71st International Astronautical Congress 2020

The Interstellar Report - Part 2 of 2

This year's Congress was a ***Cyberspace Edition*** offered without registration fee, free of charge for a global community. Principium readers were therefore able to access the whole programme. This was a possibly unique opportunity to engage with this global event without the substantial entry fee normally charged and, of course, without travel expenses.

The catalogue of all technical sessions is at -

iafastro.directory/iac/browse/IAC-20/catalog-technical-programme

In part two of this report we aim to complete our reports of all the items likely to be of special interest to Principium readers. Many were 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 more economical access to space, etc.

Our reporters are -

- Patrick Mahon (PJM)
- John I Davies (JID)
- Angelo Genovese (AG)
- Max Daniels (MD)

Our thanks to all of them.

Our reporters views are, of course, their own and don't necessarily reflect the views of the editors of Principium or of the Initiative and Institute for Interstellar Studies.

On this occasion access to both papers and presentations has been granted, to all who register by the International Astronautical Federation (IAF). Registration is available at -

iac2020.vfairs.com/en/registration

However we have also sought out open publication without registration and cited links where we have found them.

CONTENTS

B5,1,7,x59095	Edge computing and its applications in satellites	Mr. Archit Latkar	Ramaiah Institute of Technology	India

IAF cited paper:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/B5/1/manuscripts/B5,1,7,x59095.pdf

IAF cited presentation video:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/B5/1/presentations/B5,1,7,x59095.show.mp4

Open paper: None found

Reported by: John Davies

Mr Latkar observed that satellites are currently unable to perform computationally challenging tasks on board. He suggests that "Edge computing seeks to setup a distributed platform for integrating cloud technology in IOT networks" [1]. His team aim to extend technologies such as image processing, blockchain and deep learning into space - and even to small spacecraft such as cubesats - by providing a network of specialized satellites, esats, to provide services to other satellites in the vicinity - based initially on the example of Iridium satellite constellation and using ideas from the SpaceX Starlink network. They have built mathematical models and examined costs, timescales and some specific challenges. The modelling includes -

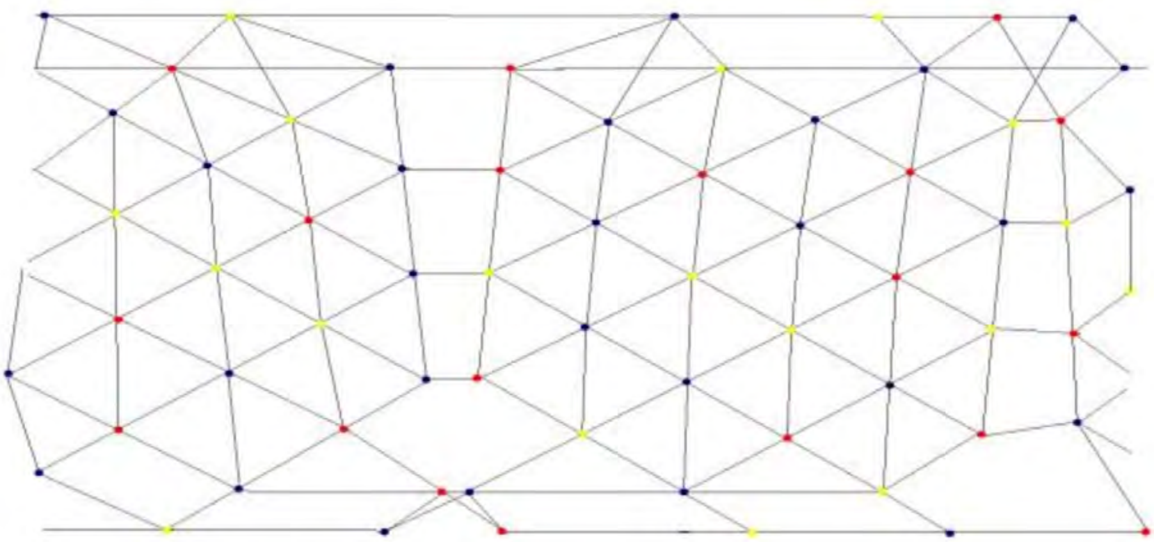
- Optimised placement and cost of esats in the Satellite Edge Network
- Optimising Resource Allocation - notably between three distinct types of esat in the network
- Estimating Time Delay - between esats in the network using queueing theory

They use a lossless model, handling congestion by handing requests between satellites of the same type.

The challenges they see are -

- Data Reduction - identifying the inadequacy of current protocols for this application
- Usability - mainly ease of integration with the user satellites
- Data Abstraction - to provide consistent user interfaces
- Service Management - to handle user requests and to integrate new services
- Privacy and Security - suggesting that existing non-defence satellite networks are weak in this respect

Mr Latkar and the team envisage a satellite edge network architecture which can potentially revolutionise the space industry. If we are to base our initial exploration of the stars on large numbers of very small probes then networking between them is likely to be a key technology and maturing this closer to home can contribute to development.



Network of 18 esats used to model behaviour showing three types (red, green and blue).
Credit: Latkar et al

Authors: Archit Latkar and 10 others, all Ramaiah Institute of Technology

[1] en.wikipedia.org/wiki/Internet_of_things

A5,4-D2.8,6,x60658	Knowledge and Technology Building Blocks for Space Access Architectures	Mr. Arun Subramanian Venkataraman	Invenk Solutions	India

IAF cited paper:
iafastro.directory/iac/proceedings/IAC-20/IAC-20/A5/4-D2.8/manuscripts/A5,4-D2.8,6,x60658.pdf

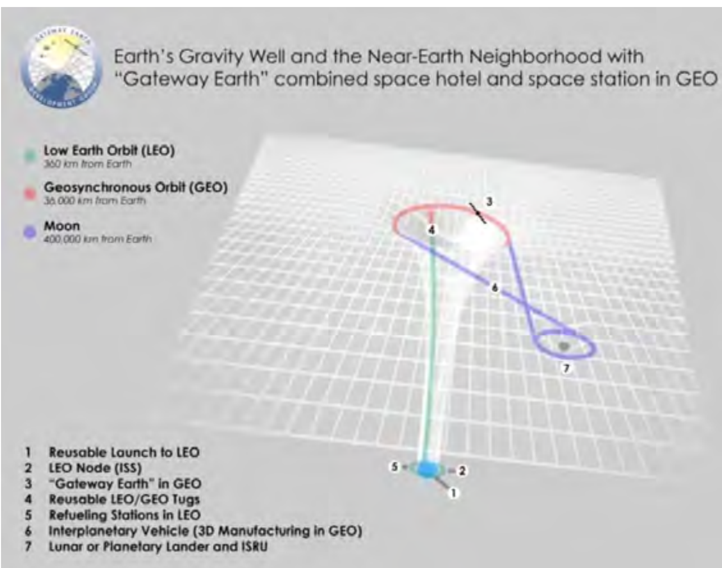
IAF cited presentation video:
iafastro.directory/iac/proceedings/IAC-20/IAC-20/A5/4-D2.8/presentations/A5,4-D2.8,6,x60658.show.mp4

Open paper: None found

Reported by: John Davies

Gateway Earth Development Group (GEDG) aims to develop a near-geostationary gateway for human exploration of the solar system. The baseline design uses Bigelow B330 inflatable modules (bigelowaerospace.com/pages/b330/). Located just above geostationary orbital radius, the gateway would provide a repair and recycling station a Satellite Repair and Manufacture Facility (SRMF), for geostationary (GEO) satellites as well as vehicles to the Moon and beyond. The NASA OSAM concept (On-orbit Servicing, Assembly, and Manufacturing - nexis.gsfc.nasa.gov/OSAM-1.html) for in orbit servicing and construction is an existing idea with similar functions. The gateway would build upon the reduced cost of GEO resulting from low-thrust orbit raising from low earth orbit (LEO) as opposed to the current use of a geostationary transfer orbit (GTO) [1]. The paper identifies relevant patents in these areas of technology and, in a substantial appendix wider technological distribution of capabilities in -

- Manufacturing in Space
- Satellite Payload Health Monitoring
- Satellite Payload Performance Monitoring
- Satellite Freighters
- In-Space Recycling & Reuse Technology

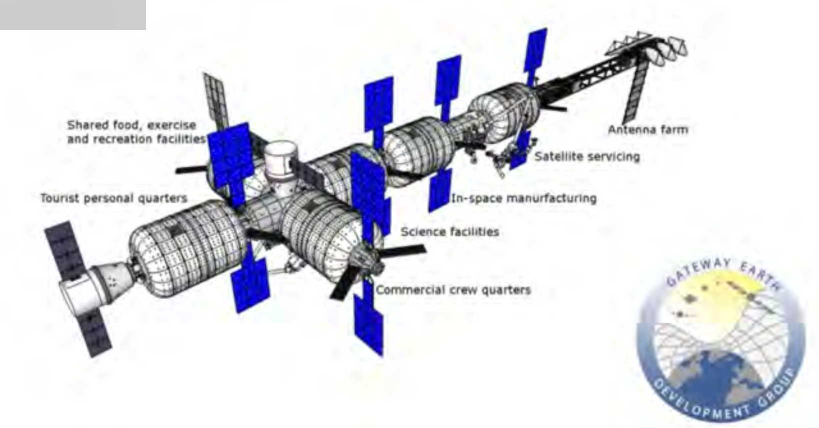


We need this vision of "routine" access, manufacturing and servicing if we are to achieve the large scale capability required by many of our interstellar visions - for example see the Bigelow modules envisaged by Michel Lamontagne for the construction of the Icarus Firefly probe on the cover of Principium 22.

Contrast between the Earth's gravity well and the Moon - showing LEO-Moon deltaV advantage (above)

Visualisation of Gateway Earth, just beyond GEO (right)

Both images credit: Gateway Earth Development Group



Authors: Venkataraman + Lewis Leslie, Robbie Anderson and Matjaz Vidmar - latter 3 all University of Edinburgh. And one other, the presenter of the video - not clearly identified.

[1] GTO payload is a key performance parameter for launchers. Example GTO performance -
GSLV Mk III (India) payload 4,000 kg to GTO (www.isro.gov.in/launchers/gslv-mk-iii)
Delta IV Heavy (USA) 10,100 to GTO (www.ulalaunch.com/docs/default-source/rockets/delta-iv-user%27s-guide.pdf - Figure 2-9 . Delta IV Mission Capabilities)

A4,2,7,x58825	The InCosmiCon Research Center and its activities in the field of SETI, Big History and interculturality	Dr. Paolo Musso	University of Insubria	Italy

IAF cited paper:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/A4/2/manuscripts/A4,2,7,x58825.pdf

IAF cited presentation video:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/A4/2/presentations/A4,2,7,x58825.show.mp4

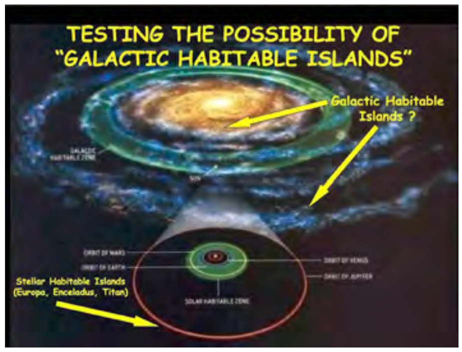
Open paper: None found

Reported by: John Davies

The University of Insubria (Italy) and the Universidad Católica Sedes Sapientiae, Lima (Peru), created a new research centre called InCosmiCon (Intelligence in the Cosmic Context), based at the Department of Human Sciences, Innovation and Territory (DISUIT) to investigate the nature of intelligence in an interdisciplinary way, as announced at IAC 19, Washington, in 2019. See the report of D Musso's talk in Principium 29, May 2020, page 37. Their work on translating Spanish texts to the languages of indigenous Amazonian peoples has been extended to Yánesha, Asháninka, Yine, Shipibo and Matsigenka. This continuing effort aims to use the unique laboratory of these mutually unintelligible languages as a testbed for the interpretation of SETI search results. The project sees some urgency here given the likely attrition of these languages.

Other InCosmiCon work includes -

- computer simulation of possible "galactic habitable islands" outside of the currently understood galactic habitable zone, as in the Solar system where habitable "islands" (eg Europa, Enceladus, Titan, and others) may exist outside of the previously limited habitable zone.
- Optical SETI in Peru - unique in South America.
- New algorithms for SETI - 5 possible "candidates" so far - spectral entropy, cognitive radio, autocorrelation, artificial intelligence, compressive cyclic analysis.
- Beauty in science - Global Research on the Aesthetic Dimensions of Science (GRADS), was conceived before InCosmiCon by Professor Brandon Vaidyanathan [1]. Investigating the relevance and the universality of beauty in science. The two projects are now cooperating. Aesthetics may well stand alongside science and mathematics as a common framework of understanding between ETIs.



Parallel between possible habitable islands the Soar System and in the Galaxy

Credit: Musso

There are 46 other authors listed on this paper, reflecting the breadth of involvement in InCosmiCon.

Broadening SETI in this way looks like an important addition to what would inevitably have implications way beyond hard science and engineering if and when SETI succeeds and thus requires a "best efforts" approach well before this happens.

