PRINCIPIUM

The Initiative and Institute for Interstellar Studies

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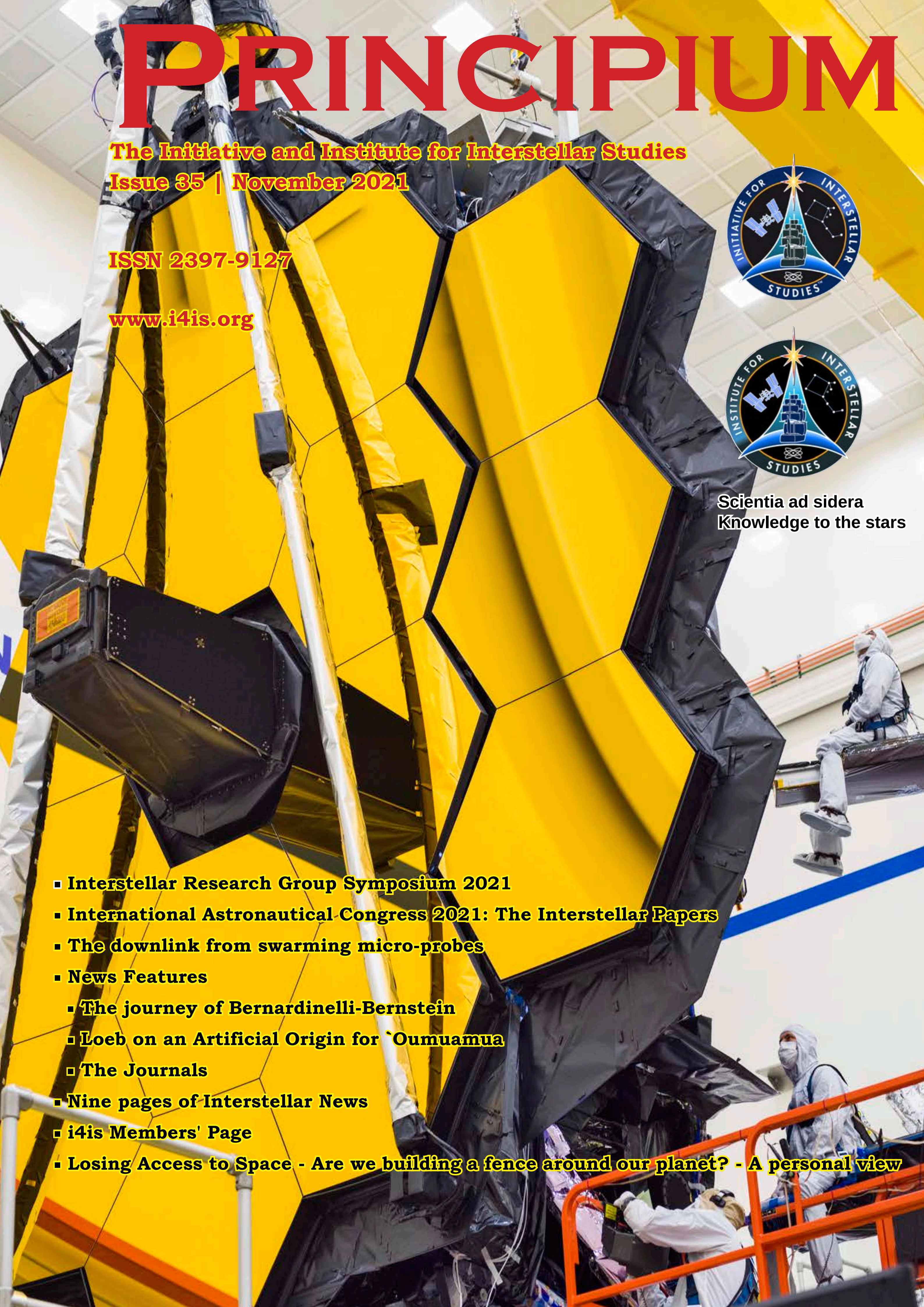
Scientia ad sidera
Knowledge to the stars



Editorial

Welcome to issue 35 of Principium, the quarterly magazine of i4is, the Initiative and Institute for Interstellar Studies. Our lead feature this time is a report from the September IRG 7th Interstellar Symposium in Tucson. This is the premier event in interstellar studies right now and our thanks go to IRG president Doug Loss and our two IRG reporters, Bart Leahy & Joseph Meany. We aim to report from the next IRG symposium in 2023.

