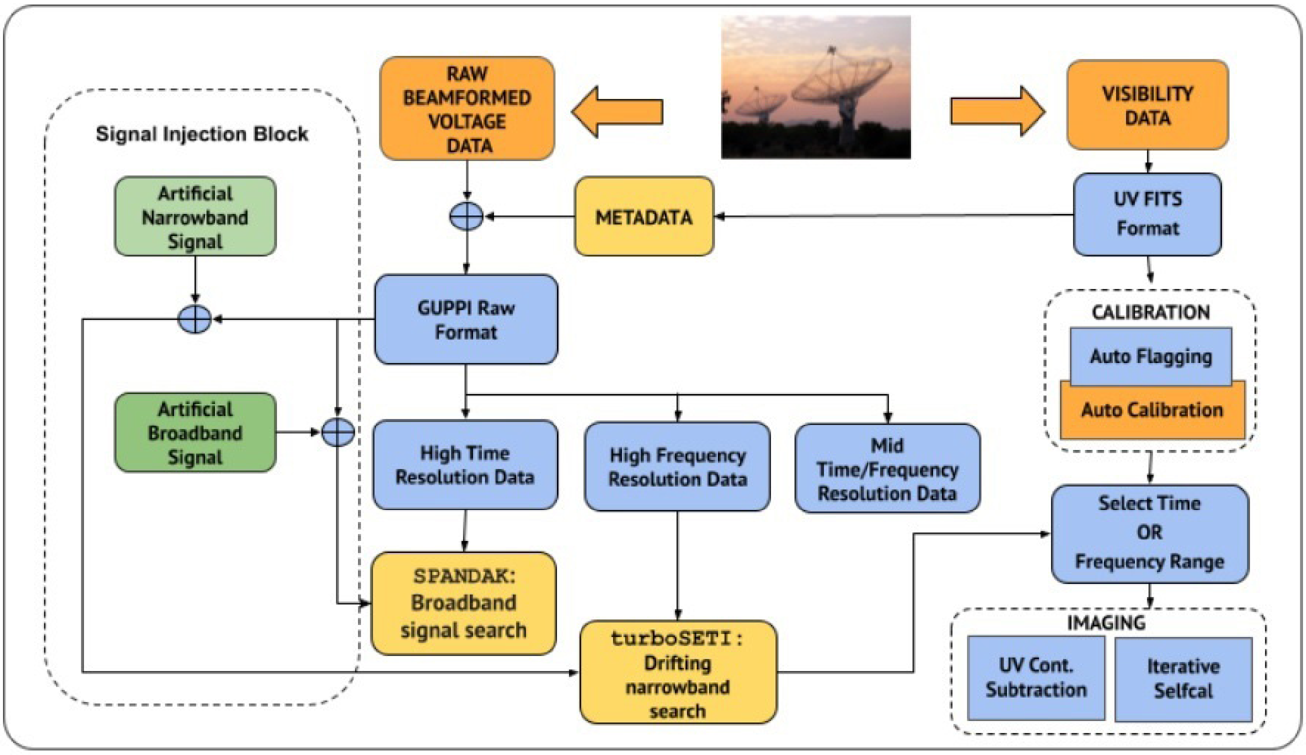


image credit: The Australian National University, Mount Stromlo Observatory www.mso.anu.edu.au/~plah/Home_Page_Stuff/GMRT_array/GMRT_array.html



The relay and telescope system and the AIS encounter vehicle. Credit: Bannova et al

IAF ref	title of talk/paper	presenter	institution	nation
D4,4,6, x67947	Transformational Release of Scientific Payloads From the Apex Anchor – Any Size, Every Day, Anywhere	Dr Peter Swan	International Space Elevator Consortium	USA

IAF abstract: iafastro.directory/iac/paper/id/67947/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/4/manuscripts/IAC-22,D4,4,6,x67947.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/4/presentations/IAC-22,D4,4,6,x67947.show.pptx

Open paper: none found

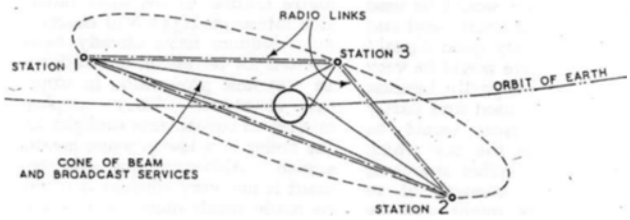
Reported by: John I Davies

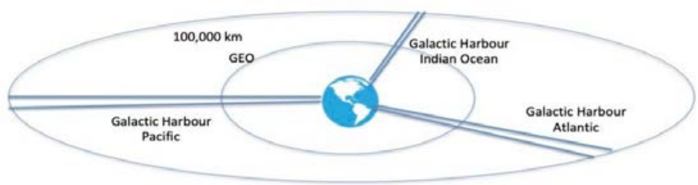
A space elevator requires an apex anchor to approximately twice geostationary altitude. A simple "thought experiment" explains why. Consider a series of unconnected satellites at altitudes up to and beyond geostationary altitude. If they have a geocentric velocity identical to that required for geostationary orbit, as all the components of a space elevator must have, then those below geostationary altitude will not be travelling fast enough to maintain orbit and will fall to Earth while those above geostationary altitude will be travelling too fast to stay in Earth orbit and must fly off into interplanetary space. A space elevator needs to have a net centre of mass which is at geostationary altitude and thus requires a mass distributed equally above and below geostationary altitude. The component above geostationary altitude forms an apex anchor and at its furthest point is a natural release point for interplanetary missions. This paper considers the usefulness of the apex anchor for such missions in the context of the broader objectives of the International Space Elevator Consortium (ISEC www.isec.org/).

This paper characterises a space elevators apex anchor as a Galactic Harbour. This would be at about 100,000 km altitude. The paper states that this would have capacity of 30,000 tonnes per year, maturing to 170,000 tonnes with launches at a minimum 7.76 km/second. For example, current missions from Earth to Mars take 8 months and are every 26 months with mass to the surface of Mars about 1 percent of the mass at launch. The paper refers to the gravitational region as the Sphere of Influence altitude and the capability to reach it without rockets as the Green Road to Space. At the more modest geostationary altitude it becomes economically feasible to assemble almost any size communications antenna or science spacecraft to be moved easily by a space tug to another position on the geostationary circle.

The paper points out that long-term planning at NASA and other space agencies is based on the economics of ground launches and that an elevator would alter that enormously. The suggested benefits are -

- Planetary Sciences: massive payloads, assembled outside of the gravity well, to any planet and at low cost. With low-cost delivery to any solar system destination, planetary science will blossom.
- Massive movement: Initial Operational Capability 30,000 tonnes/yr and Full Operational Capability 170,000 tonnes/yr.
- Rapid transit and long distance: reaching beyond Mars without reaction propulsion.
- Enhanced interstellar capability: Lift capacity will allow assembly of large vehicles and the apex anchor can add substantial deltaV.
- Mininise adverse impacts: on Earth atmosphere and clutter in low Earth orbits.





Left: Three satellite stations for complete coverage of the globe Credit: Clarke [1]. Right: Three Galactic Harbours Credit: Swan

[1] One possibility is that specialised satellite receivers and antennas would no longer be required for TV reception - making it possible for a conventional UHF television receiver to be fed from a geostationary satellite. This would deliver Arthur C Clarke's dream of universal coverage with simple receiver technology, *Extra-Terrestrial Relays – Can Rocket Stations Give World-wide Radio Coverage?* Wireless World, October 1945, scienceandsf.com/wp-content/uploads/2019/03/Extra-Terrestrial-Relays2.pdf

IAF ref	title of talk/paper	presenter	institution	nation
C4,10- C3.5,6,x67247	Nuclear Fusion Powered Titan Aircraft	Mr Michael Paluszek	Princeton Satellite Systems	USA

IAF abstract:iafastro.directory/iac/paper/id/67247/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/C4/10-C3.5/manuscripts/IAC-22,C4,10-C3.5,6,x67247.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/C4/10-C3.5/presentations/IAC-22,C4,10-C3.5,6,x67247.show.pptx

IAF cited presentation video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/C4/10-C3.5/talk/IAC-22,C4,10-C3.5,6,x67247.talk.mov

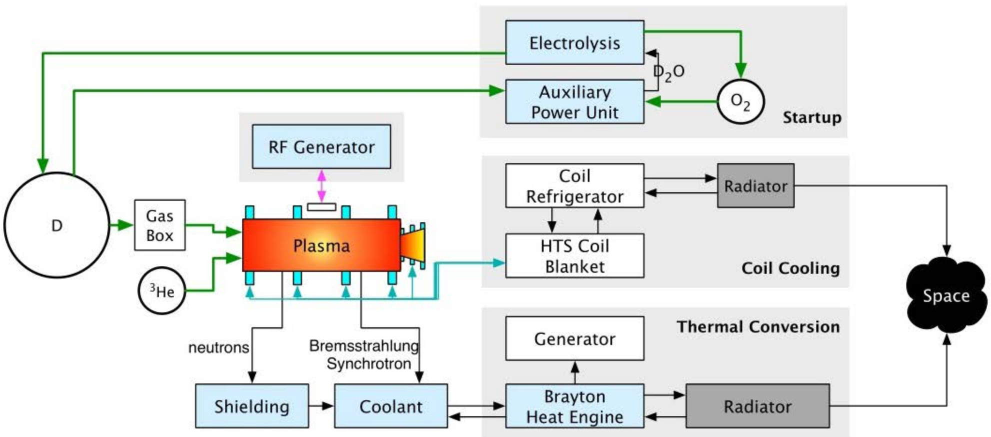
Open paper: none found

Reported by: Al Jackson

This paper is part of a series leveraging work done by Samuel A Cohen of the Princeton Plasma Physics Laboratory in the early 2000s. The core mode of propulsion here is a Direct Fusion Drive, DFD. The heart of this fusion reactor is near aneutronic fusion, that is one that produces few neutrons in the reaction process. In this case it is one of the deuterium – helium 3 reactions branches have small neutron production.