IAC-20,A4,2,12,x59772	SETI Search: Plausibility of a SETI Probe and Search Parameters for an Interstellar SETI Search	Dr Ugur Guven	UN CSSTEA[2]	USA

IAF cited paper:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/A4/2/manuscripts/A4,2,12,x59772.pdf

IAF cited presentation video:iafastro.directory/iac/proceedings/IAC-20/IAC-20/A4/2/presentations/IAC-20,A4,2,12,x59772.show.mkv

Open paper: None found

Reported by: John Davies

Dr Guven argues that the best way to do a SETI study is in outer space away from the atmospheric and magnetic distortions of Earth. He draws lessons for the form of a probe to do this from UFO sightings, most of which exhibit "symmetry along one or more axis". He discusses two probe propulsion and power altenatives, nuclear and antimatter and suggests a long term spiral SETI search by very long-lived probes.

[1] Dr. Brandon Vaidyanathan is Associate Professor and Chair of the Department of Sociology at The Catholic University of America.

[2] Centre for Space Science and Technology Education in Asia and the Pacific (CSSTEAP), www.cssteap.org/,

C4,9,2,x59647	Integrated optimization of trajectories and layout parameters of spacecraft with air-breathing electric propulsion	Mr. Alexander Golikov	Central Aerohydrodynamic Institute (TsAGI)	Russian Federation

IAF cited paper:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/C4/9/manuscripts/C4,9,2,x59647.pdf

IAF cited presentation video:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/C4/9/presentations/C4,9,2,x59647.show.mp4

Open paper: None found

Reported by: John Davies

Mr Golikov makes the case for small spacecraft in ultra-low Earth orbits (150-250 km) using air-breathing electric propulsion (ABEP) to maintain altitude. There is a clear tradeoff between altitude (more propellant input at lower altitudes) and drag (also increasing at lower alttudes). The paper provides an analytic solution thus setting requirements for the ABEP system.

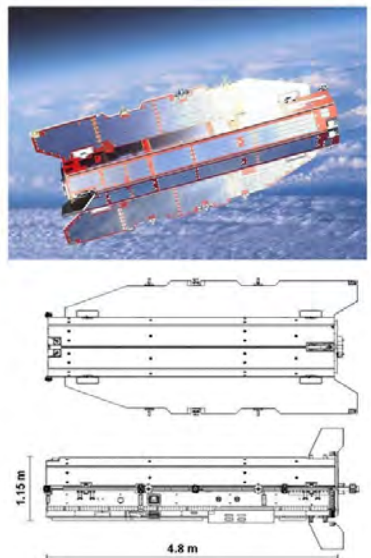
The pioneering ESA GOCE mission [1] was an early demonstrator of the possibilities but its lifetime was limited by the amount of Xenon propellant carried. The paper proposes to use only the atmosphere as the "working fluid". The ABEP system configuration would consist of -

- air intake
- thermalizer to decelerate the gas particles to thermal velocities
- ionization chamber
- acceleration region to accelerate the ionized gas in an electromagnetic field
- neutralizer for the ejected plasma particles

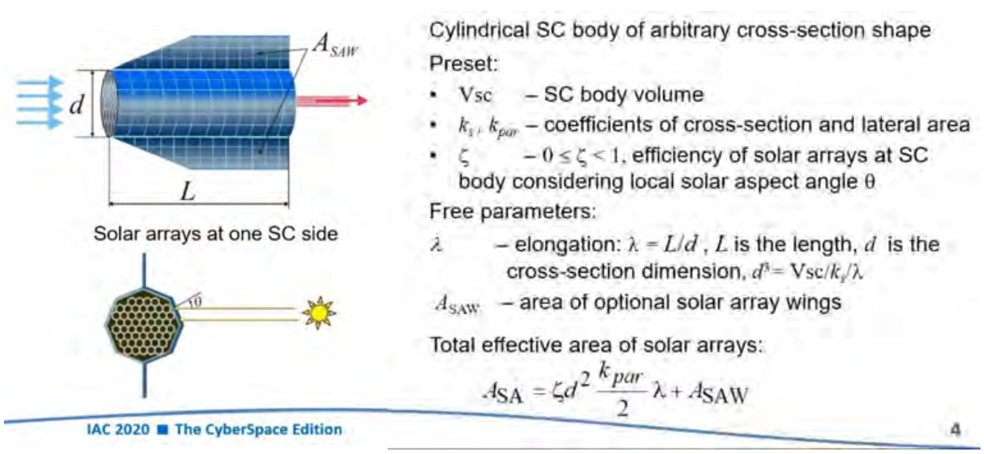
- with solar panels providing the power.

The system is, in effect, propellantless.

Based on models of the atmosphere, aerodynamic drag and of the air intake and thermalizer the paper derives conditions for long-term spacecraft existence in orbit. The paper presents curves showing dependencies of the minimal ABEP power on orbit altitude, minimum allowable gas number density in the ionization chamber and required power on the range of allowable altitudes.



The GOCE spacecraft
Credit: Steiger et al [1]



Layout of Spacecraft with ABEP

Credit: Golikov and Fitatyev

Authors: A A Golikov, A S Fitatyev

[1] ESA Gravity Field and Steady-State Ocean CirculationExplorer(GOCE) 17/03/2009 - 11/11/2013.

The Deorbiting of GOCE – A Spacecraft Operations Perspective, Steiger et al - 5th International GOCE User Workshop. Paris, 2015 - www.researchgate.net/profile/C_Steiger/publication/280114310_The_Deorbiting_of_GOCE_-_a_Spacecraft_Operations_Perspective/links/55aacf4208ae815a04279220/The-Deorbiting-of-GOCE-a-Spacecraft-Operations-Perspective.pdf

D4,5,7,x60941	Analysis of technology, economic and legislation readiness levels of asteroid mining industry: a base for the future space resource utilization missions	Ms. Smiriti Srivastava	Space Generation Advisory Council (SGAC)	Republic of Singapore

IAF cited paper:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/D4/5/manuscripts/D4,5,7,x60941.pdf

IAF cited presentation video:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/D4/5/presentations/D4,5,7,x60941.show.mp4

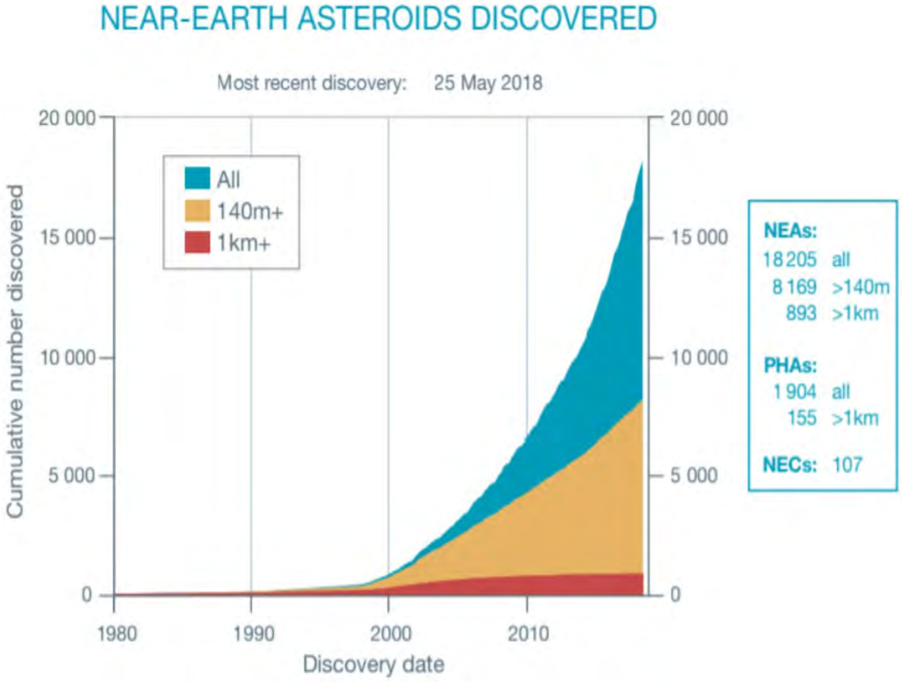
Open paper: None found

Reported by: John Davies

This paper ranges from technological readiness through business, economics, policy and legislation to sustainability and feasibility. Asteroids typically have low deltaV requirements by comparison with the Moon. They also contain usable materials in variety and accessibility superior to the Moon. An initial mission is judged to be at TRL 4 (Component Validation in Laboratory Environment) with extraction technologies Collection Mining/ Surface Mining, Shaft-Based Mining, Laser-Based Heating, Microwave Heating and Capture at the lower TRLs of 2 and 3. The team also developed Readiness Levels for policy (PRL), Business (BRL) and Investment (IRL). Economic analysis remains difficult since markets are not expected to arise for several decades. They also believe that previous Net Present Value (NPV)[1] analysis had omitted factors such as the cost of transport to the Earth.

The paper looks like an excellent starting point for the study of this subject, with 32 references for further study. The authors could usefully publish their work more widely.

Authors (all SGAC): Smiriti Srivastava, Swaraj Sagar, Bijaya Luitel, Pavithra Manghaipathy, Marco Romero



Number of known NEAs, NEOs discovered till June 2018 - sources - United Nations Office of Outer Space Affairs, Near Earth Objects And Planetary Defense A B Chamberlain.Near-Earth Object Program Office at the Jet Propulsion Laboratory, 2001.neo.jpl.nasa.gov.

Credit: Srivastava et al

[1] Net Present Value (NPV) is a measure of the current value of something which will be available at a future time, based on the principles of Discounted Cash Flow (DCF) - see www.open.edu/openlearn/nature-environment/financial-methods-environmental-decisions/content-section-1.3.4 - for a simple introduction.

D4,4,3,x56295	A Pragmatic Interstellar Probe Mission: Progress and Status	Dr. Ralph L. McNutt, Jr.	The Johns Hopkins University - Applied Physics Lab (APL)	USA

IAF cited paper:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/D4/4/manuscripts/IAC-20,D4,4,3,x56295.pdf

IAF cited presentation video:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/D4/4/presentations/D4,4,3,x56295.show.mp4

Open paper: None found

Reported by: Angelo Genovese (all images credit: McNutt)

This paper is about a robotic "Interstellar Probe" through the outer heliosphere and into the nearby "Very Local" interstellar medium (VLISM) using near-term technology. This challenging mission has been studied for more than 60 years, the central technical question being an enabling propulsion system.

To provide input to the upcoming Solar and Space Physics Decadal Survey, NASA's Heliophysics Division has funded the Johns Hopkins APL to consider a near-term, "pragmatic" Interstellar Probe mission with the following fundamental requirements:

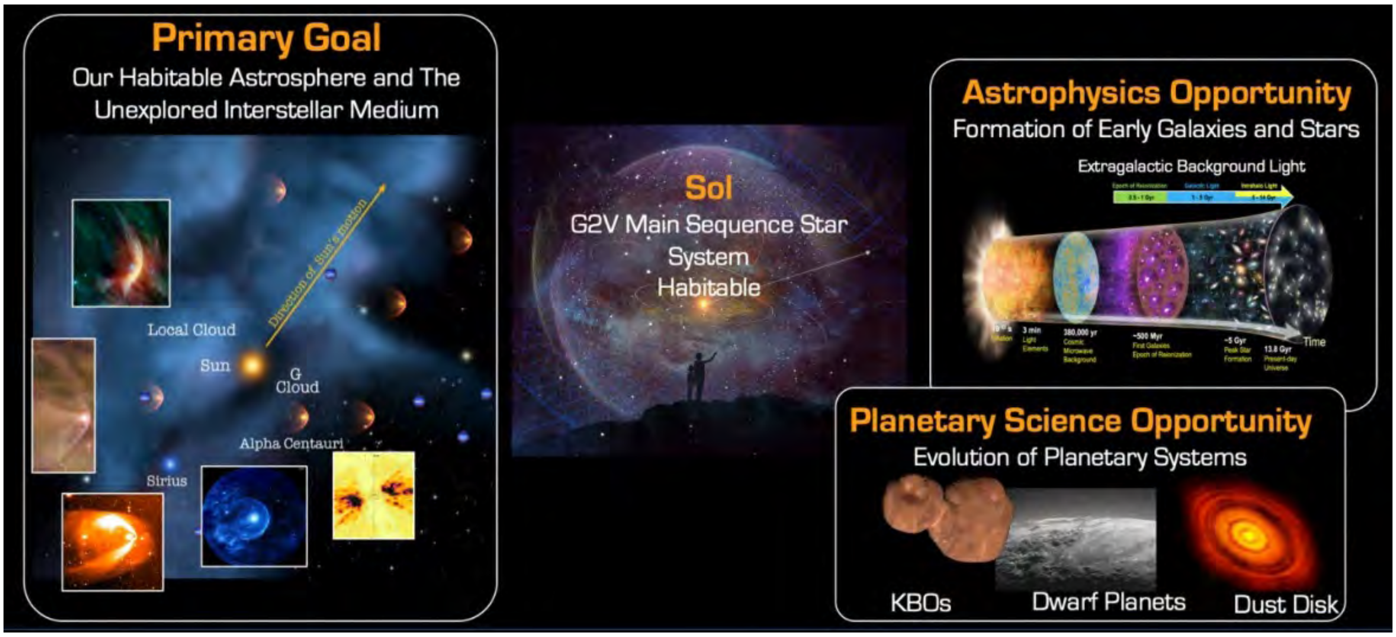
(1) READINESS, ready to launch no later than 1 January 2030;

(2) DOWNLINK, return science data from up to 1,000 astronomical units away;

(3) POWER, no more than 600 watts required at the beginning of mission and no more than 300 watts available at mission's end;

(4) LONGEVITY, spacecraft lifetime of not less than 50 years.