Our front cover image is of the assembly of the James Webb Space Telescope - now awaiting its launch from the ESA site at Kourou on 18 December. We'll be watching and hoping - for the launch, on one of the last of the Ariane 5 heavy launchers, for the unfolding in the following weeks and for first light early next year.

Night launch of an Ariane 5

Credit: arianespace.com

The rear cover image is the amazing trajectory of the NASA Lucy probe to the Jupiter Trojan asteroids.

Both front and rear images give us cause to hope for advancement to the stars - by knowledge of them and by demonstration of a low energy trajectory which must be one of the founding factors of our future interplanetary civilisation. More in *Cover Images* inside the rear cover.

Less optimistically, proliferating space debris may ultimately prevent us reaching the stars according to a personal view of the editor - *Losing Access to Space - Are we building a fence around our planet?*

We have our regular *i4is Members' Page* and 9 pages of *Interstellar News* with 17 items including *Avoiding the "Great Filter"* and *A real, albeit humble, warp bubble?*

We have the first of two pieces on interstellar downlink communications, *The downlink from swarming micro-probes* about the (very) "light brigade" swarming micro-probes - inspired by the work of David Messerschmitt *et al* and i4is team work now in progress. The piece on the "heavy brigade", based on the Icarus Firefly downlink and its predecessor the BIS Daedalus downlink, is postponed to P36 in February.

We have an initial report on some interstellar items from the October 2021 International Astronautical Congress in Dubai - with much more to follow in our next issue, P36 in February when we will also have a Report on *Limitless Space Institute: Human Exploration of the Far Solar System and on to the Stars*.

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

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

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More in *The i4is Members' Page* - page 54

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Please support us through membership of i4is. Join the interstellar community and help to reach the stars! Privileges for members and discounts for students, seniors and BIS members. More on page 52 of this issue and at i4is.org/membership.

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

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Interstellar Research Group Symposium 2021

LEAD FEATURE

Bart Leahy & Joseph Meany

The Tennessee Valley Interstellar Workshop (TVIW) is now the Interstellar Research Group (IRG). IRG/TVIW has been in existence for about as long as i4is. The idea of holding an Interstellar Symposium in the Tennessee Valley was conceived in Italy in July 2011, and the first TVIW (TVIW2011) was hosted by Robert Kennedy, now the i4is US president, in November 2011, in Oak Ridge, Tennessee, with subsequent workshops 2011, 2013, 2014, 2016, 2017, 2018, 2019 and 2021.

This report is from the 2021 event held in Tucson, Arizona, and arises from discussion between Doug Loss, President of IRG, and John Davies, editor of Principium, from mid 2020. Our thanks to Doug and to our two reporters, Bart Leahy & Joseph Meany.

We look forward to reporting from IRG2023 at McGill University, Montreal.

Despite health concerns, travel restrictions, and a last-minute shift of a NASA event to the Zoom app, the Interstellar Research Group (IRG) managed to host a successful four-day, mixed-media event in Tucson, Arizona this past September. Hosting nearly 40 speakers in person and online, IRG brought together its usual intriguing mix of academics, scientists, engineers, science fiction authors, and even members of the United States Space Force to continue its biennial symposium.

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All images are credit Bart Leahy unless otherwise stated.

Day 1 September 24

The first set of events in Tucson were not part of the symposium proper. However, attendees enjoyed a mix of activities, including a tour of the Pima Air & Space Museum as well as the University of Arizona's Richard F Caris Mirror Lab. At the former, attendees got to see historic aircraft such as the B-29, MiG-15, B-52, and Air Force One. At the latter, visitors got to see mirrors being fabricated for the Giant Magellan Telescope, a segmented mirror telescope that will employ seven monolith mirrors to provide a single optical surface 24.5 meters (80 feet) in diameter with a total collecting area of 368 square meters (3,961 square feet).