The Direct Fusion Drive (DFD) is a conceptual fusion-powered spacecraft engine, named for its ability to produce thrust from fusion without going through an intermediary electricity-generating step. The DFD uses a novel magnetic confinement and heating system, fuelled with a mixture of helium-3 (He-3) and deuterium (D), to produce a high specific power, variable thrust and specific impulse, and a low-neutron-radiation spacecraft propulsion system. Missions to Mars, Pluto and Titan where proposed using this system [2].

This paper summarizes a previous study about a mission to Titan (rendezvous with Saturn is required). An exploration vehicle is part of the mission payload. It uses a second fusion reactor, configured as a power reactor, and would be used for an electric Titan science aircraft. This vehicle would do a powered entry to Titan and then have the capability to fly anywhere on the moon at subsonic speeds. Studies presented in the paper show that the propulsion system is only used at low speeds during entry; hence a distributed propeller system was designed. After its first landing, the aircraft could perform aerial reconnaissance of the surface from any altitude and land at interesting spots. The aircraft could carry multiple payloads including a Titan submarine and a high-power drill. The science vehicle would have up to 1 MW of available power. This would be used for the engine, but also would be available to other contained science payloads. The transfer stage would remain in orbit, acting as a high-power communications relay, and would have its own set of science missions.



Block diagram of the DFD engine - x67247 Figure 7
Credit: Paluszek et al

◀

IAF ref	title of talk/paper	presenter	institution	nation
A1,LBA,9,x74467	Transcriptomic analysis of angiogenesis on datasets derived from experiments performed on mice in space	Mr Subhrajit Barua	ITMO University	Russian Federation

IAF abstract: iafastro.directory/iac/paper/id/74467/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A1/LBA/manuscripts/IAC-22,A1,LBA,9,x74467.matter.pdf

IAF cited presentation video: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A1/LBA/talk/IAC-22,A1,LBA,9,x74467.talk.mp4

Open paper: none found

Reported by: Cassidy Cobbs [1]

One of the many physiological effects of spaceflight that has been observed in humans is delayed wound healing. While wound healing is a complex, multi-stage process, one of the most important stages is angiogenesis, or the formation of new blood vessels from existing ones. The new vessels bring nutrients and other factors needed for the later stages of healing. The authors noted a 2008 study showing decreased vascularization in the wounds of rabbits exposed to hindlimb unloading prior to injury, which they consider a reasonable stand-in for microgravity, and sought to examine the expression of genes related to angiogenesis in mice. The NASA Gene Lab has made available multiple RNA-Seq (a molecular method for quantifying gene expression) datasets from the Rodent Research 5 & 6 missions. The authors downloaded raw RNA-Seq files from homogenized skin samples for secondary analysis. They sought to compare angiogenesis genes between mice that had experienced ~30 days microgravity and ground control mice in two strains that differ in their innate immune responses. They identified 12 genes associated with angiogenesis that were differentially expressed between the two mouse strains, however based on Principal Component Analysis, strain played a much larger role in differential expression than microgravity exposure. The authors conclude that genetic background has an effect on the degree or type of delayed wound healing, and that any solutions may have to be personalized. However, the mice in this study were not subjected to wounding, so the gene expression patterns analysed were their baseline skin transcription pattern. It is possible that in the presence of a wound, different expression patterns would emerge between strains and/or between mice in space and on the ground. Authors: Subhrajit Barua (Faculty of Biotechnologies, ITMO University), Ruth Singh (Dept of Biophysics, University of Mumbai), Palvi Garg (Dept of Chemical Engineering, Ambedkar NIT, India), Sarah Rizwan (St Joseph's Girls School).

IAF reference	Title of talk/paper	presenter	institution	nation
D4,4,3,x73132	Advanced Electric Propulsion Concepts for Fast Missions to the Outer Solar System and Beyond	Angelo Genovese, Nadim Maraqten	Initiative for Interstellar Studies	Germany

IAF abstract: iafastro.directory/iac/paper/id/73132/summary/
IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/D4/4/manuscripts/IAC-22,D4,4,3,x73132.pdf
IAF cited presentation video: none available
Open paper: www.researchgate.net/publication/363862726_Advanced_Electric_Propulsion_Concepts_for_Fast_Missions_to_the_Outer_Solar_System_and_Beyond [2]

[1] Cassidy is Secretary of the Institute for Interstellar Studies, the US-based part of our organisation. More about her in *Cassidy Cobbs - Bioscientist* Principium 29, May 2020. i4is.org/wp-content/uploads/2020/05/Principium29-print-2005271554opt.pdf
[2] See also: *Advanced Electric Propulsion Concepts for Fast Missions to the Outer Solar System and Beyond*, Angelo Genovese & Nadim Maraqten www.researchgate.net/publication/363862726_Advanced_Electric_Propulsion_Concepts_for_Fast_Missions_to_the_Outer_Solar_System_and_Beyond

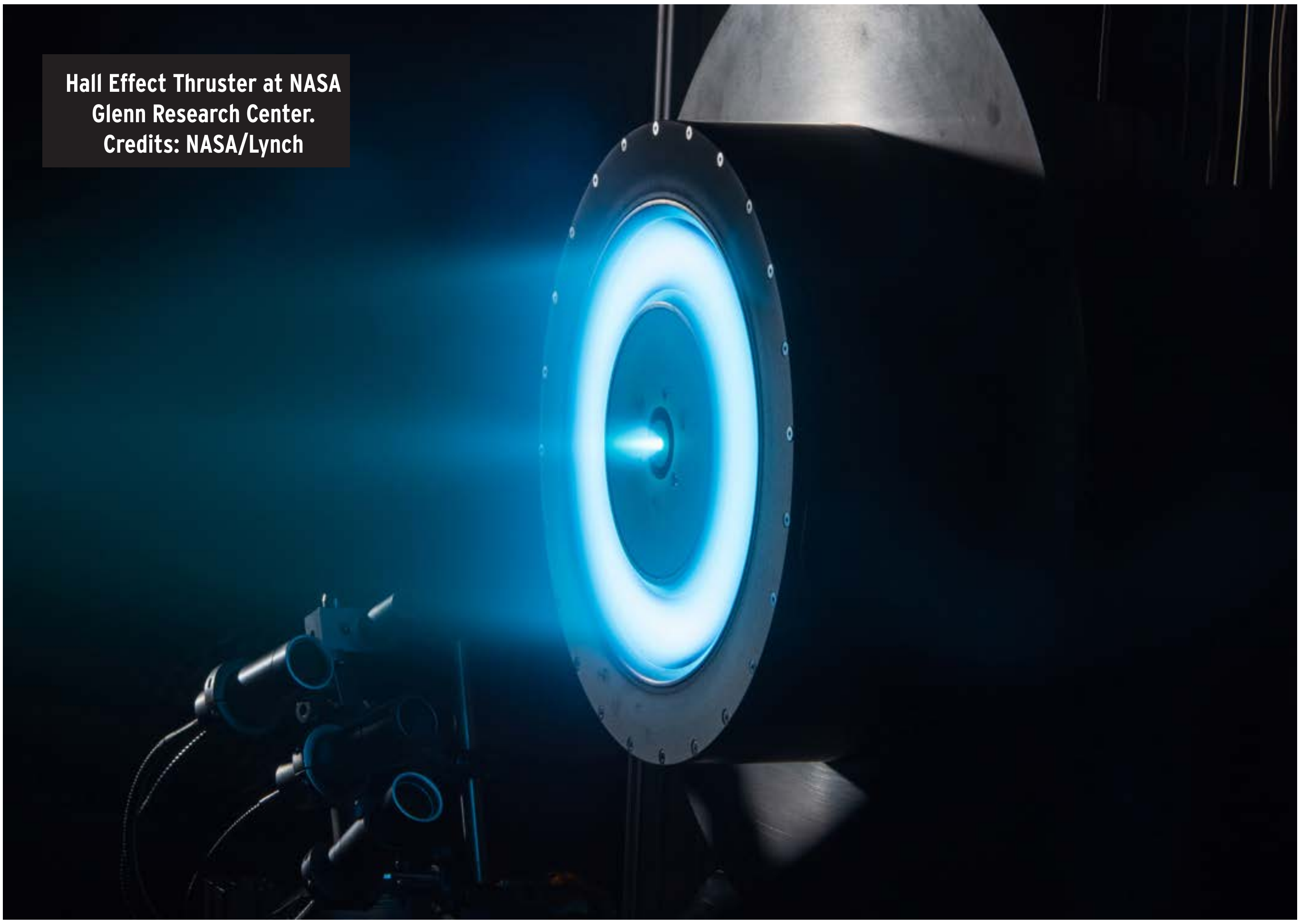
▶

◀ We have two reports on this paper -

REPORT 1 of 2, reported by: Nadim Maraqten (Nadim is also co-author of this paper)

By electrically accelerating ions, the limitations of conventional chemical rockets (Isp < 500 seconds) can be breached and very high specific impulses (> 5000 s) achieved; thus allowing for interstellar precursor missions. In contrast to other proposed propulsion technologies, electric propulsion (EP) has a decades-long heritage and already enabled several demanding missions (DAWN, DART, Hayabusa2, etc). Starting with the first historical sparks, the paper showcases the status quo of electric propulsion and highlights several advanced electric propulsion concepts.

As a matter of fact, it were none other than Robert H Goddard and Konstantin Tsiolkovsky who independently began to consider early forms of electric rockets at the beginning of the 20th century. This ignited the development of a variety of different electric thruster types creating a whole industry branch with enterprises specializing on exactly these systems. Among the most common established ones are the Hall Effect Thruster (HET) and the Gridded Ion Thruster (GIT). The 10 kW regime of these systems shows specific impulses of 2,800 – 7,400 s and thrusts of 610 – 270 mN (both high TRL). Besides these, several advanced high-power (100s kW) thrusters like the Variable Specific Impulse Magnetoplasma Rocket VX-200SS (Isp = 4,900s, T = 5,820 mN) and Applied-Field MagnetoPlasmaDynamic Thruster SX3 (Isp = 4,700 s, T = 2,750 mN) are in development (medium TRL). However, interstellar missions might necessitate even higher specific impulses, which could be provided by Dual-Stage 4-Grid (DS4G) ion thruster (Isp = 15,000s, TRL = 3). Studies suggest that DS4G technology could enable even higher specific impulses of up to 40,000 seconds [1].