This paper provides a progress report on continuing refinements and trades being addressed in the study.



Propulsion

Near-term trades support the use of the Space Launch System (SLS) Block 2 configuration with existing or near-term kick stages and an unpowered Jupiter gravity assist (Option 1) or a Jupiter gravity assist powered by the uppermost stage (Option 2). An "advanced" concept using a near-Sun ("Oberth") manoeuvre is also being investigated by building from Parker Solar Probe thermal shield technology (Option 3).

Payload

A nominal core payload of 10 heliospheric instruments is included with a mass of ~90 kg. The baseline scenario tends to be driven to a spin-stabilized configuration to accomplish all heliospheric science observations with a minimum-sensor/aperture (and hence minimum mass) implementation. To accommodate desired plasma wave sensitivity, a plasma wave system (PWS) with four, 50 m long wire antennas.

Trajectory/ Launch Vehicle

Based upon the analyses to date, the use of an SLS Block 2 with an Atlas V Centaur and a Star 48 BV has been baselined for the launch configuration. This has been examined for use on both Option 1 and Option 2.

The overall separated wet mass of the spacecraft sets the performance of the final escape trajectory from the Sun's gravity field. The baseline design uses a launch capability of 860 kg including 101 kg of hydrazine propellant, yielding a 28% mass reserve for Option 1. With the same mass reserve for Option 2, 170 kg of propellant is needed for a launch capability of 930 kg. Maximum asymptotic escape speeds from the Sun tend to range from ~7.0 to 7.5 AU/yr for this initial baseline (present Voyager 1 speed is 3.6 AU/yr).

Spot checks for a particular trajectory show that asymptotic escape speed is not a strong function of spacecraft mass: each additional 50 kg of wet mass decrease the flyout speed by ~0.17 AU/yr.

As regards Option 3 (Oberth manoeuvre as close as possible to the Sun), refractory metal shields would be required for the thermal protection system (TPS), as done for the Parker Solar Probe. However, their added mass would negate any advantage to be gained from firing a kick stage near the Sun.

To support further investigations of the viability and possible advantages of Option 3 on the asymptotic escape speed, APL is currently examining the state of ultra-high temperature (UHT) materials; lightweight, high-strength metal carbide layers on carbon cores to provide the required UHT shield materials. Such materials have the potential of use up to 4,200K, with the mechanical strength of carbon fibre maintained. A TPS based upon this material could significantly lower the mass for Option 3. This will, in turn, allow a bestcase analysis of the utility of Option 3 using near-term existing materials.

Downlink

This challenging requirement (capability to operate and successfully downlink scientific data to Earth from at least 1,000 AU) is mostly driven by pointing as the downlink beam from the spacecraft must intersect the receiver on the Earth. The Voyager telecommunications system, with sufficient attitude control fuel, power, and no hardware failures, was estimated to be operable to ~300 AU. The Voyager usage of X-band was possible with no reaction wheels and could deal with pointing with the attitude control jets as the lower frequency opens up the required pointing accuracy.

The near-term technology, mass, and lifetime requirements have pushed the baseline selection toward a body-fixed high-gain antenna (HGA).

Power Considerations

Current estimated power requirements are shown below for one RTG (two RTGs are baselined); the downlink and payload requirements tend to be the power drivers.

Subsystem	Power (W)
Payload	94
Telecom	101
Power	25
Avionics	13
Total	233

Baseline power budget for one RTG showing margins -

RTG Capability	300
Margin	22%

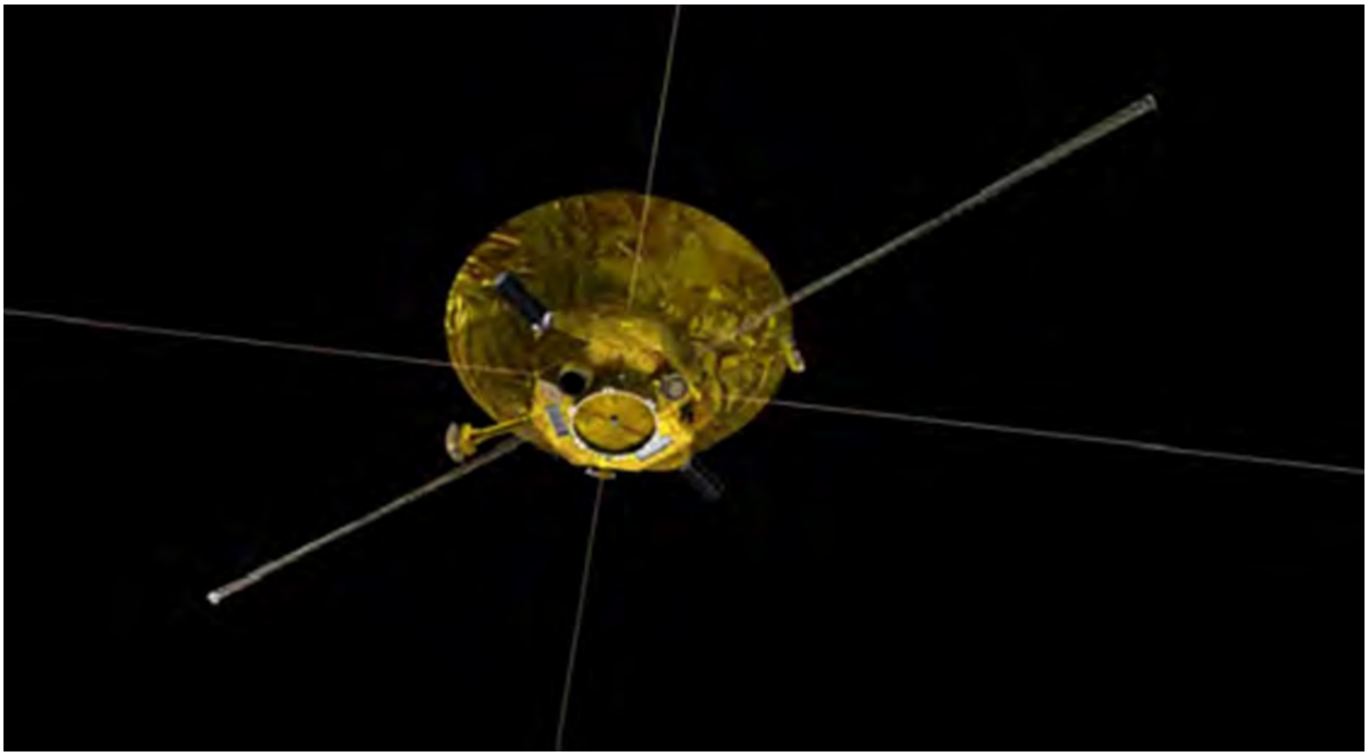
Credit: McNutt

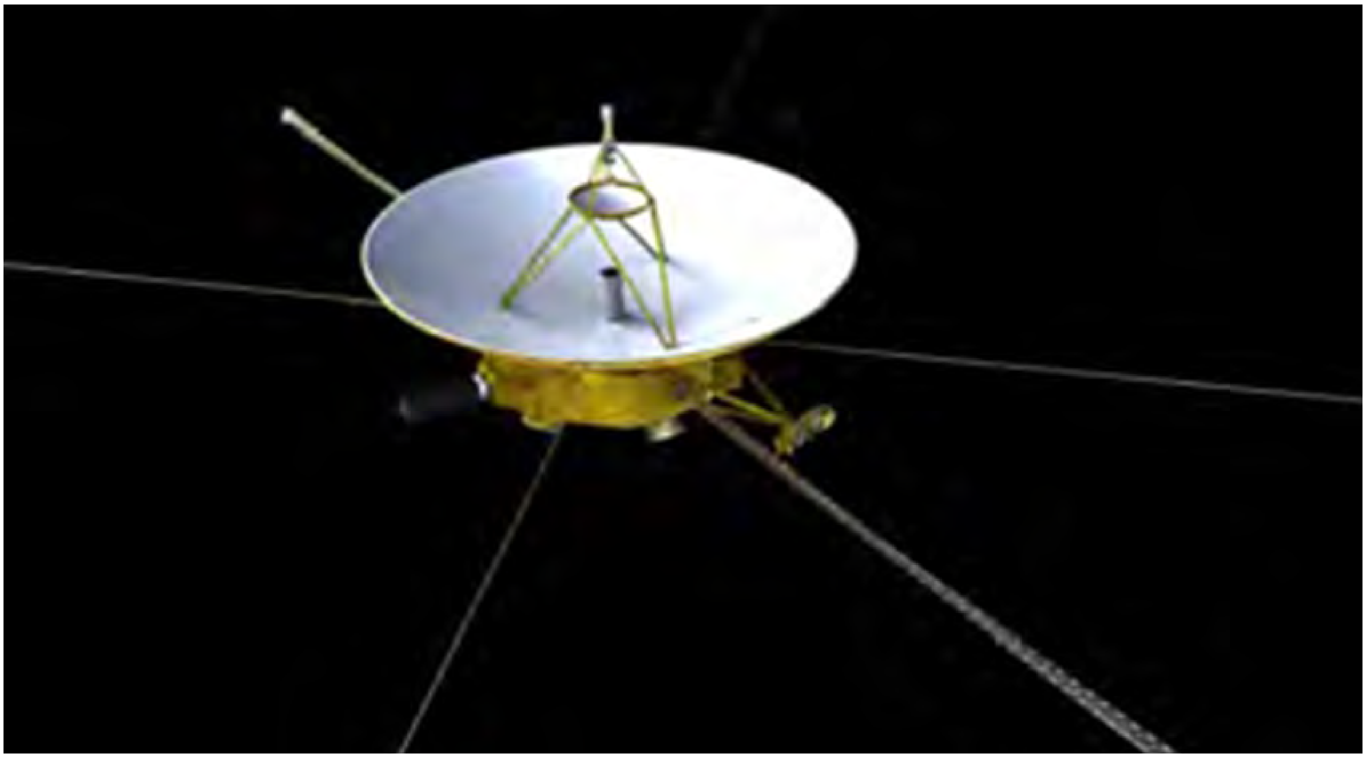
Mechanical Design

A corresponding baseline mechanical design has been established based upon the preceding considerations. The approach has been to establish a basic spacecraft design for an Option 1 trajectory for the heliospheric core mission and then examine changes to that design as needed for implementing the same mission using Option 2. Implementation with an Option 3 trajectory will require fundamental changes in approach and will be dealt with separately in the upcoming year of the study.

The spacecraft is (not surprisingly) dominated by the HGA (5 m diameter) as depicted below (credit: McNutt).

Views from below (top) and from above (bottom) of the current baseline concept. Prominent features are the HGA, four PWS antennas, two magnetometer booms, and two RTGs, The symmetry is needed to help spin balance the system, both for observations and the downlink requirements.





C4,9,3,x60528	Sitael’s activities on the development of air breathing technology	Dr. Tommaso Andreussi	Sitael Spa	Italy

IAF cited paper:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/C4/9/manuscripts/C4,9,3,x60528.pdf

IAF cited presentation video:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/C4/9/presentations/C4,9,3,x60528.show.mp4

Open paper: None found

Reported by: John Davies

Air-breathing electric propulsion is being explored by several organisations worldwide. For a Russian example see the paper by Golikov (C4,9,2,x59647) earlier in this report. This paper emphasises the importance of an inexhaustible supply of propellant and an inexhaustible supply of energy, solar radiation. This Air-Breathing Electric Propulsion (RAM-EP) system has been under development since 2014.

The authors see this as a form of In Situ Resource Utilisation, as studied for asteroids and the Moon. Under this definition we could also include all other forms of air-breathing propulsion and even the Bussard ramjet!

Very Low Earth Orbit (VLEO) is defined as altitudes between 150 and 250 km.The advantages of VLEO are - better resolution by any optical payload, improved radiometric performance, lower communication latency especially important for bi-directional and real time telecommunication services, geospatial position accuracy, reduction in dimensions and mass of the payload, simple de-orbiting strategy (they also claim that risk of debris creation is "fully eliminated"), significant protection from space radiation allowing use commercial of the shelf (COTS) electronic components instead of space qualified components (thus reducing costs) and better space accessibility from VLEO.

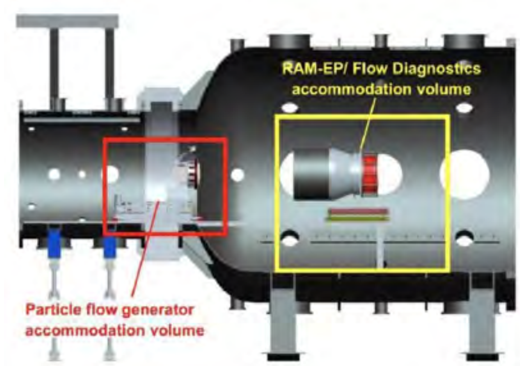
By testing their RAM-EP concept on-ground SITAEL claim an important milestone in air-breathing electric propulsion history with the first ignition and stable operation of a full air-breathing system operated in a representative environment. A 5 kW class Hall thruster was placed in front of the system intake and operated with atmospheric propellant to generate a VLEO representative flow. The test showed thrust of 6 mN but at this stage the test setup showed a drag force of 26±1 mN so there is clearly work still to be done.