At the symposium hotel adjacent to the University of Arizona Campus, attendees had the choice of two morning and two afternoon seminars. The morning sessions included "Terraforming Planets: Why and How" and "Astrobiology and the Search for Nearby Habitable Worlds" while the afternoon sessions included "Space Law: An Overview, Past, Present, and Future" as well as "The Challenge of Closed-Loop and Bioregenerative Life Support for Long Duration Space Exploration."

Dr Betül Kaçar provided an introduction to how the study of life and biological evolution informs astrobiology about extrasolar habitats and biosignatures. Dr Apai reviewed the search for the closest habitable worlds and methods to characterize them, including searches for signatures of life. Hands-on activities related to the presentations allowed participants to put in practice the concepts they learned.

"Space Law: An Overview, Past, Present, and Future" covered the US domestic regulatory environment for space activities. These efforts include the legal authority and regulatory requirements of the Federal Aviation Administration, the Federal Communications Commission, and the National Oceanic and Atmospheric Administration over space transportation, satellite communications, and remote sensing from space. The presentation also addressed issues in space law arising from the Outer Space Treaty that could affect interstellar operations: property rights, the regulation of new activities, and planetary protection.

On the evening of the 24th, participants were able to attend a reception featuring space art as well as a presentation featuring images and drone videos captured near a set of volcanoes being formed in Iceland in Spring 2021.

1.1 Space Law: An Overview, Past, Present, and Future

Laura Montgomery, who teaches space law at Catholic University, gave an in-depth presentation covering the processes for implementing regulations and laws related to space activities in the United States. She tied those discussions to international efforts at space law such as the Outer Space Treaty of 1967. The Outer Space Treaty requires its signatories (nation-states) to regulate the space-related activities of its citizens so they comply with international law. These activities also will have implications for future interstellar travel.

The US government faces challenges with the new private space activities now happening. The Legislative Branch, which makes laws, is not required to regulate everything, and the Executive Branch, which enforces laws, does not have the authority to deny an activity just because it might be unregulated. Private space activities could include exploration, transport and commerce, science, or even piracy. Another problem the US could face on the international front is that while the US Constitution states that treaties "shall be the supreme Law of the Land," the US Supreme Court has ruled that not even the President may enforce a non-self-executing treaty. If the President can't enforce it, how can a federal agency?

Conflicts are already arising over the interpretation of the Outer Space Treaty and the Moon Treaty, for example. The Outer Space Treaty bars appropriation of celestial bodies by national governments, but does not bar private appropriation. However, the 1979 Moon Treaty, not signed by the US, states that "The exploration and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries." That could imply that space is a global commons, which would interfere with commerce. Yet another long-term problem will be determining jurisdiction over space-related legal matters. Eventually the US will need to establish laws and regulations that recognize and comply with international space legal arrangements.

Space law also could affect beyond-Earth activities related to planetary protection or contamination. While strong measures are taken by organizations like NASA and its contractors to prevent contamination of planets like Mars, that is a government policy, not a law. Private individuals and organizations sending robots or people to Mars without NASA contracts might not be subject to the policy.

While there are still grey areas, the US government has co-operated internationally on activities such as vehicle launches and re-entries, radio spectrum bandwidth, spaceports, remote sensing, and damage caused by space hardware. Various government agencies have the authority to approve, issue licenses for, or prohibit launches, re-entries, and remote sensing of the planet.

The Federal Aviation Administration (FAA) has jurisdiction over commercial human spaceflight. Passengers of these companies operate under what's known as an "informed consent" regime for spaceflight, wherein they travel at their own risk. This will likely change the first time there is a death, serious injury or close call. However, right now the current legal environment prevents even individualized license conditions from protecting passengers or crew absent regulations. Also, the FAA imposes financial responsibility requirements on commercial space carriers by requiring insurance or other means up to statutory limits. All of these legal regimes will need to be clarified before humanity expands into space on a mass basis.