Hall Effect Thruster at NASA Glenn Research Center. Credits: NASA/Lynch

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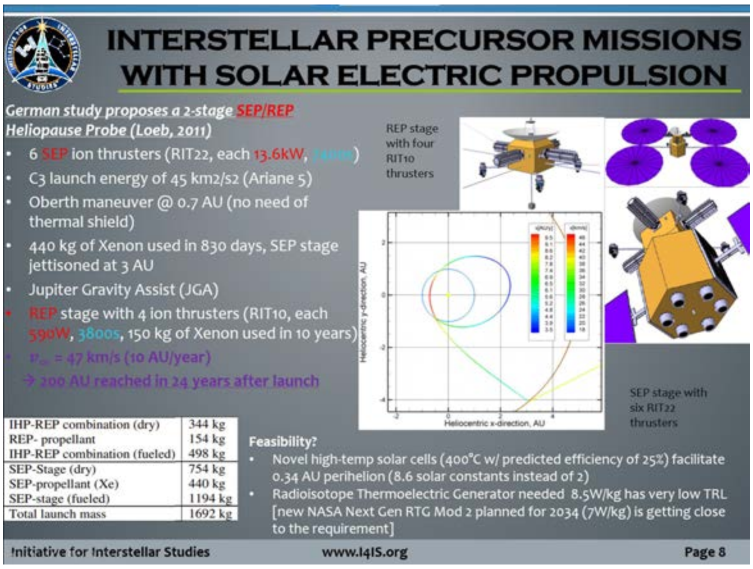
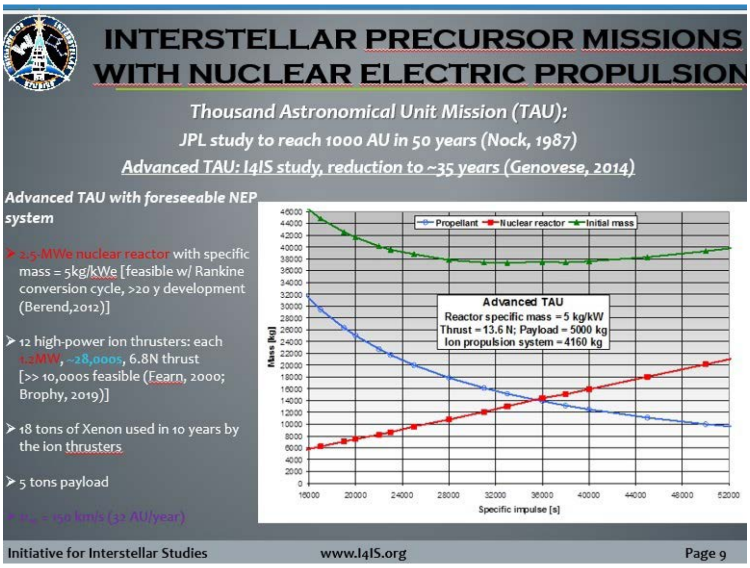
To combine the high Isp with a reasonable high thrust and enable interstellar precursor missions, there is no way around feeding power from a strong and lightweight power plant into the thruster(s). To tackle this issue, three major concepts have been proposed:

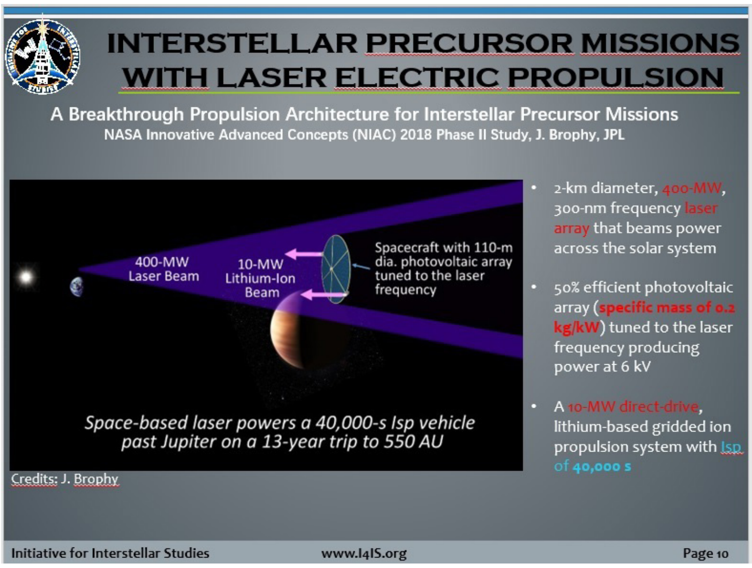
1) Solar Electric Propulsion is the most tangible concept, which has already been exploited by several electric propulsion missions. A near-sun flyby could supply large amounts of power to the solar panels while exploiting the Oberth effect. In combination with Radioisotope Electric Propulsion and a Jupiter gravity assist, a 200 AU mission could be realized within the near future.





2) Nuclear Electric Propulsion with a nuclear power plant of <5 g/kW could facilitate a 1,000 AU mission within 35 years.

3) Laser Electric Propulsion could lead to a paradigm change in power specific mass (0.2 kg/kW) and enable a 550 AU mission in 13 years. A powerful 400 MW laser array could beam power across the solar system which is converted by a photovoltaic array to power a direct-drive EP system.



To conclude, electric propulsion is a major candidate as propulsion system of challenging interstellar precursor missions with “reasonable” trip times. A 7,000s Isp thruster is already flight-ready, while even more advanced systems are in development. Key to the realization of advanced electric propulsion concepts is the realization of (ultra-)low specific mass power plants. Nevertheless, a solar powered 200 AU mission might be possible already within the near-future.

REPORT 2 of 2, reported by: Adam Hibberd

A fascinating article which first usefully outlines the history of spacecraft electric propulsion and then gives an overview of the current state-of-play, with particular regard to interstellar precursor missions, this latter is clearly of relevance to i4is.

It turns out that certain luminaries in the history of astronautics have made significant and sometimes breakthrough discoveries in the field of electric propulsion. Ranging from the ‘God’ and rocket pioneer, Robert H Goddard; Konstantin Eduardovitch Tsiolkovsky who was the discoverer of the eponymous Tsiolkovsky rocket equation; all the way through to the likes of Hermann Oberth and Wernher von Braun. Additionally Ernst Stuhlinger, an assistant to von Braun, conducted sterling work as far as specifying, designing and quantifying electric propulsion systems, writing a few seminal papers in the field.

Some prophetic quotations

If we look at historical missions, there have been two stand-out missions which have demonstrated the huge value of EP, namely the Deep Space 1 mission and Dawn. The latter mission involved rendezvous with two separate celestial bodies, Vesta and Ceres, which is exceedingly impressive.

With high specific impulses yet low thrust forces, EP systems naturally take their time to achieve what chemical can achieve in seconds or minutes, the pay-off being that the on-board propellant is used much more effectively and efficiently. The paper points out two more salient parameters which affect the design of a spacecraft with EP, namely the ‘Specific Power’ (measure in kW/N) and secondly the mass to power ratio of the power source (kg/W). Note the tyrannical truth for EP, which is equivalent to that of the Tsiolkovsky for chemical propulsion, is that generally as Specific Impulse increases for EP, so does the Specific Power requirement, thereby necessitating longer periods of thrust to generate the required ΔV.

Addressing the problem of exiting the heliosphere and stepping out into interstellar space, the goal is generally to reach large distances (> 200 AU) in short times (25 years), can EP be brought to bear on this?

Several solutions present themselves depending on the nature of the power-source used. SEP (Solar Electric Propulsion) suffers the disadvantage that an interstellar mission, by its very nature, would involve long periods at huge distances away from the sun (where solar flux reduces as the inverse square of distance).

However Loeb (HW and not A) suggests a combined SEP with REP system can readily do the job – where REP is Radioisotope Electric Propulsion and is fairly self-explanatory. The idea is that SEP would provide the propulsion whilst the vehicle is close to the sun (and so the vehicle can receive huge benefits from the Oberth Effect), following which the REP takes over from the SEP, but first with a velocity-boost from a GA (gravitational assist) of Jupiter.

For the TAU (1,000 au) mission to the ISM, the time requirement is now 50 years which corresponds to a larger heliocentric speed (factor of 2.5 x the velocity of the 200 au goal mission), a challenge which needs pioneering technology to achieve lower mass to power ratios and higher specific impulses. Two solution options are articulated, namely NEP (Nuclear EP) and LEP (Laser EP). The explanation of the NEP option cites a paper Genovese himself constructed a while ago on behalf of i4is.

The LEP option is where photovoltaic cells on board the spacecraft receive intense illumination from a laser beamed from Earth to power the EP.

IAF ref	title of talk/paper	presenter	institution	nation
A4,2,15,x73175	Romanticism in Science as a form of cognitive bias and SETI	Dr Gabriel G De la Torre	University of Cádiz	Spain

IAF abstract: iafastro.directory/iac/paper/id/73175/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A4/2/manuscripts/IAC-22,A4,2,15,x73175.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A4/2/presentations/IAC-22,A4,2,15,x73175.show.pptx

Open paper: none found

Reported by: Alan Cranston

Is science, is SETI, influenced by our cultural values? Gabriel De la Torre's paper examines the question with particular reference to Romanticism. This cultural movement of the early 19th century was particularly powerful and its influence on our way of seeing the world persists even to this day.

To examine the question let's first consider the nature of Romanticism. It is sometimes seen as a reactionary movement against emerging industrialism and science itself. But if Romanticism was merely reactionary, its force would quickly have been spent instead of exerting the extraordinary force that it did. We should also remember that it was not merely a literary and artistic phenomenon. It had radical thoughts on science too. The difficulty Romanticism had with the science of the day was its mechanistic nature, its belief that everything could (at least in principle) be reduced to simple parts and rules. Romantic science asserted that this was not correct. The whole could not always, even in principle, be understood as the sum of the parts, nature was somehow greater than that.

This view of science is both positive and in principle testable – and is still debated today. It was of course perfectly aligned with other elements of Romantic thought: the literature and art that celebrated rather than feared nature, that found the 'sublime' in it, a higher level of existence than mere rocks and vegetation. Modernism (in art for example) may have tried to make us look more clearly, but Romanticism still holds an influence beyond mere nostalgia. In England, for example, many people in the UK still find the barren hills of the Lake District, 'picturesque' despite the fact that they are biologically a barren desert. The question is whether there are similar issues in science and in SETI.