This work is part of two programmes -

• AETHER (EU H2020 project, GA 870436)

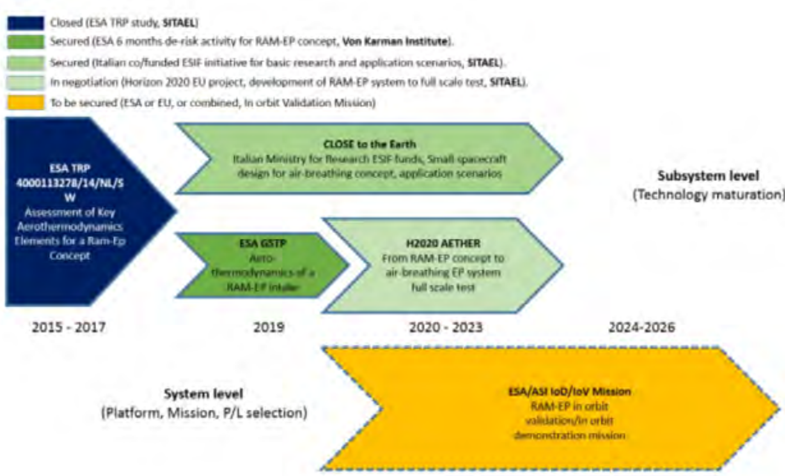
• Close to the Earth (Italian MIUR project, ARS0l_00141)

- from the European Union and Italian government respectively. In orbit demonstration is expected by the mid 2020s.



RAM-EP concept validation test setup in SITAEL’s IV4 vacuum facility.

Credit: Andreussi / Sitael Spa



RAM-EP Development Roadmap

Credit: Andreussi / Sitael Spa

A3,4A,8,x59688	Trajectory analysis and design for an European Fast Kinetic Deflection Mission	Mr. Marcello Sciarra	Deimos Space SLU	Spain

IAF cited paper:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/A3/4A/manuscripts/A3,4A,8,x59688.pdf

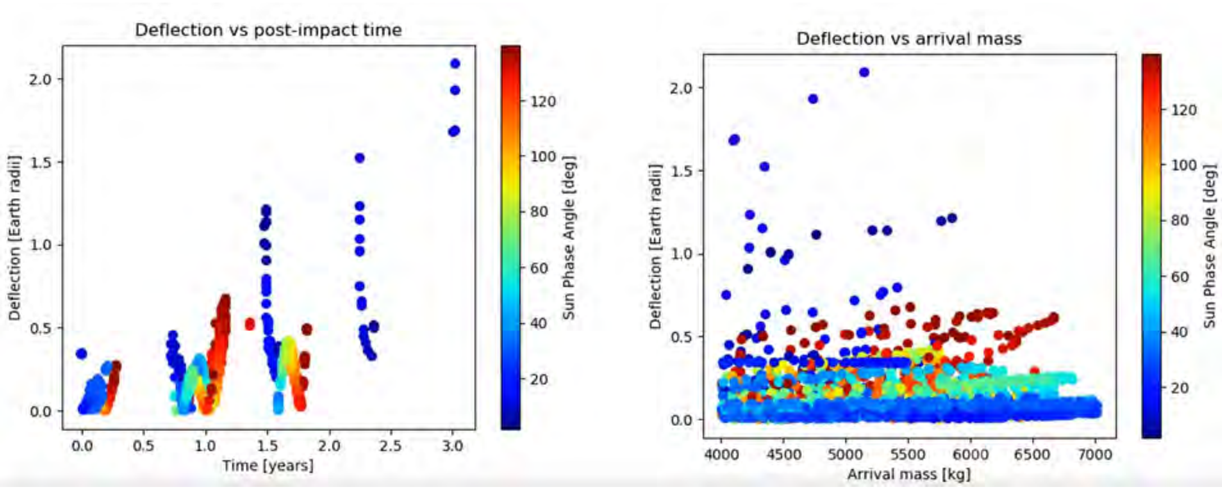
IAF cited presentation video:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/A3/4A/presentations/A3,4A,8,x59688.show.mp4

Open paper: None found

Reported by: Adam Hibberd

This research here was conducted by the Deimos/Elecnor Group and involves determining the degree of deflection of an asteroid as induced by an impactor launched from Earth. The collision is assumed to be inelastic (with β=2). The deflection is quantified by the change in closest approach distance of the Asteroid in the Modified Target Plane (MTP), this being measured in units of Earth radii.



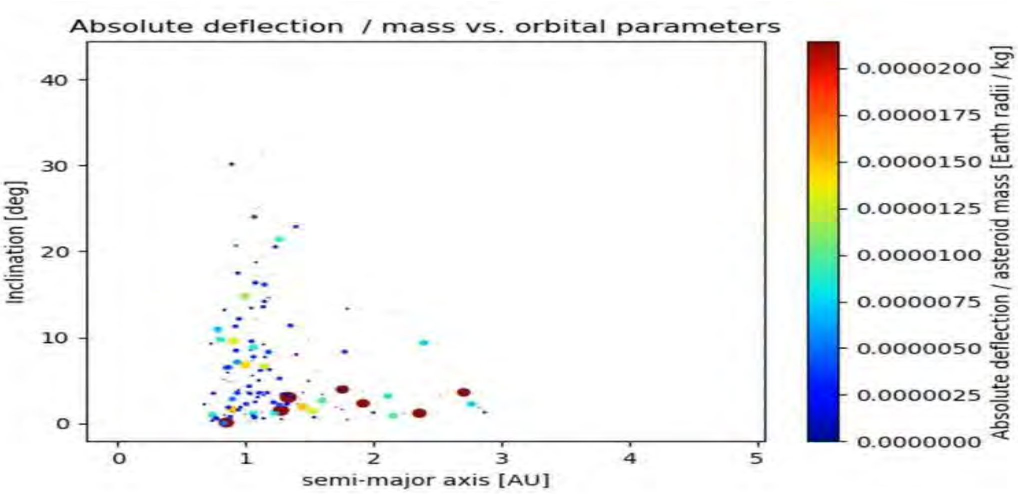
The targets are selected from a catalogue of PHA (Potenitally Hazardous Asteroids) and NEA (Near Earth Asteroids).

The process is to take an Asteroid, construct a grid of launch dates and flight times, solving the Lambert problem at each point on this grid (which gives a trajectory connecting Earth and the Asteroid up). These trajectories are then filtered according to three criteria:

1) They must have impact speeds of 5-15 km/s

2) They must have a solar phase angle of < 140 degs

3) The impact must occur before the closest approach of the Asteroid to Earth



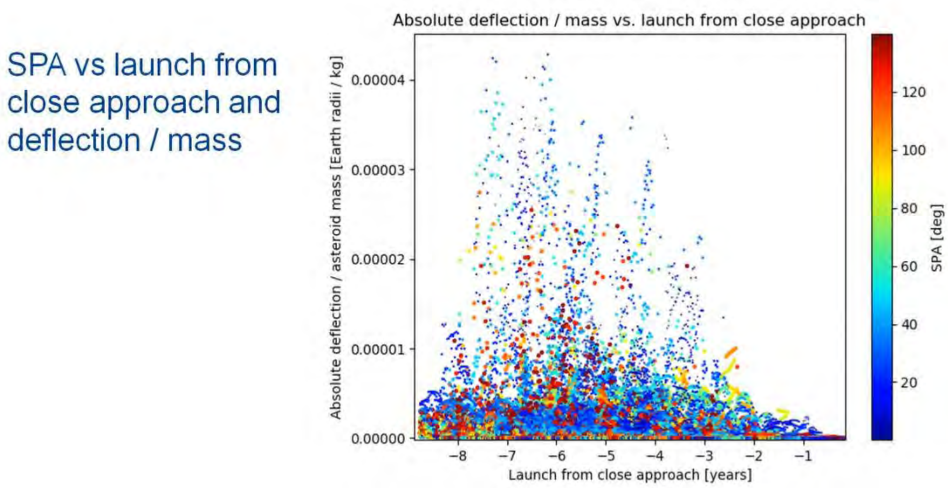
Deflection / mass
vs
sma and inclination

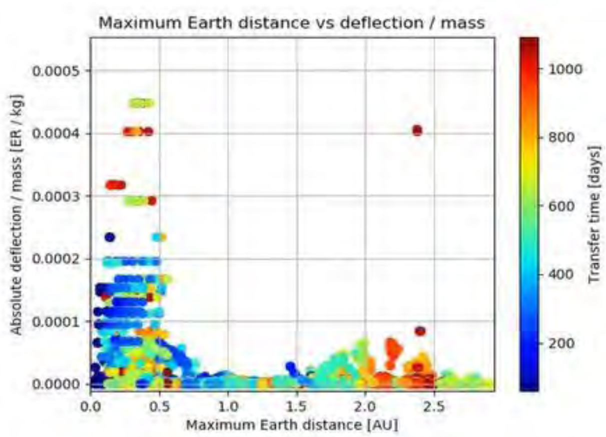
For the trajectories which satisfy the above, the deltaV applied by the impactor to the Asteroid is determined and the perturbed Asteroid trajectory is then propagated to determine the aforementioned degree of deflection.

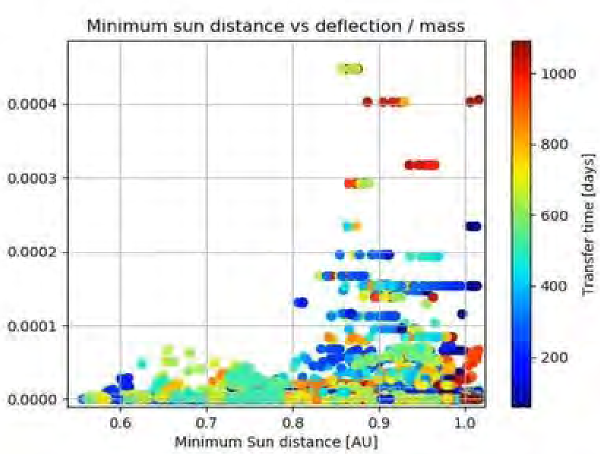
Further assumptions are made which are not detailed here, except that an Ariane 6.4 is used to launch the spacecraft.

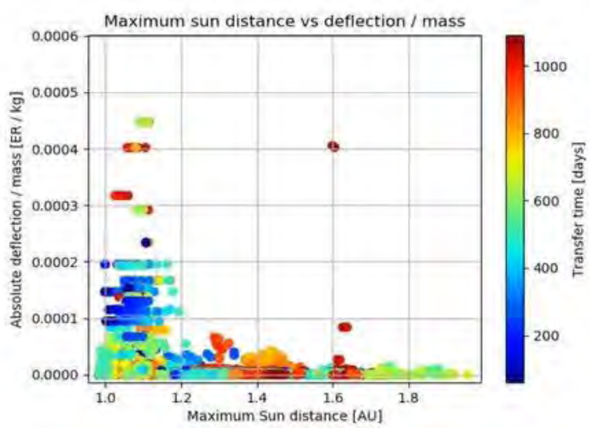
Results are that the lower the inclination of the Asteroid is to the ecliptic, the higher the degree of deflection. In addition, the longer the post-spacecraft-impact time, the higher the degree of deflection. There is also very little correlation between impactor mass and degree of deflection, because spacecraft (s/c) mass is coupled with launcher performance. Thus with greater s/c mass, the impact velocity is reduced because the hyperbolic escape speed of the launcher from Earth is reduced.

Also, generally speaking, the earlier the launch date compared to s/c impact time, the greater the degree of deflection. Please refer to attached plots.









A4,2,6,x60955	A Comprehensive View of SETI: Technical, Legal, and Outreach Considerations	Ms. Mirandah Ackley	International Space University	France

IAF cited paper:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/A4/2/manuscripts/A4,2,6,x60955.pdf

IAF cited presentation video:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/A4/2/presentations/A4,2,6,x60955.show.mp4

Open paper: None found

Reported by: Max Daniels

Ms. Ackley and colleagues observed that there are gaps in the field of the search for extra-terrestrial intelligence (SETI) that hinder its progression. These are in three areas: science and technology, legal and policy implications, and outreach endeavours. To remedy these gaps, the authors first asked three questions:

1) How can we detect signals from other intelligent lifeforms?

2) What should humanity do after a positive detection?

3) How can we raise awareness of SETI within our societies to normalise detection initiatives?

Question 1) was answered by adopting general principles, followed by two phases:

1) Analysing data from space telescopes that use light curves to detect exoplanets (the Galactic Technosignature Observatory (GTO));

2) The launch of an interplanetary CubeSat (NoisyCube) that aims to characterise the distortion of the Earth's signature from its orbital satellite infrastructure.

For both phases, the methods are extended to the detection of artificial objects. The authors stressed the importance of GTO and NoisyCube data being made available to the public.

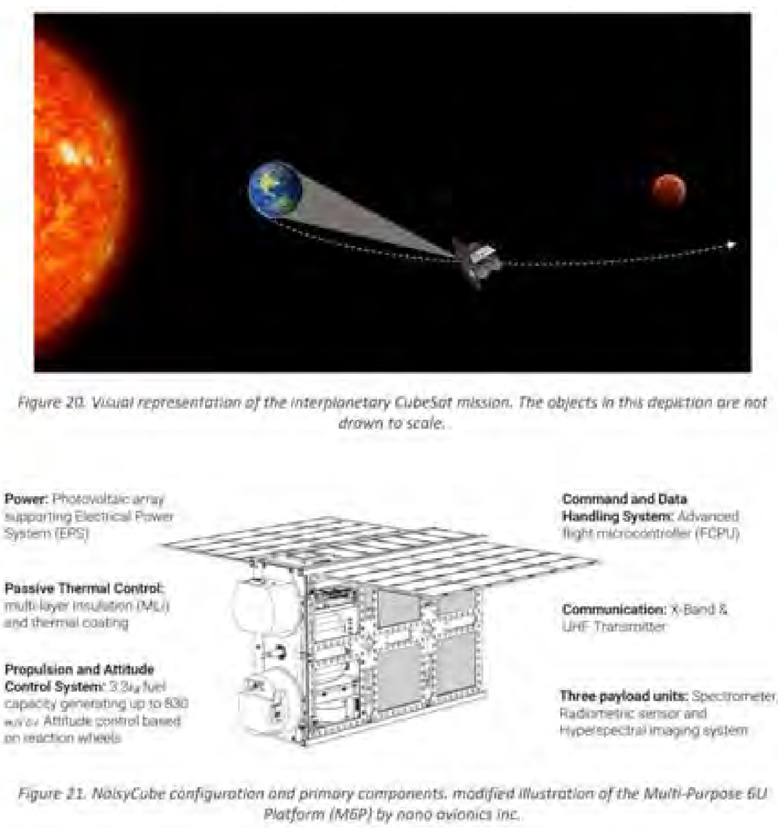


Figure 1: Visual representation of the interplanetary CubeSat mission (not to scale)

Credit: Ackley and colleagues (paper)

[1] A.E. Goodman, Diplomacy and the Search for Extraterrestrial Intelligence (SETI), Acta Astronautica 21/2 (1990) 137–141. www.sciencedirect.com/science/article/abs/pii/0094576590901417 (paywalled)

Question 2) was answered by considering the four proposals of Goodman [1] and first identifying their weaknesses, which comprise:

1) There are no examples of SETI being treated as part of space exploration

2) Its communication to the general public

3) The uncertainty of findings.

To address shortcomings in the existing legal framework, the authors proposed updates to the 2010 International Academy of Astronautics post-detection principles. They suggested legitimising these principles by framing NoisyCube as space exploration, and so tying SETI legally to the Outer Space Treaty. Modelling humans' relations with animals, they concluded that it is necessary to move away from an anthropocentric view of the world towards an appreciation of each individual component of the cosmos.

Question 3) was answered by making three objectives:

1) To normalise SETI as a topic

2) To disseminate related science to alter the narrative that extra-terrestrial intelligence is only science fiction

3) To share findings and proposals developed by researchers.

For these objectives, they identified three target audiences (and forms of outreach):

1) The general public (through publicity-generating merchandise and a website)

2) The SETI and space community (also through merchandise and a website)

3) Young children (through a children's book).

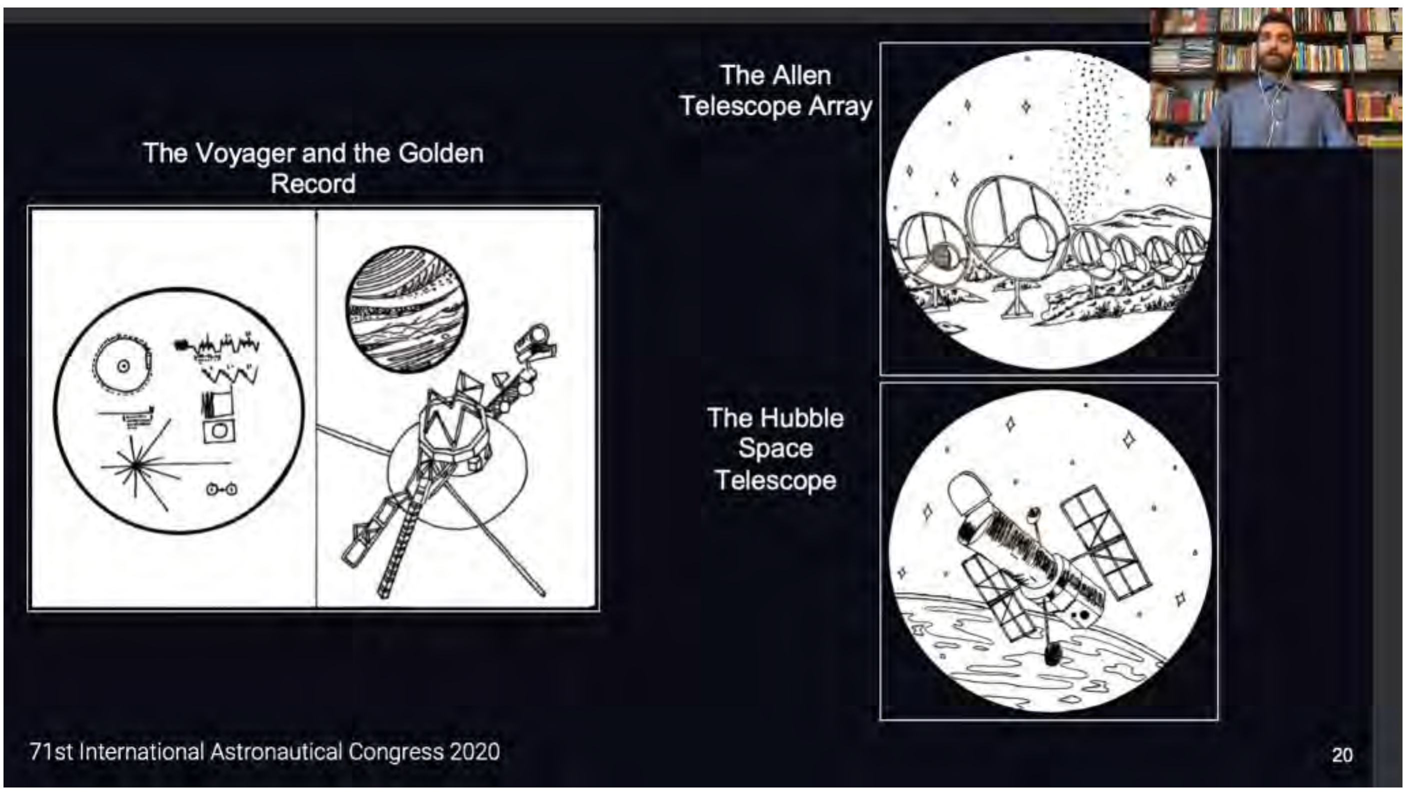


Figure 2: Merchandise branding, part of the outreach for the normalisation of SETI
Credit: Ackley and colleagues (presentation)

Authors: Mirandah Ackley and 10 others (primary authors), and 10 others (contributing authors), all International Space University

E1,6,8,x56502	How online influencers help tell the world the story of space	Mr. Remco Timmermans	International Space University (ISU)	United Kingdom

IAF cited paper:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/E1/6/manuscripts/E1,6,8,x56502.pdf

IAF cited presentation video:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/E1/6/presentations/E1,6,8,x56502.show.mp4

Open paper: None found

Reported by: John Davies

Mr Timmermans is Media and Content Coordinator for Groundstation Space at the Noordwijk Space Campus, Netherlands and has managed a number of programmes for the ISU. Here he gives a generic marketing overview of how different industry sectors have used online influencers in social media. Influencers fall into three categories fan-based (broad category, potentially numerous but sometimes not easy to identify), brand ambassadors (your own, niche but influential) and paid influencers (not numerous in the space sector apart from volunteers encouraged by expenses paid conference attendance). Perceived authenticity is vital - as is continuous monitoring and testing influencers and tags to see how well they are working. NASA, ESA and ESO (European Southern Observatory) are particularly successful - responding to social media posts promptly especially for live events. Return of investment (ROI) has not been well enough monitored and the sector remains immature in many respects. The paper cites a number of campaigns as examples of social media use in the space sector.

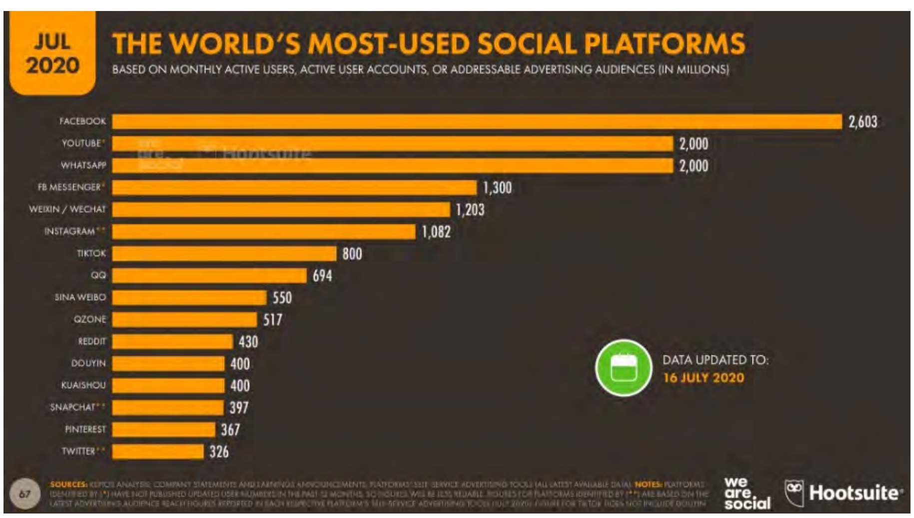
Authors:

Remco Timmermans (@timmermansr)

Tara Foster (@taraustralis).

Social Media use around the world (source:WeAreSocial)

Credit: Timmermans/Foster



Social Media use by platform (source:WeAreSocial)

Credit: Timmermans/Foster

Reporters note: Ownership of the six most used of these (more than one billion monthly active users) is shared. The (owners) are Facebook, YouTube (Google), Whatsapp (Facebook), FB Messenger (Facebook), Weixin aka Wechat (Tencent), Instagram (Facebook). Tencent and the next most used, Tiktok, are widely thought to have close relations with the government of China.

This is a relatively small "pond".

D4,1,3,x59908	ChipSats - New Opportunities	Frederic Schoutetens	International Space University (ISU)	France

IAF cited paper:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/D4/1/manuscripts/D4,1,3,x59908.pdf

IAF cited presentation video:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/D4/1/presentations/D4,1,3,x59908.show.mov

Open paper: None found

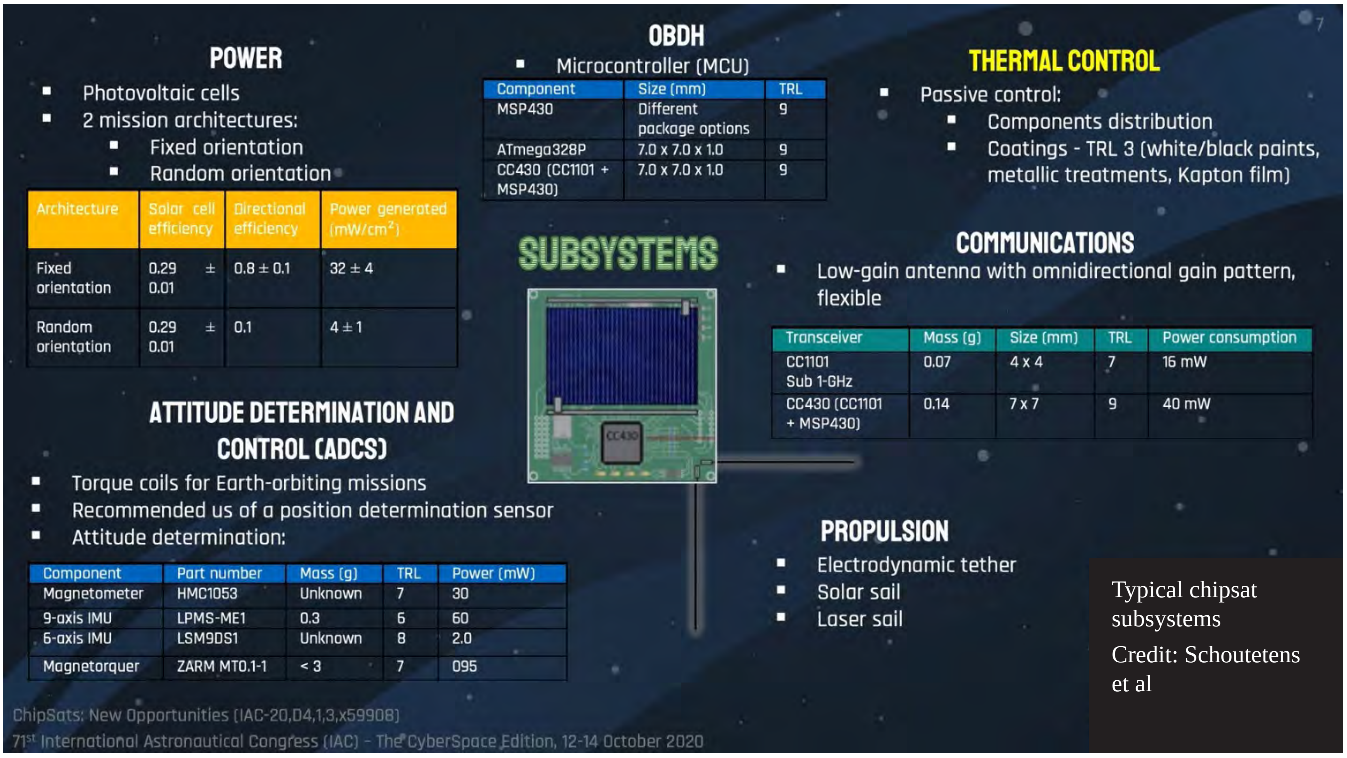
Reported by: Patrick Mahon

Andrea Carrillo (one of the co-authors of this ISU paper) highlighted how the huge cost per kilogramme of launching a spacecraft into orbit had driven continual miniaturisation of satellites, with it now being possible to create a simple but viable spacecraft the size of a credit card: a ChipSat. The concept dates back to 1994, but came of age in 2011, when Zachary Manchester designed the KickSat 1 mission (a CubeSat containing 104 'Sprite' ChipSats) as part of his PhD at Cornell. Although KickSat 1 was ultimately unsuccessful, KickSat 2 successfully deployed its Sprites in orbit in 2019.