The charge that was quickly made against Romanticism in science was of plain irrationality, but this was not correct. Rather, Romanticism argued that reductionism itself distorted and limited our understanding of the natural world. One of the greatest scientists of the time (still too little recognised in the anglophone world), Humboldt was a Romantic. Much influenced by Goethe, he saw the connectedness of nature and was perhaps the first modern ecologist. Reading him now, one sees how much he anticipates James Lovelock and the Gaia metaphor. But still, narrower views regained sway in the middle of the 19th century as positivism came to the fore, largely restoring Enlightenment values. Though ideas such as Humboldt's, and other non-reductionist approaches continue to gain support in modern science. But – in SETI – what remains and what influence, for better or worse does it have?

De la Torre's starting point is another aspect of Romanticism: belief in the heroic, and in humanity itself being more than just flesh and blood. Bertrand Russell saw this as the dark side of Romanticism, the fantasy that led to the Third Reich, but De la Torre fairly makes the point that heroic adventure remains a key part of scientific endeavour, be it in space or particle research. If Romanticism had never happened would our science be more mechanical, more prosaic?

To elucidate how matters are, De la Torre conducted a study of beliefs held by SETI folk, with questions about various possibilities of detecting extra-terrestrial life. I confess I did not readily see how the questions bore on the level of Romantic 'overhang' in the minds of the respondents. They seemed to me to be more a measure of scientific optimism.

◀ De la Torre also sometimes seems to associate Romanticism with an (impliedly dangerous or unhelpful) anthropocentric perspective. For my part I am not sure I see the link. Man (in Western culture) has tended to place himself above the world since Biblical times and in fact it was the arch-reductionist Descartes who reduced all else to mere automata. And anyway, if we naturally think of possible intelligent extra-terrestrial life forms as probably a bit like us, is that such a bad thing? As De la Torre's short paper is good and interesting and I would have liked to hear his illustrated presentation. It is important for scientists to understand that their work is never conducted in some kind of cultural vacuum, that there is always history and context. I'm completely sure that he is right that Romanticism remains an important influence. Whether it is as important in science as he suggests it might be, I am less sure. I am also unsure whether it really matters. We all, scientists included, live by stories; it is arguable that we simply could not live structured lives without them. If modern SETI folk live by stories, by ideas, and by optimism, that seems to me to be a good thing. It is only when the stories begin to determine the facts that we should become concerned.

IAF ref	title of talk/paper	presenter	institution	nation
B2,1,1,x69864	Methods for Navigation in the Nearby Interstellar Medium	Dr John Christian	Georgia Institute of Technology	USA

IAF abstract: iafastro.directory/iac/paper/id/69864/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/B2/1/manuscripts/IAC-22,B2,1,1,x69864.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/B2/1/presentations/IAC-22,B2,1,1,x69864.show.pptx Open paper: none found

Reported by: Adam Hibberd

An introduction which squarely lays down the goal of the paper, to summarise the various on-board navigation options which can be exploited by spacecraft intending to explore the nearby interstellar medium (NISM). It neglects the importance of interstellar objects (ISOs) and how these visitors to our Solar System may provide revolutionary insights to other systems in our galaxy, instead adopting the now obsolete viewpoint that objects beyond our Solar System can only be studied by remote sensing.

Nevertheless it makes the extremely compelling point that if humanity is to embark on interstellar travel by robotic spacecraft, then a clear and in-depth knowledge of the nature and composition of the NISM will be needed, and this can best be achieved by precursor missions out to 2,000 AU. But what navigation options are there for such missions?

Firstly IMUs (Inertial Measurement Units). These provide measurements of acceleration with respect to. an inertial reference frame, which when integrated can compute velocity and then again to compute position. There is an issue with IMUs which I know all-to-well from my experience of Ariane 4 (the European work-horse launch vehicle) in that they fail to measure gravitational accelerations, only accelerations due to thrust (and for Ariane 4 drag). Furthermore due to biases and misalignments inherent in these devices, over long periods of time these measurements become unreliable. Thus for long duration missions to the NISM, where thrust will be extremely rare and where flight times are extremely protracted, IMUs may not be the best option.

Next Radiometric Navigation. Exemplified by the NASA DSN (Deep Space Network), this is a tried and trusted technique for interplanetary missions, but what about its use for missions to the NISM? As the Earth-Spacecraft distance increases, complications arise in the form of inaccuracies, especially when 2-way or 3-way ranging methods are used. There is promise on the horizon however, in the development of extremely precise atomic clocks and what's more their gradual reduction in mass and size. Such a clock installed on a spacecraft would allow accurate 1-way ranging to be performed.

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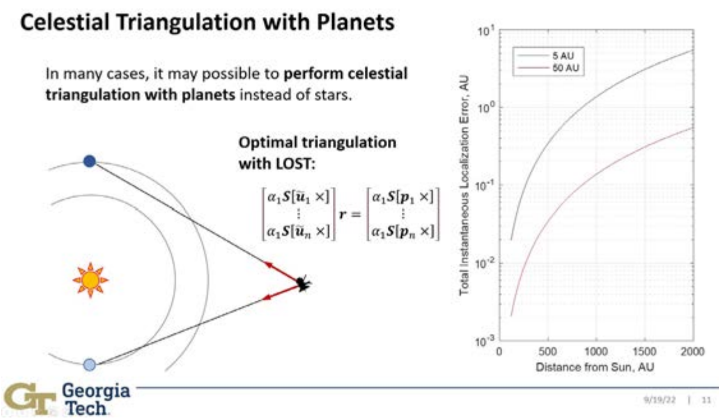
Star Trackers for Attitude Determination. As used currently, star trackers exploit optical observations of stars to identify the current attitude of the spacecraft, but what about their use for attitude determination in interstellar missions? For accurate determination of the spacecraft's attitude, clearly pattern recognition will be important, thus mapping a set of current visible star locations against a catalogue stored in the onboard computer. Various algorithms to solve such a problem exist and note that dimmer stars – which tend to be further away – would be prioritised as they are less affected by parallax.

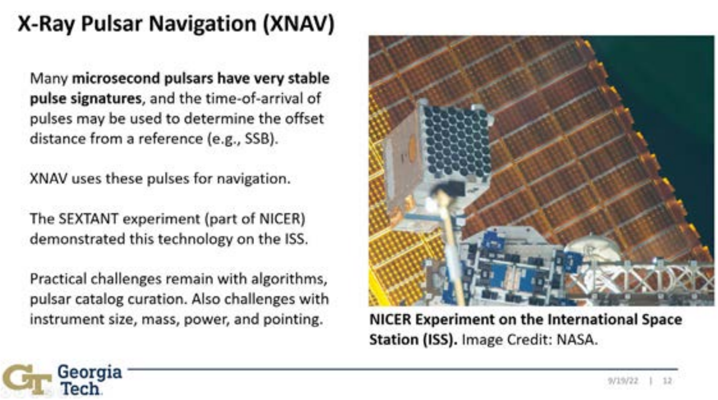
Celestial Triangulation with Stars. As the spacecraft moves through interstellar space, the apparent location of distant stars will stay fixed making them useless for navigation. Although as previously mentioned this low parallax is extremely desirous for attitude determination, for the purpose of navigation, the higher parallax of nearby, brighter stars can be conveniently and usefully exploited to derive position. We obviously need accurate knowledge of the 3D locations of these stars and estimates of the positional error achievable through triangulation are around 1.3 AU, which is rather large compared to radiometric navigation for example.

Doppler Shift of Stellar Spectra. This technique uses the shifts in stellar spectra due to the spacecraft's velocity with respect to the stars in question. The article does not mention the uncertainty which might be inherent due to exoplanets orbiting these stars, affecting the Doppler shift measurements, however by their nature these will be periodic and so therefore might be correctable. Also StarNAV is a tried technique (for lunar missions) to measure stellar aberration of lots of stars to determine the spacecraft's velocity vector. In the context of an interstellar probe, its velocity would remain pretty-much unchanged and so positional information would be problematic to derive.

Celestial Triangulation with Planets and other Celestial Bodies. This is a self-explanatory method used extensively by interplanetary spacecraft which exploits our accurate knowledge of the positions and velocities of solar system bodies such as planets, moons and asteroids, to enable triangulation in an analogous approach to that of celestial triangulation with stars. However for missions to the NISM, with the corresponding large distances from the sun, uncertainties of 150,000 km would be present.



Credit: Christian



Credit: Christian

Finally, X-Ray Pulsar Navigation (XNAV). Neutron stars are extremely compact rotating spheres which have a magnetic field. X-rays are projected out from the poles which may not align with the spin vector, introducing a conic spread of emitted X-ray directions and so a periodicity is observed in the intensity of these X-rays observed at Earth - Pulsars. Moreover, the period of each cycle is extremely precise (their stability is on the order of an atomic clock) and so can be used as celestial clocks for accurate interstellar navigation, we have XNAV. An outstanding problem with this technology is the very fact that the pulses are so precisely repeated in time. This causes the cold start problem which is that given the XNAV detects a particular pulse from a specific pulsar – how does it relate this to a reference pulse? The XNAV may be an integer N out, introducing navigational errors. These problems and others are mainly issues with algorithm development which need to be further addressed for future missions.

IAF ref	title of talk/paper	presenter	institution	nation
A6,8-E9.1,10,x69130	Financial Incentives for Debris Removal Services	Mrs Morgane Lecas	Astroscale Ltd	UK

IAF abstract: iafastro.directory/iac/paper/id/69130/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A6/8-E9.1/manuscripts/IAC-22,A6,8-E9.1,10,x69130.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A6/8-E9.1/presentations/IAC-22,A6,8-E9.1,10,x69130.show.pptx

Open paper: none found

Reported by: Samar AbdelFattah

The objective of this paper is to discuss potential incentives for satellite operators to motivate them to adopt debris removal services. Since debris generating events continue to occur (with already more than 36,500 debris objects larger than 10 cm and 4,852 active satellites in orbit), the risk on existing and future satellites will only continue to increase. Debris generating events include the Fengyun-1C Anti Satellite Weapons (ASAT) test (2007), Iridium Cosmos Collision (2009), and more recently the Russian ASAT test destroying Cosmos 1408 (2021) which created 1,500 pieces of debris larger than 10 cm and thousands of smaller ones.