Carrillo reviewed the major elements of a typical ChipSat, including structure, thermal control, power, data, communications, attitude control, propulsion, and reviewed the Technology Readiness Levels of each, identifying thermal control, power storage, communications and attitude control as key limitations at present.

Reporter's Note: *Table 8 in the paper gives a handy list of the elements of a typical chipsat, with prices*

Table 8. Components, price, and learning outcomes of a basic ChipSat training kit		
Components	Unit Price (USD) (March, 2020)	Learning Outcomes
Base plate		
PCB design component	2.50	Soldering with 1 trail PCB
ATmega328	3.0	Working with Arduino libraries
Basic components		
Transceiver	2.66	Programming, satellite communication
Solar cells	4.0	Operating principles of solar cells
Gyroscope and accelerometer	4.99	Satellite stabilization methods
Resistors	1.0	Laws of electronics and physics
Capacitors	1.0	Laws of electronics and electrical component functionality
Total	19.15	
Sensor Selection (1 sensor included/ kit)		
Temperature, Humidity, Pressure and Volatile Organic Compounds (VOC) sensor	10.53	To measure VOC in environment
UV sensor	4.41	Optimal UV intensity for humans and in a classroom
GPS sensor	9.33	Operating principles of Global Navigation Satellite System (GNSS)
Total with min. sensor price	23.56 USD (only including GPS sensor)	
Total with max. sensor price	29.68 USD (only including VOC sensor)	
Note: the corresponding price for resistors and capacitors are approximated and are subjected to change depending on their nominal value and tolerance.		



Typical chipsat subsystems
Credit: Schoutetens et al

The team had developed an 'ISU ChipSat Roadmap', intended to enable ISU to launch its own ChipSat. The three elements were: (a) a ChipSat Programme, to strengthen ISU's capability to design, build and launch a simple 'Sputnik-style' ChipSat to Low Earth Orbit (LEO) within five years; (b) a Regulatory Framework, to work through the main legal challenges, such as licensing and debris mitigation; and (c) an Outreach Programme, to use the ChipSat programme to promote STEM education to students in underrepresented groups and countries.

Carrillo concluded the talk with a SWOT analysis of ChipSats and eleven recommendations for priority issues that will need to be addressed if the promise of ChipSats is to be realised.

Reporter's Note: *Table 10 in the paper is the SWOT analysis.*

Table 10. Analysis of strengths, weaknesses, opportunities and threats of and for ChipSats

Strengths	*Weaknesses*
Massive cost reduction	Lack of regulation
Lower entry barriers for space technology	Launch opportunity restrictions
Accessibility and rapid development	Low functionality
Redundancy due to quantity	Space debris
Design modularity	Short orbit lifetime
Opportunities	***Threats***
Distributed system	Policy restrictions
Innovation	Misuse
Lowering ground segment dependency	Debris damages
Ability for new scientific missions and new applications for social economy	Loss of satellite
	Unproven business cases

Authors: (All ISU) Frederic Schoutetens, Andrea Carrillo, Marco Marsh, Taavishe Gupta, Shreya Sarkar, Christine Tiballi, Iliass Tanouti

D4,4,1,x57895	Interstellar Probe: Science Discoveries at the Boundary to Interstellar Space and Beyond	Dr. Pontus Brandt	Johns Hopkins University Applied Physics Laboratory	United States

IAF cited paper:
iafastro.directory/iac/proceedings/IAC-20/IAC-20/D4/4/manuscripts/D4,4,1,x57895.pdf

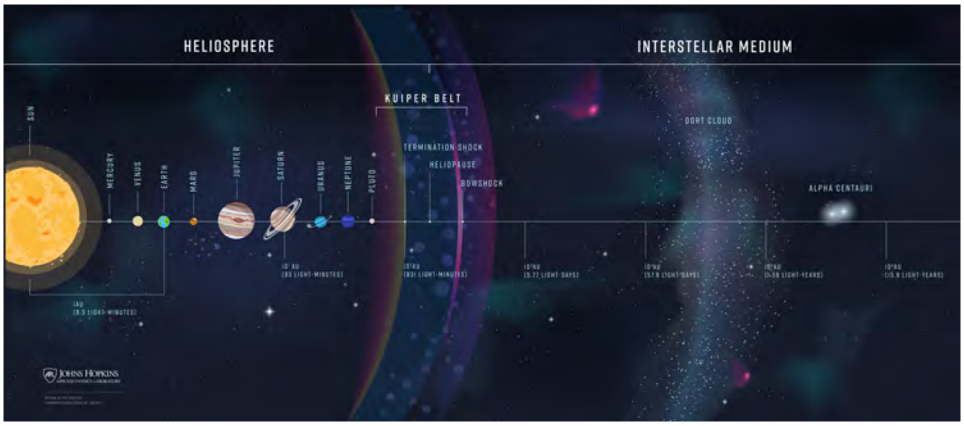
IAF cited presentation video:
iafastro.directory/iac/proceedings/IAC-20/IAC-20/D4/4/presentations/D4,4,1,x57895.show.mp4

Open paper: None found

Reported by: Patrick Mahon

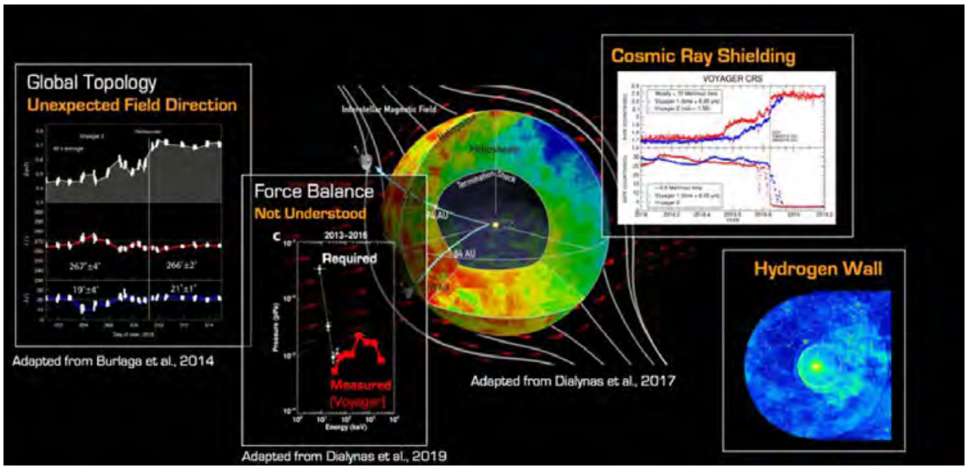
This is one of three papers delivered at the 2020 IAC, all covering different aspects of the JHUAPL Interstellar Probe project. See P31 (page 46) for a summary of sister paper D4.4.2 by Leon Alkali et al and the report of D4,4,3 by Dr. Ralph L. McNutt, Jr. earlier in these reports.

Here Brandt focuses attention on the space physics goals for such a mission, and in particular exploration of the interactions between the heliosphere and the local interstellar medium (LISM) at the heliopause, the boundary of our solar system.

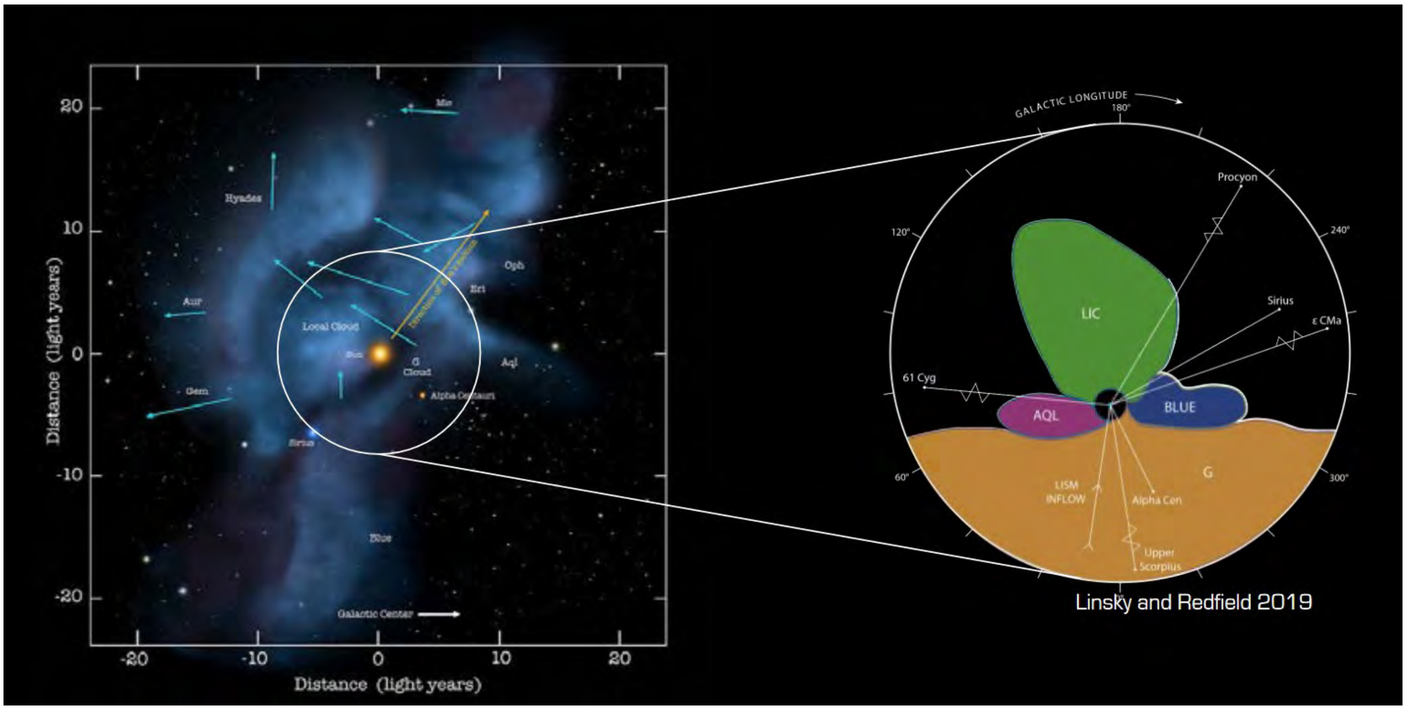


An Interstellar Probe would explore the boundary region of the heliosphere and represent the first explicit step in to the unknown LISM well beyond the heliopause. interstellarprobe.jhuapl.edu/Resources/News-and-Gallery/ Credit: JHU APL

To date, the only two spacecraft to have left the heliosphere are Voyagers 1 and 2, which did so in 2012 and 2018 respectively, both at a distance of around 120 AU from the Sun. However, their limited capabilities, so far beyond their intended design lives, mean that they have posed many more questions than they have answered. Other missions, including the Interstellar Boundary Explorer (IBEX, 2008-present) and the Cassini mission to Saturn (1997-2017), as well as the forthcoming Interstellar Mapping and Acceleration Probe (IMAP, launch due 2025) have or will probe this region remotely, but a full capability in-situ probe would transform our understanding.



" a new regime of space physics" Credit: Brandt/JHU-APL



The Local Interstellar Medium (LISM)

"...evidence is mounting that the heliosphere is in contact with four interstellar clouds with different properties and is leaving the Local Interstellar Cloud within relatively short galactic time scales". Credit: Brandt JHU APL

Questions that have been raised by the limited observations to date include the existence of a strange ribbon or belt, identified by energetic neutral atom (ENA) imaging by IBEX and Cassini, and contradictory conclusions about the global shape of the heliosphere. In addition, recent evidence suggests that the solar system is leaving the Local Interstellar Cloud (LIC) and will, over the next 6,000 years, move into a new region of interstellar space with quite different properties from the LIC.

The science mission has been designed by reference to three goals:

• Primary goal 1 (Heliophysics): to understand our Heliosphere as a Habitable Astrosphere and its Home in the Galaxy;

• Supporting goal 2 (Planetary Sciences): to understand Planetary System Evolution; and

• Supporting goal 3 (Astrophysics): to explore the Universe Beyond our Circum-Solar Dust Cloud.

These three goals are used to define the design architecture for the Interstellar Probe and the package of scientific instruments most necessary to achieve the mission objectives. Beyond heliophysics, the mission could include flybys of dwarf planets or other Kuiper Belt Objects (KBOs).

Two alternate scientific instrument packages have been defined, each weighing 80-90 kg, with one focusing on the primary heliophysics goal, while the other enables greater investigation of the two supporting goals above. Both packages include magnetometers, and spectrometers to measure plasma, particles and cosmic rays, and interstellar dust analysers. The alternate payload includes visible/near-infrared and ultraviolet cameras for the dwarf planet or other KBO flyby, swapped out for some of the heliophysics instruments.

All mission requirements have been constrained by the need for existing or very near-term technology, so that the probe could be ready to launch in January 2030. Work continues to refine the definition of the mission and the scientific payload.

D4,4,5,x58922	Mitigation of interplanetary dust for laser-driven interstellar travel	John Kokkalis	McGill University	Canada

IAF cited paper: iafastro.directory/iac/proceedings/IAC-20/IAC-20/D4/4/manuscripts/D4,4,5,x58922.pdf

IAF cited presentation video: iafastro.directory/iac/proceedings/IAC-20/IAC-20/D4/4/presentations/D4,4,5,x58922.show.mp4

Open paper: None found

Reported by: Patrick Mahon

John Kokkalis and co-author Monika Azmanska summarised the reasons why laser sails are a promising propulsion option for an interstellar spacecraft mission, potentially enabling a cruise velocity up to one-fifth the speed of light. However, one of the significant technical concerns is that a collision with interplanetary dust grains during the acceleration phase of the mission could create damage which propagates across the sail with catastrophic consequences.

Given that a laser sail cannot absorb more than a tiny fraction of the incoming laser energy if it is not to melt, making them from dielectric materials becomes an attractive option. For such materials, there is a trade-off between sail reflectance and thickness: more reflective sails will be thicker and weigh more. They suggest the best compromise comes with a sail that is 25% reflective, so that 75% of the laser light passes through. They have investigated whether that 'wasted' laser light can be used to burn off any dust grains in front of the sail before it reaches them. Their mathematical modelling concludes that the laser energy passing through a 25% reflective laser sail could vaporise dust grains up to 50,000 km ahead of the sail.

Once the spacecraft has accelerated to its target velocity, the laser energy will no longer be available to destroy dust grains. Instead, they propose that during the cruise phase, the spacecraft can best be protected from dust grain impacts through a combination of turning the sail side-on to the direction of travel, and incorporating a dust shield and crystal channelling to ablate and deflect incoming dust grains before they hit the leading edge of the sail.

A3,1,9,x57930	Advancing Space Exploration through Crowdfunding Space Projects	Dr. Bruce Betts	The Planetary Society	United States

IAF cited paper:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/A3/1/manuscripts/A3,1,9,x57930.pdf

IAF cited presentation video:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/A3/1/presentations/A3,1,9,x57930.show.mp4

Open paper: None found

Reported by: Patrick Mahon

Bruce Betts explained that although the term 'crowdfunding' was relatively new, the idea of funding projects through small donations from large numbers of people is something that the Planetary Society has been doing for 40 years, ever since its first fundraising drive in 1981, just a year after the organisation's formation.

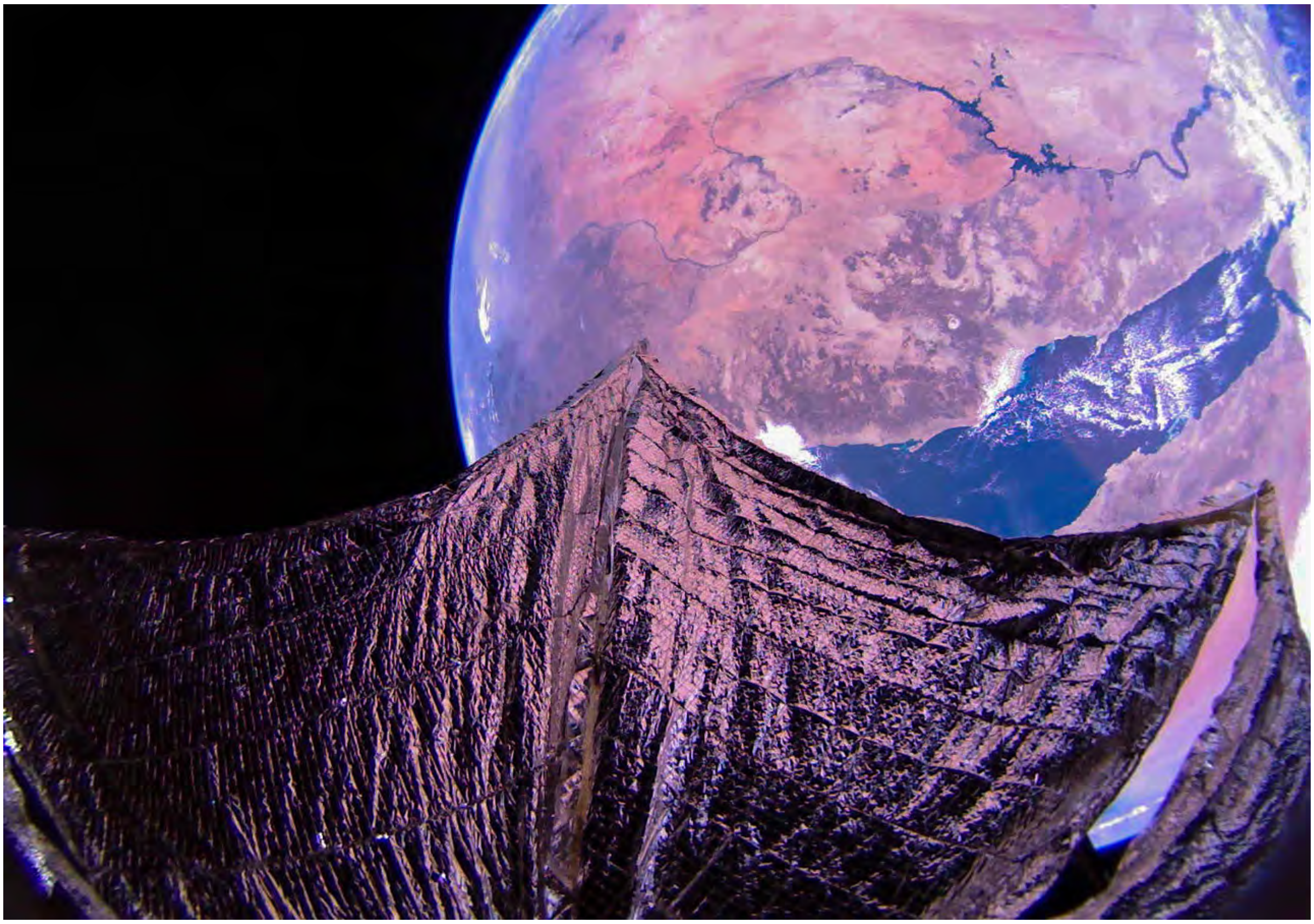
Since then, they have organised more than 100 crowdfunded projects, ranging in size from small to large. He gave several examples, including:

• their Shoemaker NEO grants to amateur and professional astronomers to help track and characterise near-Earth objects (small);

• PlanetVac, a low-cost approach to collecting soil samples during interplanetary missions, which is scheduled to fly to the Moon on a NASA-funded probe in 2023 (medium); and

• the recent LightSail 2 solar sail mission which successfully deployed in Earth orbit in mid-2019 and in mid-2020 entered an extended mission phase (large).

The Planetary Society sees crowdfunding as a highly effective way to achieve meaningful public



LightSail 2 over the Nile River and the Red Sea.
Credit: The Planetary Society

involvement in space activities. They believe there is currently untapped potential, which they want to develop and grow, by matching strong project ideas with viable crowdfunders. To this end, they intend to set up a new competitive grant programme in early 2021, which will provide seed funding to credible research and hardware development projects that might be suitable for future crowdfunding.

Authors: Bruce Betts, Jennifer Vaughn, Bill Nye (all The Planetary Society).

Some crowdfunders at the LightSail 2 launch
Credit: The Planetary Society

A4,1,1,x60743	The Breakthrough Listen Search for Extraterrestrial Intelligence: Overview	Dr. Steve Croft	University California Berkeley	United States

IAF cited paper: (abstract only)

iafastro.directory/iac/proceedings/IAC-20/IAC-20/A4/1/manuscripts/A4,1,1,x60743.pdf

IAF cited presentation video:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/A4/1/presentations/A4,1,1,x60743.show.mp4

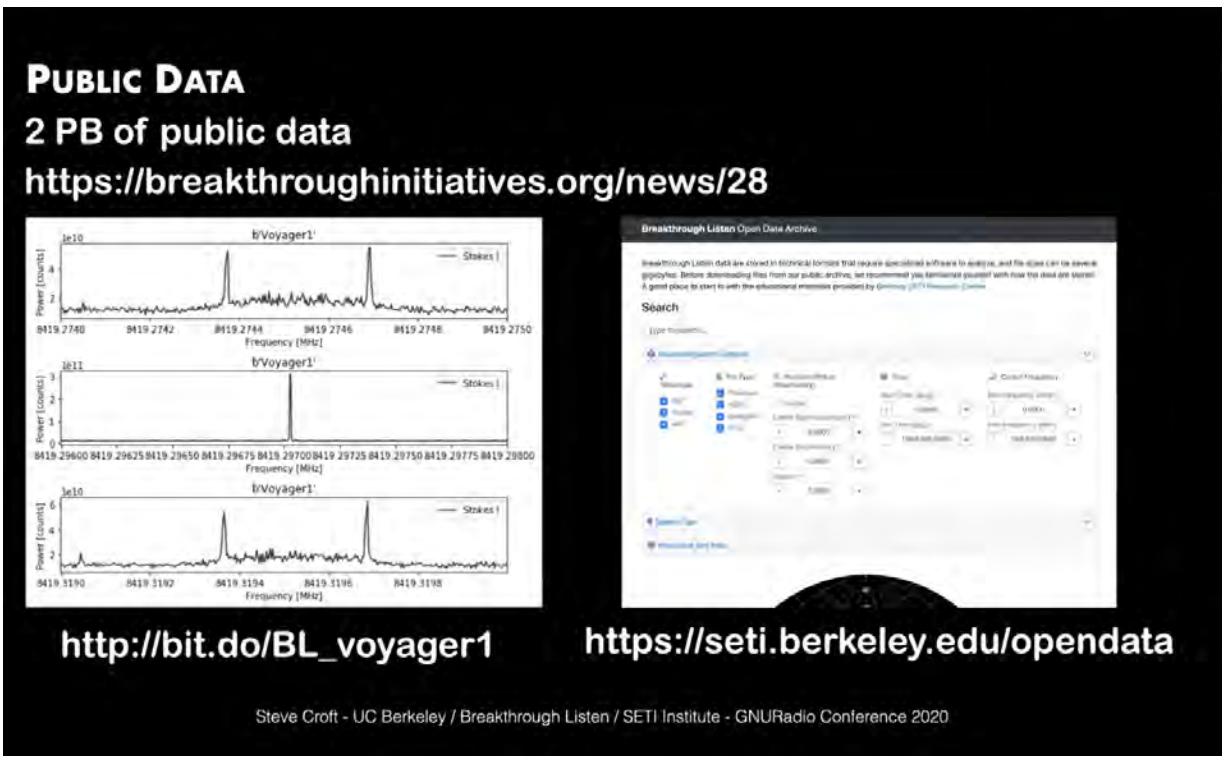
Open paper: Background on the project is available at arxiv.org/abs/1907.05519

Reported by: Patrick Mahon

Steve Croft summarised the work that the Breakthrough Listen team had undertaken to date. They were principally using three telescopes: the Green Bank radio telescope in West Virginia, USA, the Parkes radio telescope in New South Wales, Australia, and the MeerKAT radio telescope array in South Africa (see summary of talk A4.1.4 for more detail on the latter). They are using Green Bank to survey all the nearby stars in the Northern hemisphere, along with targets identified by the Transiting Exoplanet Survey Satellite (TESS) and several galaxies. Parkes is surveying the Southern hemisphere, the galactic plane, and 189 nearby stars. They are also collaborating with other telescope teams, including Jodrell Bank in the UK, and the Low-Frequency Array (LOFAR) in Ireland and Sweden. As at March 2020 they had generated over 10 PB of data.

In addition to radio SETI, they are also doing optical SETI, searching for technosignatures across 847 stars and five galaxies that have been observed to date, using the Automated Planet Finder at the Lick Observatory.

All their spectra are being made publicly available, and they are working with many interns who have done excellent work, several examples of which Croft summarised. They are also using machine learning and the Cloud to accelerate progress, and are using the open-source GNU Radio signal processing toolkit. They look forward to collaborating with many more colleagues in future to drive rapid progress in SETI.



PUBLIC DATA 2 PB of public data breakthroughinitiatives.org/news/28

bit.do/BL_voyager1 The data from Voyager is a useful test case for a technosiganture

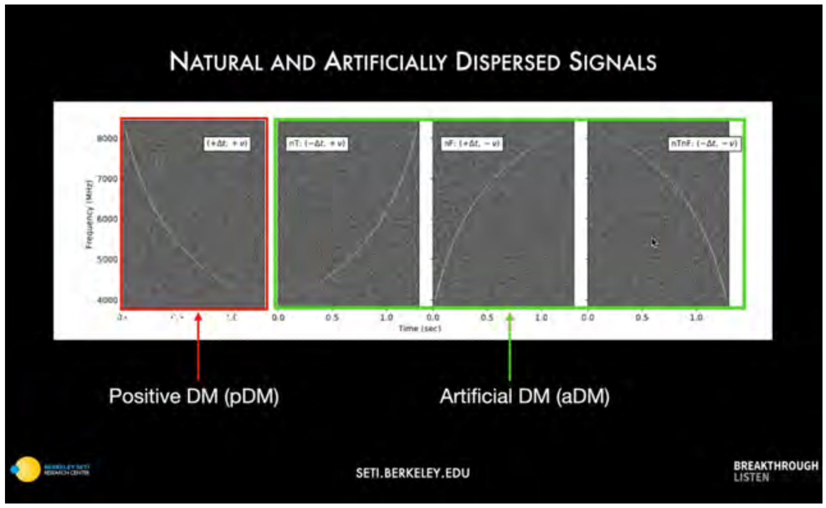
seti.berkeley.edu/opendata All data is open. Breakthrough Listen researchers have been working with GNU Radio, a free & open-source software development toolkit providing signal processing to implement software radios (www.gnuradio.org/).