Space debris poses a persistent threat to governments, industry space assets, and their downstream applications, as well as a growing risk to the sustainability of the entire orbital environment.

The main idea is to have debris removal funds to be accounted during the operational and revenue generating phase of an asset life using potential incentive models presented to satellite stakeholders. The survey conducted by the Organisation for Economic Cooperation and Development (OECD) Space Forum in 2019 for a group of twenty commercial satellite operators active in satellite communications and Earth Observation showed that implementation of incentives for sustainable operations over the imposition of fines for pollutive practices is the most preferred model.

Thus, the paper will assess different financial incentives including external sinking funds, advanced market commitments (AMCs), subsidies, and performance bonds. This assessment is presented in the format of advantages and disadvantages of each method.

However, governments have more tools and approaches at their disposal to empower debris removal services, including:

- Invest in Research and Development (R&D) to mature debris removal technology
- Advocate and prioritize space debris solutions on the public and political agenda
- Become a customer and early adopter of debris removal services
- Support industry in overcoming barriers for debris removal service adoption
- Incentivise the commercial debris removal market

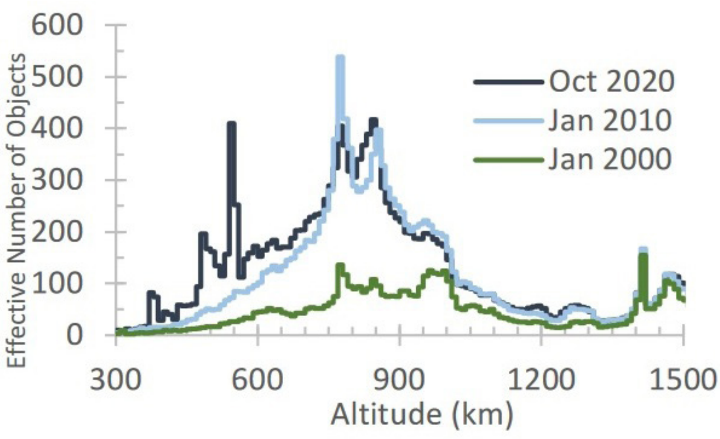


Fig. 1. Evolution of objects in LEO Credit (image and caption): NASA Orbital Debris Program Office

Financial Incentives Assessment

1. External Sinking Funds: funds set aside during the operational lifetime of an asset to cover future decommissioning costs.

Advantages	Disadvantages
• Operator pays during operational lifetime whilst assets are revenue generating. • Ensures funding for End-of-Life (EOL) is reliably acquired, depending on definition of decommissioning/thresholds set for space debris mitigation.	• Sufficient funds must be accrued ahead of the end of life of the installation or asset. • Uncertainty around fund size and timescale of satellite operators

2. Subsidies: include payments from governments to producers, grants, subsidized loans, loan guarantees, Value Added Tax (VAT) exemptions on specific technologies (eg electric cars), feed-in tariffs, or tax credits for environmentally relevant investments.

Advantages	Disadvantages
• Provides immediate benefit for the debris removal market, depending on how the subsidy is structured, reducing barriers for satellite operator to adopt EOL services.	• Risk of technology lock-in, rebound effects, windfall gains and free-riding. • Unlikely to work as a market-based solution.

3. Advance Market Commitments (AMCs): AMCs are financial mechanisms through which binding contracts are secured in advance to purchase a set quantity of useful, but currently unavailable products, thereby establishing a guaranteed viable initial market for the products at an attractive starting price once it has been successfully developed by the private sector. In exchange, private sector developers agree to offer a minimum quantity of the product or service at a lower subsidized rate for a set period. AMCs offset the private sector's hesitance to invest in cost-intensive technologies that could meet a critical need but are considered high-risk in the absence of reliable or easily predicted indicators of future demand or returns.

Advantages	Disadvantages
• Reduces demand uncertainty thus incentivising market entry. • Creates demand that justifies research and development (R&D) investment.	• Relies on Government agreeing to pay for debris removal. • Challenging to identify a single entity to manage an AMC; best applied collaboratively.

4. Performance Bonds: A performance bond is a surety bond issued by an insurance company or a bank to guarantee satisfactory completion of a project by a contractor. The underwriter guarantees an amount equal to the decommissioning sum in return for an arrangement fee and premium. Performance bonds are used in other industries that operate under risk-laden conditions in extreme environments, such as offshore wind, maritime, and mining industries. For these industries, performance bonds applied to decommissioning operational equipment at end-of-life are often coupled with other incentives, such as subsidies, levies, and tax incentives, among others.

Advantages	Disadvantages
• Surety bonds boost liquidity and financial flexibility and allows for other investments or paying down on debt. • Ensures funding for EOL in advance, depending on definition of decommissioning/ thresholds set for space debris mitigation. • Established precedent for bonds in the satellite industry.	• Lack of enforceability and capacity of the government to enforce them • Only covers partially the estimated liabilities (leaving the financial risk to government). • Uncertainty around performance bond value and timescale of satellite operators that could be agreed through satellite licensing process

Challenges

In Japan, sub-working group for on-orbit servicing formed by the Japanese Government's Space Debris Task Force, has discussed the economic externality of space debris issues. The study report by the Sub-Working Group on On-Orbit Servicing pointed out that “what is needed now is to make it clear how a government vision and design in order to create an economic ecosystem where Active Debris Removal commercially viable.” Since “any rule that enable to internalize the cost of removal of space debris requires an approach that adopts both regulation and incentives”, the report introduces some policy ideas instead of making a single policy recommendation and leaves it for future consideration that includes economic incentives.

While in the US, operators’ response to the suggested performance bond rule was that if implemented, the proposed performance bond calculation methodology could lead to unintended consequences wherein satellite operators seek to minimize the bond value, at the expense of space safety. Astroscale US called for the establishment of a working group to help assess methodology proposed by the Commission, with the intention of successful application to space activities.

ESA’s countries such as the UK and France already introduced in-orbit third party liability insurance and France also has one of the most stringent regulations regarding legally binding debris mitigation requirement which could be coupled with financial incentives to incentivise compliance and support the market of In-Orbit Services.

The authors initial recommendation is to use AMCs and performance bond could present an effective financial incentive provided industry criticisms are addressed. Once tailored for the industry, AMCs and performance bond ensure that funds are allocated to decommissioning thus reducing the uncertainty on market demand and allowing for investment in debris removal services.

Implementation wise, financial incentives could be part of the satellite mission license process to enforce required measurements. This can sustain both space environment neutrality and enablement of debris removal market and technologies.

IAF ref	title of talk/paper	presenter	institution	nation
D4.4.9,x69502	The Pragmatic Interstellar Probe Study: Results	Ralph L McNutt, Jr	Johns Hopkins University	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: interstellarprobe.jhuapl.edu/Resources/Publications/

Reported by: Samar AbdelFattah

Previous edition (P38) reviewed the Interstellar Probe mission which is a joint effort that was requested by the Heliophysics Division within NASA’s Science Mission Directorate (SMD), focuses on a pragmatic interstellar probe with the ability to operate at 1,000 AU and a design lifetime of 50 years and assesses its technical readiness for a launch in 2030 to help support the next round of Decadal Surveys covering the time frame of 2023–2032 (For mission preview, please refer to P38-IAC2021 report).

The mission funded by NASA Heliophysics Division to provide data on the Solar and Space Physics Decadal Survey which has recently started operations. Even though the concept is not really new and goes back to at least 1960. The nominal mission expected to use Super Heavy Lift Launch Vehicle SHLLV with additional 3rd and 4th stages and a separated space craft “observatory” of 860 Kg holding 90 Kg of instruments.

Starting with a quick review on launch scenarios starting with the "new ingredient" of using The Ares V in combination with a spacecraft using an advanced radioisotope electric propulsion (REP) system and cryogenic upper stages which was report in 2009 during the 60th IAC. However, the Ares V and the Constellation Program were cancelled in October 2010. Also, a quick review on the use of the Space Launch System (SLS) to enable an Interstellar Probe. The initial work was presented in the 65th and 66th IAC. In addition, work on Interstellar Systems for Interstellar Probe was presented in the 67th and updated in the 68th IAC meetings.

The broad engineering requirements for the mission were set as the following, conditioned by being ready to launch by 2030:

1. Readiness: Launch no later than 1 January 2030

2. Downlink: Operate from 1,000 au

3. Power:

a. Power at start: No more than 600 Watts required

b. Power at end: No less than half at beginning

4. Longevity: Lifetime of not less than 50 years

Spacecraft systems were driven by recent missions with very similar requirements, including:

1. New Horizons – 16-year design lifetime, General Purpose Heat Source-Radioisotope Thermoelectric Generators GPHS-RTG, significant autonomy, dual-mode (3-axis stabilized/spin stabilized)

2. Van Allen Probes – Space physics payload. Long (50 m) wire booms, spin stabilized

3. Parker Solar Probe (PSP) – Space physics payload including imager (coronal), 3-axis stabilized, heavily autonomous operation

Figure 1 Science Tracibility Matrix (STM) for Goal 1 "Baseline Mission"
Credit (image and caption): McNutt et al