Steve Croft - UC Berkeley/ Breakthrough Listen / SETI Institute - GNU Radio Conference 2020

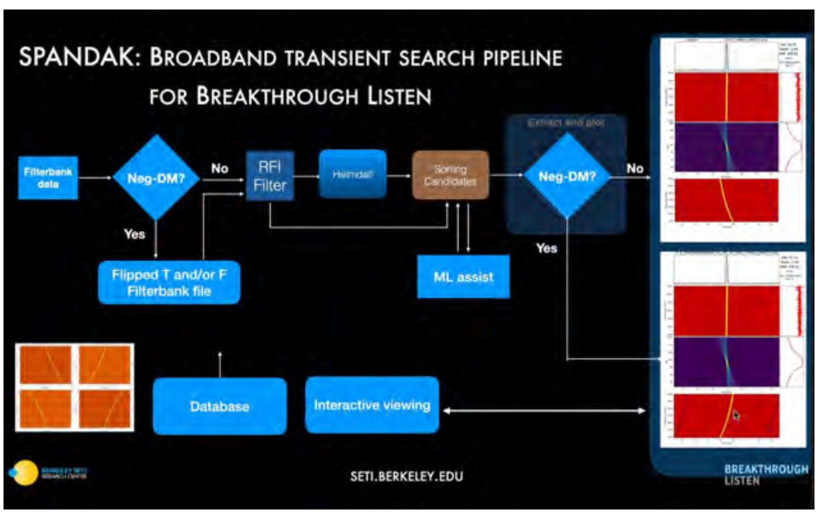
Credit: Croft / Breakthrough Listen

A4,1,3,x60842	On the search for artificially dispersed signals towards the Galactic center and nearby stars with the Breakthrough Listen program	Dr. Vishal Gajjar	University of California, Berkeley	United States

IAF cited paper: (Abstract only – no full paper available)
iafastro.directory/iac/proceedings/IAC-20/IAC-20/A4/1/manuscripts/A4,1,3,x60842.pdf
IAF cited presentation video:
iafastro.directory/iac/proceedings/IAC-20/IAC-20/A4/1/presentations/A4,1,3,x60842.show.mp4
Open paper: None found
Reported by: Patrick Mahon



Vishal Gajjar asked what the best strategy might be for finding any intelligent life elsewhere in the Universe. To date, most SETI activities had been focused on looking for narrow-band signals at around 1420 MHz, the 21 centimetre line at which hydrogen, the most abundant element, naturally emits. An alternative strategy involves looking towards the Galactic Centre (GC), where the high density of stars should provide many target planetary systems. Intelligent aliens, wanting their signals to stand out from natural astrophysical sources, might create artificially dispersed signals. With radio emissions that are naturally dispersed by the interstellar medium, the high frequency component arrives first, with the lower frequencies following. They are therefore searching for signals that are dispersed in precisely the opposite way, since these seem likely to be artificially created.



The search is being conducted using a neural network-based machine learning system called SPANDAK.

To date they have identified several interesting signals, but they have all turned out to be due to natural interference from the GC. In the current (October 2020) phase of the project, they are taking the same approach but focusing the Green Bank telescope on 2,360 nearby stars instead of the GC. They have so far found 390,000 candidate signals, which were under investigation at the time of the conference.

Co-Authors: Dr. Andrew Siemion, Berkeley SETI Research Center, Dr. Steve Croft, University California (UC) Berkeley, Dr. Daniel Czech, University of California, Berkeley, Mr. Matt Lebofsky, UC Berkeley, Mr. Howard Isaacson, UC Berkeley, Mr. David MacMahon, Berkeley SETI Research Center, Ms. Claire Webb, Massachusetts Institute of Technology (MIT), Dr. Daniel Price, UC Berkeley, Dr. David DeBoer, UC Berkeley, Ms. Julia DeMarines, University of California, Berkeley, Mr. Jamie Drew, Breakthrough Initiatives, Dr. Pete Worden,, Ms. Karen Perez, Columbia University.

IAC--20,A4,1,4,x61207	Commensal SETI Survey Strategies for MeerKAT	Dr Daniel Czech	University of California, Berkeley	USA

IAF cited paper:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/A4/1/manuscripts/A4,1,4,x61207.pdf

IAF cited presentation video:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/A4/1/presentations/A4,1,4,x61207.show.mp4

Open paper: None found

Reported by: Patrick Mahon

Daniel Czech summarised his short paper, which discusses a mathematical strategy for filling in as many gaps as possible in a SETI sky survey that is piggybacking on someone else's project. In brief, Breakthrough Listen has an extremely ambitious goal to observe at least one million nearby stars for technosignatures, using the MeerKAT radio telescope array in South Africa. To achieve this goal, the starting point is that the SETI observations will be performed as a secondary objective while MeerKAT is being pointed at different areas of the sky to fulfil other, non-SETI, scientific objectives. Such an approach is known as a 'commensal' survey approach, a term which originates in the biological sciences, describing a situation where 'commensal' species A benefits from co-location with species B, while species B neither benefits nor is harmed itself.

The problem with this commensal search strategy is that the primary science objectives are unlikely to lead to uniform coverage of the whole sky, leaving some regions of the sky underrepresented in the SETI dataset. If Breakthrough Listen are successful in booking any time on MeerKAT purely for their own priorities, the question arises of how to maximise the value of that limited observation time to their primary objective, given a knowledge of where their existing dataset is thinnest, and where their target stars are.

This reduces to a mathematical problem: if you have a map (the sky) with a set of points (the target stars) drawn on it, and each successive telescope observation is represented by a circle of a uniform diameter, what is the most efficient strategy for choosing where to point the telescope each time (your circles), so that by the end of your observing time you have covered the greatest number of stars/points possible?

Czech concluded with the happy news that they had developed and tested an algorithm to solve this problem – and it works.

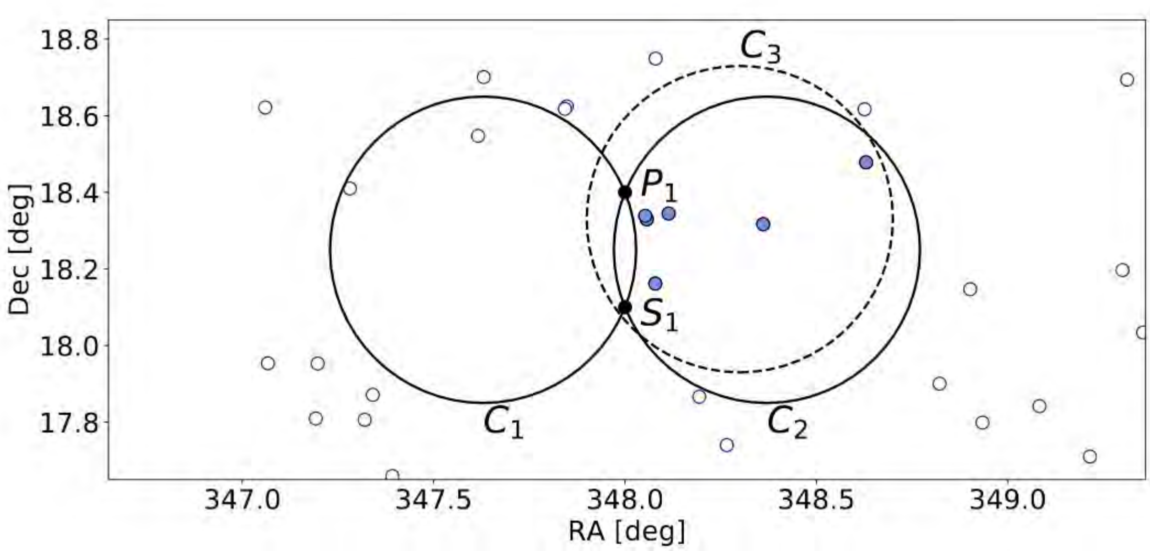


Figure 1. An illustration of the circle placement algorithm (similar to the one described by Xiao et al) applied in this work. An arbitrary portion of the sky has been selected for this example, in which each marker represents a star drawn from the selection.

Credit(image and caption): Czech

A3,4A,9,x58609	Spacecraft Trajectory Simulation for Autonomous Landing on Small Planetary Bodies	Ms. Larissa Balestrero Machado	Universität der Bundeswehr München	Germany

IAF cited paper:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/A3/4A/manuscripts/A3,4A,9,x58609.pdf

IAF cited presentation video:

iafastro.directory/iac/proceedings/IAC-20/IAC-20/A3/4A/presentations/A3,4A,9,x58609.show.mp4

Open paper: None found

Reported by: Patrick Mahon

Larissa Machado introduced the paper by recounting that spacecraft had been exploring small planetary bodies (such as asteroids and comets) since 1991, when the Galileo spacecraft did a flyby of asteroid 951 Gaspra on its way to Jupiter. A decade later, NASA's Near Earth Asteroid Rendezvous (NEAR) – Shoemaker probe successfully landed on the asteroid 433 Eros. Since then, JAXA's two Hayabusa missions have successfully landed on asteroids in 2005 and 2019, while ESA's Rosetta mission to comet 67P/Churymov-Gerasimenko included a bold but only partially successful landing of the Philae lander on the comet in 2014. Landing is a pre-requisite for detailed in-situ measurement of such bodies, let alone asteroid mining, but is highly challenging, particularly if the surface is uneven. Autonomous landing capability will be necessary, given the delays in signals from Earth being received by spacecraft in the asteroid belt or even further out.

The project summarised in her paper is part of a DLR-funded programme intended to advance the Guidance, Navigation & Control (GNC) algorithms needed for autonomous landing on small planetary bodies (such as asteroids or comets) to a Technology Readiness Level (TRL) of 5. They have simulated the powered descent phase of such a mission, which is the most dangerous part of the landing phase, when the spacecraft needs to locate and avoid hazards, identify a suitable landing site, and then either land or abort back to orbit. The project models both hardware and software elements. The hardware consists of a multicopter Unmanned Aerial Vehicle (UAV), which models the spacecraft dynamics and includes sensors for navigation and hazard detection. The software includes a dynamic model of the spacecraft, a model of the microgravity forces existing in the vicinity of a small planetary body, and the GNC algorithms. The main constraint placed on the simulations is an objective to minimise propellant use during the landing phase.

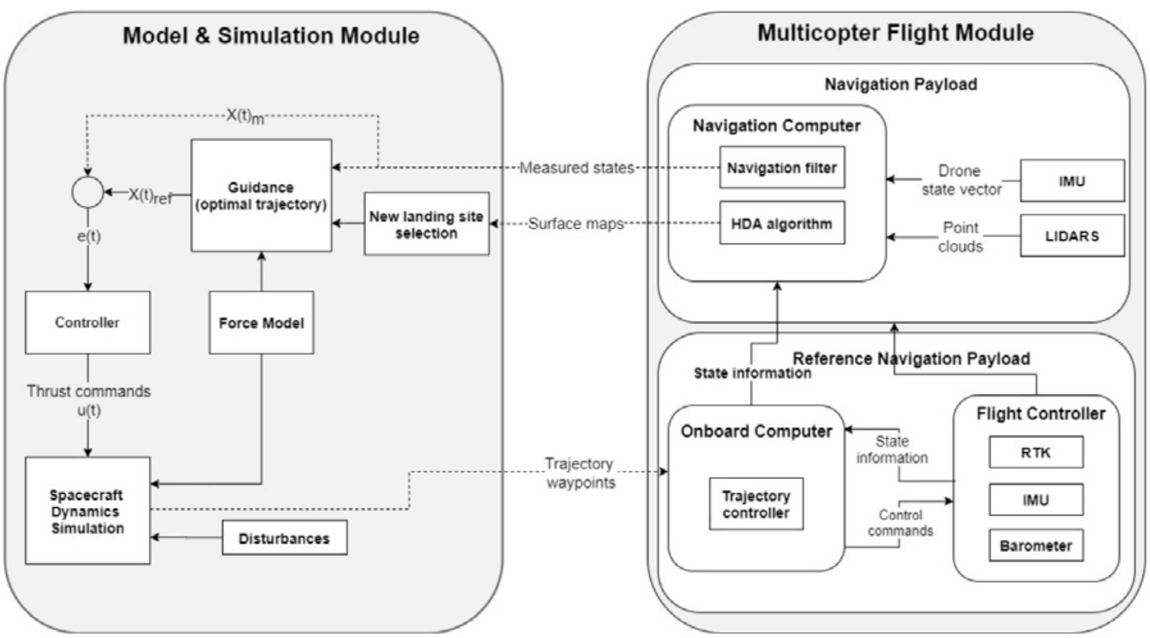


Fig. 4. Small Body Autonomous Landing Development and Validation Environment. Credit: Machado (graphic and caption)

The approach has been tested with reference to a simply ellipsoidal asteroid, and most mission parameters remained within the set constraints through to landing, although a fully vertical landing proved highly challenging. [Editor's note: this is something that SpaceX have demonstrated more recently with the Starship SN9 flight test on 2 February.] Further work will model more realistic asteroid or comet geographies, to test the model under more realistic conditions.