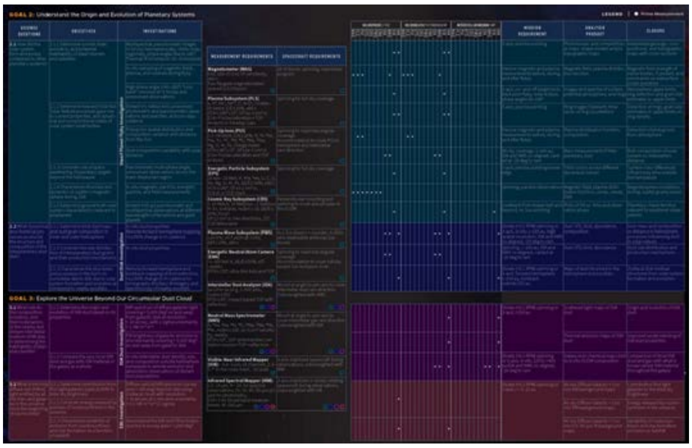
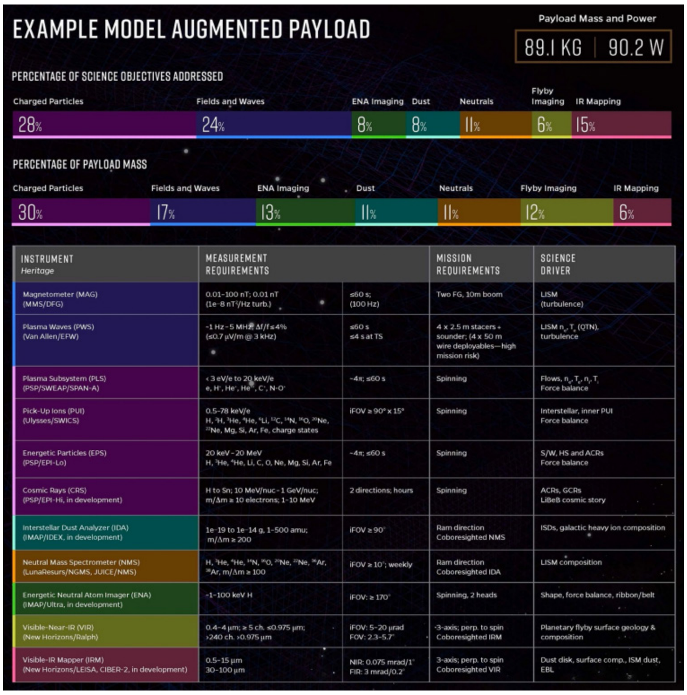


Figure 2 Science Tracibility Matrix (STM) for Goals 2&3 "Augment Mission"
Credit (image and caption): McNutt et al

The mission development starts with developing a Science Traceability Matrix (STM), its logic flow and aligning the goals to it with the baseline Goal 1 and Augmented mission Goals 2, 3. The STM for Goal 1 is shown in Fig.1, while Fig. 2 is showing the augmented mission Goals 2 & 3 along with Goal 1, with the modified payload.



EXAMPLE MODEL AUGMENTED PAYLOAD

Payload Mass and Power: 89.1 KG | 90.2 W

PERCENTAGE OF SCIENCE OBJECTIVES ADDRESSED

Charged Particles	Fields and Waves	ENA Imaging	Dust	Neutrals	Flyby Imaging	IR Mapping
28%	24%	8%	8%	11%	6%	15%

PERCENTAGE OF PAYLOAD MASS

Charged Particles	Fields and Waves	ENA Imaging	Dust	Neutrals	Flyby Imaging	IR Mapping
30%	17%	13%	11%	11%	12%	6%

INSTRUMENT *Heritage*	MEASUREMENT REQUIREMENTS		MISSION REQUIREMENTS	SCIENCE DRIVER
Magnetometer (MAG) (MMS/DFG)	0.01–100 nT; 0.01 nT (1e-8 nT^2/Hz turb.)	≤60 s; (100 Hz)	Two FG, 10m boom	LISM (turbulence)
Plasma Waves (PWS) (Van Allen/EFW)	~1 Hz – 5 MHz; Δf/f ≤ 4% (≤0.7 μV/m @ 3 kHz)	≤60 s ≤4 s at TS	4 x 2.5 m stacers + sounder; (4 x 50 m wire deployables—high mission risk)	LISM n_e, T_e (QTN), turbulence
Plasma Subsystem (PLS) (PSP/SWEAP/SPAN-A)	< 3 eV/e to 20 keV/e e, H^+, He^+, He^{++}, C^+, N-O^+	~4π; ≤60 s	Spinning	Flows, n_e, T_e, n_i, T_i Force balance
Pick-Up Ions (PUI) (Ulysses/SWICS)	0.5–78 keV/e H, ^{2}H, ^{3}He, ^{4}He, ^{6}Li, ^{12}C, ^{14}N, ^{16}O, ^{20}Ne, ^{22}Ne, Mg, Si, Ar, Fe, charge states	iFOV ≥ 90° x 15°	Spinning	Interstellar, inner PUI Force balance
Energetic Particles (EPS) (PSP/EPI-Lo)	20 keV – 20 MeV H, ^{3}He, ^{4}He, Li, C, O, Ne, Mg, Si, Ar, Fe	~4π; ≤60 s	Spinning	S/W, HS and ACRs Force balance
Cosmic Rays (CRS) (PSP/EPI-Hi, in development)	H to Sn; 10 MeV/nuc – 1 GeV/nuc; m/Δm ≥ 10 electrons; 1–10 MeV	2 directions; hours	Spinning	ACRs, GCRs LiBeB cosmic story
Interstellar Dust Analyzer (IDA) (IMAP/IDEX, in development)	1e-19 to 1e-14 g, 1-500 amu; m/Δm ≥ 200	iFOV ≥ 90°	Ram direction Coboresighted NMS	ISDs, galactic heavy ion composition
Neutral Mass Spectrometer (NMS) (LunaResurs/NGMS, JUICE/NMS)	H, ^{3}He, ^{4}He, ^{14}N, ^{16}O, ^{20}Ne, ^{22}Ne, ^{36}Ar, ^{38}Ar, m/Δm ≥ 100	iFOV ≥ 10°; weekly	Ram direction Coboresighted IDA	LISM composition
Energetic Neutral Atom Imager (ENA) (IMAP/Ultra, in development)	~1–100 keV H	iFOV: ≥ 170°	Spinning, 2 heads	Shape, force balance, ribbon/belt
Visible-Near-IR (VIR) (New Horizons/Ralph)	0.4–4 μm; ≥ 5 ch. ≤0.975 μm; >240 ch. >0.975 μm	iFOV: 5–20 μrad FOV: 2.3–5.7°	3-axis; perp. to spin Coboresighted IRM	Planetary flyby surface geology & composition
Visible-IR Mapper (IRM) (New Horizons/LEISA, CIBER-2, in development)	0.5–15 μm 30–100 μm	NIR: 0.075 mrad/1° FIR: 3 mrad/0.2°	3-axis; perp. to spin Coboresighted VIR	Dust disk, surface comp., ISM dust, EBL

The paper then present the example models for both baseline mission and augmented mission. In Fig. 3 an example model for the augmented mission can be shown with detailed instrument capabilities, masses, power and data downlink requirements, as well as estimated instrument costs have been studied and are detailed in the final report. The corresponding integrated spacecraft layout of the augmented mission is shown in Fig. 4. From the various other optimization studies, all spacecraft stages are used during and shortly after leaving Earth orbit. The spacecraft is then spun up to its nominal cruise characteristics. The magnetometer boom and plasma wave system wire antennas are then deployed.

Figure 3 Example Model for Augmented Payload
Credit (image and caption): McNutt et al

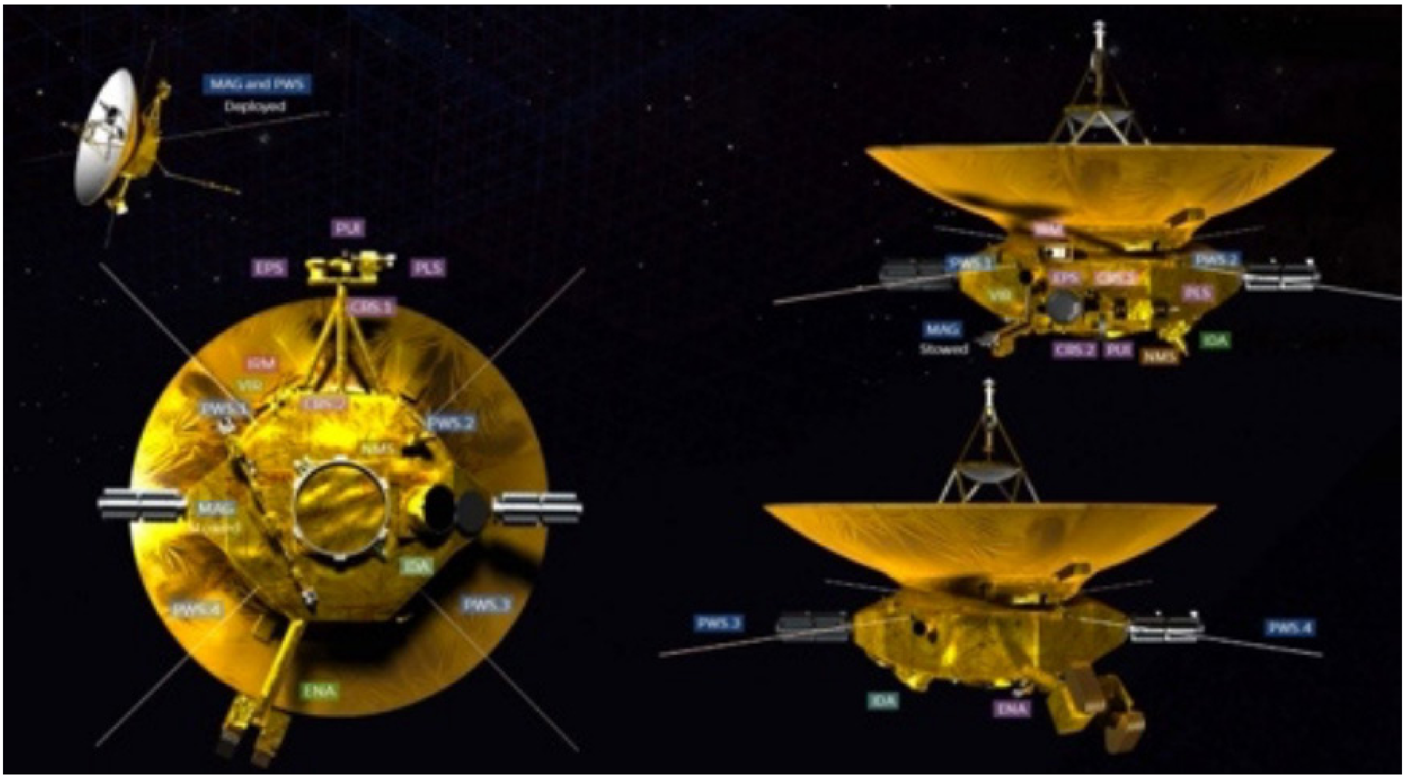


Figure 4 Instrument Layout for the Augmented Mission
Credit (image and caption): McNutt et al

Mission details include the Launch Vehicle where initial work had focused on the notional SLS Block 2 Cargo configuration as an SHLV that should be available in the 2030s and also have the appropriate number of launches to be certifiable for including a radioisotope power supply (RPS) akin to the notional NextGen Radioisotope Thermoelectric Generator (RTG) now under development by the Department of Energy (DOE) for NASA.

The mass and power requirements for both baseline and augmented mission were agreed to be "payload agnostic" with appropriate margins and reserves to inform the mass of the spacecraft till the completion of new thermal material investigation. In addition, the team developed an analytic tool to estimate flyout times and asymptotic solar system escape speeds using coplanar, circular orbits for Jupiter and Earth and a patched conic approximation to deal with flybys for -

- Option 1 (passive Jupiter flyby),
- Option 2 (powered Jupiter flyby),
- Option 3 (passive Jupiter flyby.

- followed by a powered close-Sun flyby (perihelia of 2 to 6 solar radii from the centre of the Sun in steps of one solar radius). A "best" Option 1 and Option 2 configuration were then examined in depth across the Jupiter orbit of the Sun from 2030 through 2042 for looking at more launch details, including science enabled for the final aim point in the sky.

For telecommunication, a set of trades were made across X-band, Ka-band, and optical downlink, and use of ground-assets as receiving stations. At the spacecraft systems level, the favourable choice is a 5 m diameter high gain antenna (HGA).

The sustainability of the mission targeted lifetime of 50 years and the fund for such mission were also considered in the mission study. An overview of the mission top level requirements can be shown in Fig. 5.

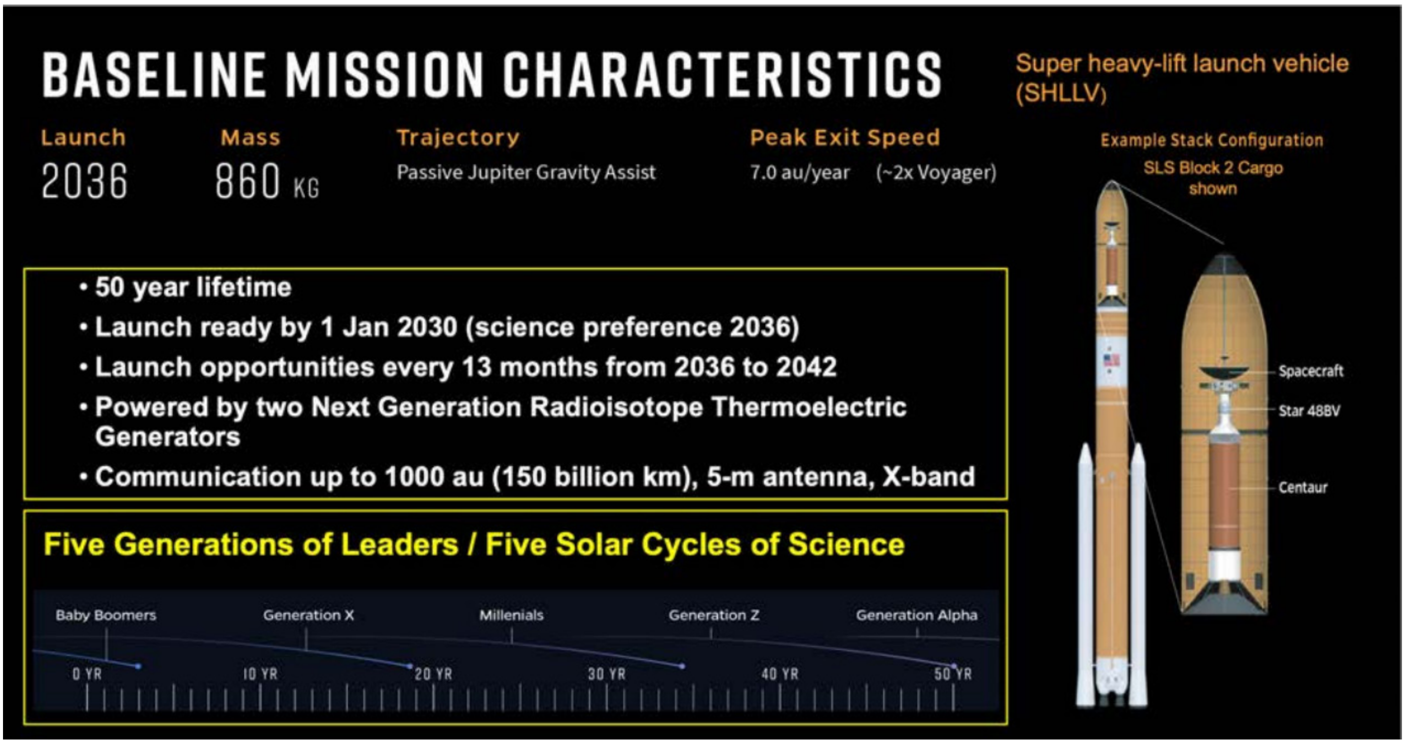


Figure 5 Baseline Mission Summary & Overview
Credit (image and caption): McNutt et al

In general, the Interstellar Probe mission has been an iterative one so most of the work updates have been progressively shared during IAC events but also collectively presented in the mission report published to the public. Thus, it is recommended to go through the Interstellar Probe report (interstellarprobe.jhuapl.edu/).

IAF ref	title of talk/paper	presenter	institution	nation
A6.1.x71592	On-orbit Optical Detection of Lethal Non-Trackable Debris	Mr Andrew Nicholas	Naval Research Laboratory	USA

IAF abstract: iafastro.directory/iac/paper/id/71592/summary/

IAF cited paper: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A6/1/manuscripts/IAC-22,A6,1,8,x71592.pdf

IAF cited presentation: iafastro.directory/iac/proceedings/IAC-22/IAC-22/A6/1/presentations/IAC-22,A6,1,8,x71592.show.pptx

Open paper: none found

Reported by: Samar AbdelFattah

Concerned by the alarming rate of increase of debris objects, small objects in the size of few centimetres to 0.1 mm are considered in this paper. Since they are abundant, difficult to track or even to detect on a routine basis, and have enough kinetic energy to damage spacecraft, they are labelled as "lethal-non-trackable" objects. A sample of damage caused by small objected moving at orbital velocities is shown in Fig. 1.

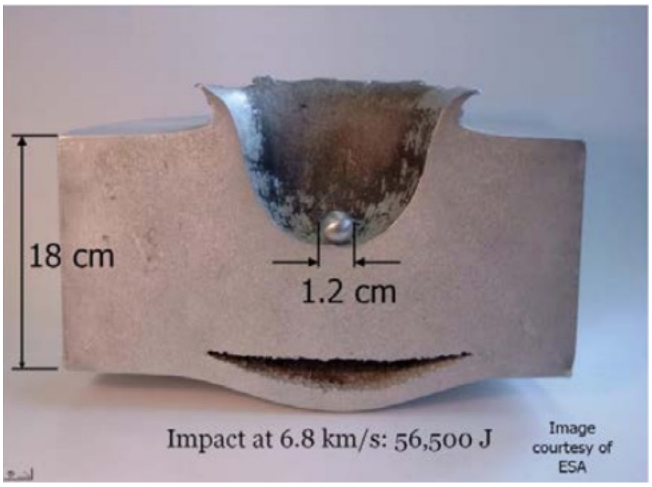


Figure 1 Damage caused by a 1.2 cm diameter aluminum sphere striking an 18 cm thick plate of aluminum at 6.8 km/s. Credit: ESA

The paper presents a method, Lightsheet Anomaly Resolution And Debris Observation (LARADO), to use a sensor-based light sheet that would be able to detect photons passing by the host spacecraft. The concept will enable detection of tiny to small objects that the current concept won't be able to detect.

The lightsheet is created via a collimated light source that is connected to a diffusive optic, such as an axicon, Powell lens, or engineered diffuser. An optical lens coupled to a detector provides a method to monitor the scene. This system creates a virtual witness plate (VWP) for debris observations as seen in Fig. 2 with a scalable functional area defined by the system components including the laser power, the diffusive optic, the lens field of view (FOV) and aperture, and the detector sensitivity.

The LARADO system will be hosted on the DoD Space Test Program on the STP-Sat7 spacecraft.

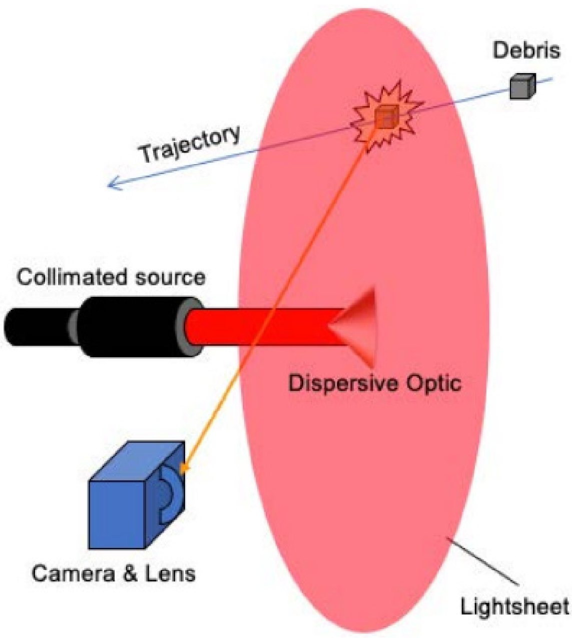


Figure 2 Representative Components for the LARADO Sensor Concept. Credit: Nicholas et al

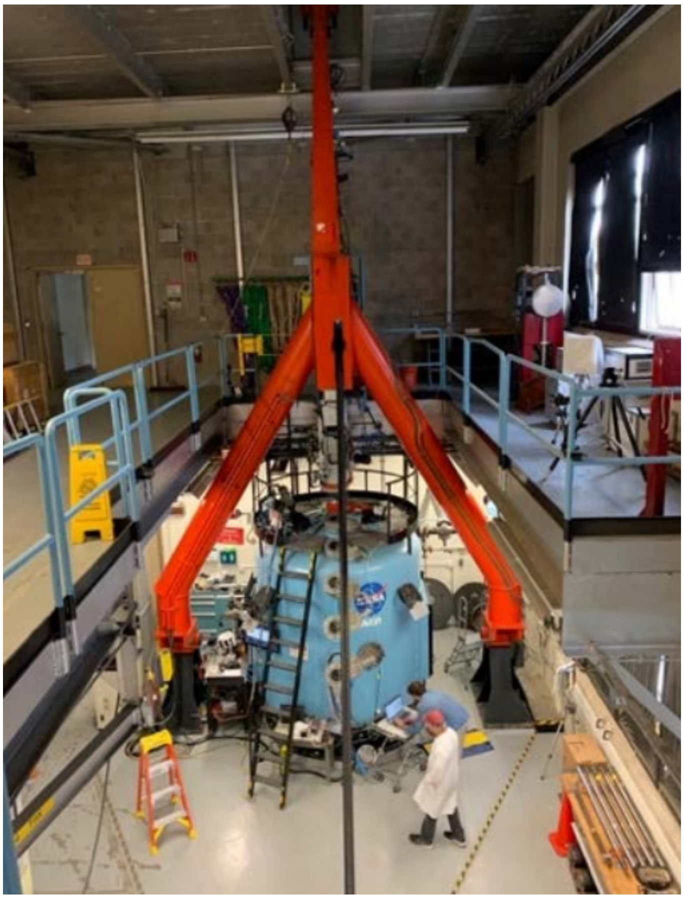


Figure 3 Presents a photo of the AVGR facility, the blue structure is the vacuum chamber, the orange structure raises and lowers the gun.
Credit: Nicholas et al

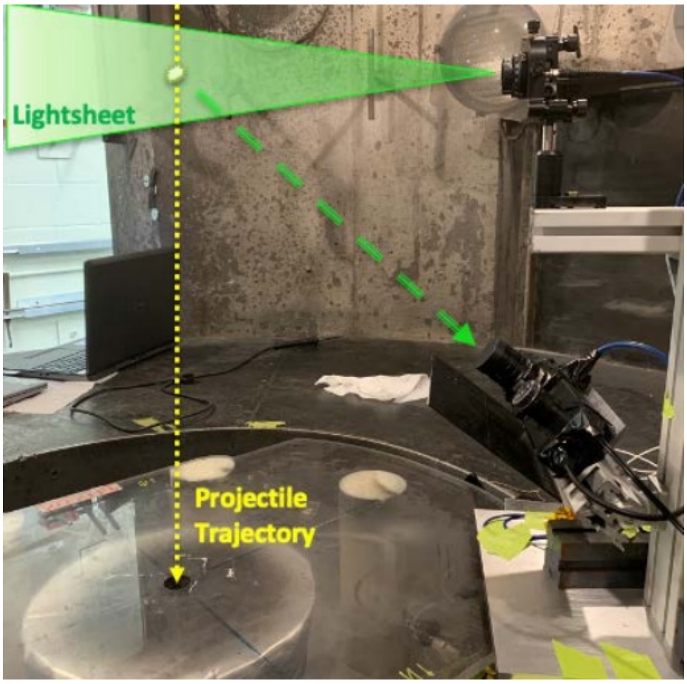


Figure 4 Annotated photo of the LARADO test setup in the AVGR chamber
Credit: Nicholas et al

Testing

The system was tested at the NASA AMES using the Ames Vertical Gun Range (AVGR), Fig.3. With its unique hinged gun apparatus, the AVGR can vary the impact angle relative to the gravity vector (from horizontal to vertical). Targets are contained within a large impact chamber that can be evacuated to simulate impacts on an airless body or backfilled with air or various gases to simulate different environments. The LARADO test support frame was constructed from 80/20 hardware with a 1/2” thick aluminium plate as its base. The setup includes: two cameras, a Ximea and a Prophesee (see below), and the laser sheet generation assembly. A photo of the system during test setup is shown in Fig. 4.

For the laser setup, a survey for available laser and fibre optic combinations was made. Minimal size, weight, and power for future space flight opportunities were the main features during the selection process. Wavelengths compatible with COTS optics and sensors were also necessary. The test reported in this paper was operated at settings that produced 15W optical output.

The light sheet generation was employed through two different methods in general. The first one was using an engineered diffuser which is an array of micro lenses generated by micro replication in a polymer. The engineered diffuser worked well at lower power but the micro lenses and their plastic substrates melted at higher laser powers at exposures of over 1 minute.

Thus, the second method was used in the test presented in the paper, which used cylindrical lens called Powell lens to generate the light sheet. The cylindrical lens made of glass can be figured to produce uniform light sheets based on the laser beam diameter and intensity distribution and is able to survive the 30 W beam in vacuum without convective cooling.

In addition to the laser setup and light sheet lens, two cameras were used as part of the test setup in the AVGR. A XIMEA camera and Prophesee (Neuromorphic) camera. Table 1 shows the angular fields of view (FOV) for the two cameras with various short focal length lenses.

Table 1. Camera and Lens Specifications

Camera	Ximea 1" format	Prophesee 1/2.5" format				
	length	width	diagonal	length	width	diagonal
Chip size mm	12.485	9.988	15.989	6.220	3.499	7.136
Focal length mm	FoV full angle deg.					
2	144.47	136.35	151.91	114.51	82.36	121.46
4.7	106.05	93.47	119.10	66.99	40.83	74.41
6	92.27	79.54	106.22	54.80	32.51	61.48
8	75.93	63.95	89.96	42.49	24.67	48.08
10	63.95	53.08	77.28	34.55	19.85	39.28
12.5	53.08	43.56	65.20	27.94	15.93	31.86
14	48.06	39.26	59.45	25.05	14.25	28.60

Credit: Nicholas et al

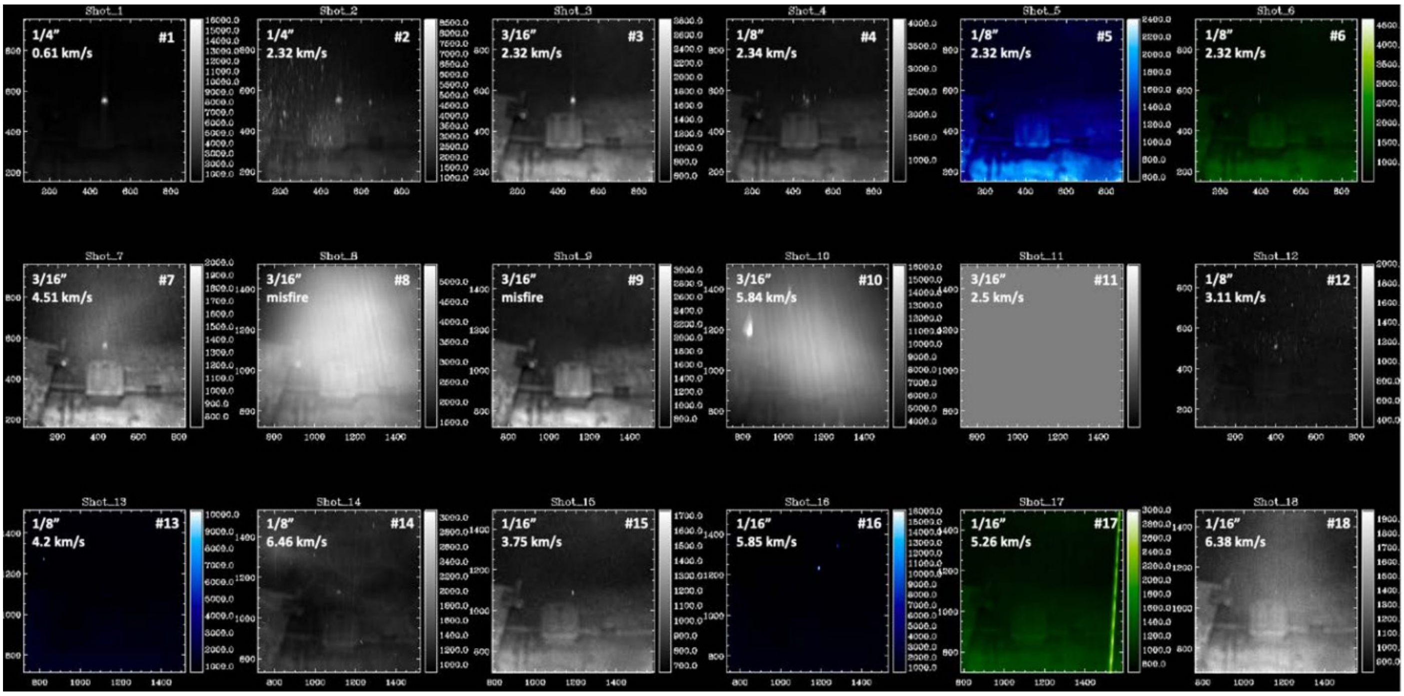


Figure 5 Cropped (100 x 100) differenced 18 shots. Grayscale images represent alumina shots, green represent quartz or borosilicate glass, and blue images represent aluminum projectiles
Credit: Nicholas et al

AVGR Data

In total twenty shots were taken over a test period of five days at the AVGR facility. Six shots were taken with the powder gun (PG), twelve shots were taken with the light gas gun (LGG), and additional two LGG shots were taken in an alternate configuration for an application on the surface of the moon. The analysis was then carried out by creating image difference between the simulated debris event crossing frame and the frame of image before using the Ximea CCD camera images. The difference images were represented for alumina, quartz, borosilicate glass and aluminium projectiles. The 18 shots used in the analysis had exposure times of 40 ms, and the start of the exposure time was random with respect to the projectile crossing time, hence sometimes there is little gas accumulation in the frame with the event and other times there is a lot. This gas accumulation along with Light Gas Gun (LGG) misfires, different signal strengths, and camera connection issues were shown in the 18 shots sequence, Fig 5.

The Prophesee neuromorphic camera was able to measure the projectiles crossing the laser sheet but after the optic filter issue were fixed by fitting stock 5 mm lens. However, further analysis and tuning of the neuromorphic camera's bias settings are planned for future research. In general, lasersheet technique has been verified using small projectiles at near orbital velocities. This has increased the technological readiness level (TRL) of the LARADO sensing technique to TRL 6 on the NASA scale. Critical Design Review (CDR), along with future work is expected to be done to include the LARADO instrument on the STPSat-7 spacecraft which is expected to launch early-mid 2024.