1.2 Terraforming Planets: Why and How

IRG member and retired engineer Ken Roy focused on potential methods for "Earth shaping" or transforming a planet or moon into an Earth-like environment.

He differentiated between planetological terraforming, which is geologically and atmospherically stable and requires minimal maintenance, and habitable terraforming, which requires technological intervention, maintenance, and replenishment. Roy also addressed some of the philosophical objections to terraforming, insisting that the long-term survival of humanity is a good thing. However, he cautioned against terraforming planets with existing biospheres because similar DNA-based life systems could produce cross-species allergies, toxins, or other problems.

Roy identified the most important habitability elements as being: atmosphere, temperature range, gravity, Earth-like biosphere, correct chemical balance, oceans, orbital position (liquid water), and the local sun's light intensity/spectrum, each with varying values. He identified a general flow of activities needed to terraform a world, but indicated that each world would present its own challenges. One potential flow would first address the planet's temperature, pressure, and constituents, then add life to start a soil food web, including plants, fungi, nematodes, arthropods, bacteria, and animals.

Roy compared the terraforming of Venus and Mars. Venus could be terraformed given its similar size and gravity to Earth. However, it possesses a slow rotation, excess nitrogen and carbon dioxide, lack of liquid water, and lack of plate tectonics. The planet's temperature could be reduced by orbiting a sunshade to drop the temperature low enough to freeze out and sequester the carbon dioxide, which would take several decades. Importing water, calcium, and magnesium could take another 10,000 to 100,000 years. Conversely, Mars would need a thicker, warmer atmosphere; perchlorates washed out of the regolith through rain; and the moon Phobos relocated because of its eventual collision with the surface in 100 million years. Transforming Mars could take a millennium or longer and would require constant maintenance.

Another alternative to terraforming, paraterraforming, would cover and pressurise a glass-roofed structure 1-3 kilometers tall, then add other structures beside it until, bit by bit, the entire planet was covered. This process would provide an expandable, climate-controlled surface and immediate return on investment. However, there could be structural issues if there is no native atmosphere; breathable atmosphere would have to be imported; and the entire effort would require a lot of resources and maintenance.

A step between paraterraforming and full terraforming would be a "shell world." The shell would enclose up to 10-15 kilometers on Mars, with gravity pulling the atmosphere-enclosing membrane down and pressure holding it up. A shell world would not require as much atmosphere as a full terraforming effort; there would be less atmospheric loss; and they could be built independent of the planet's spin or habitable zone. However, shell worlds would require a lot of energy; pose construction difficulties; require artificial lighting or a digitized sky projection; and require a lot of effort and environmental maintenance. The bottom line of Roy's seminar was that humanity has choices and options, but most of them will require resources, time, and patience to make massive transformations of other worlds possible.

1.3 The Challenge of Closed-Loop and Bioregenerative Life Support for Long Duration Space Exploration – Kai Staats, Trent Tresch, Shawn Gellenbeck, Joel Cuello

Kai Staats and Trent Tresch are helping Biosphere 2 in Oracle, Arizona restore one of their smaller units to make it into a Mars Analogue facility called SAM (Space Analog for the Moon and Mars). The key technological feature of this sealed Analogue will be its sole dependence on bioregenerative life-support to maintain the health the participating crews. Shawn Gellenbeck is a graduate student and Paragon Space Development Corp aerospace engineer working on life support systems. Dr Joel L Cuello is Professor of Agricultural & Biosystems Engineering and Director of the BioImagineering Laboratory at the University of Arizona who has been concentrating on growing algae in bioreactors and vertical farming. Applying their combined interests and expertise, the four speakers discussed incorporating living systems into the life support of an interstellar worldship.

The assumptions of their vehicle included a voyage of 100+ years; 100% self-sufficiency; all supplies being on board from start to finish; approximately one Earth gravity of acceleration or a rotating spacecraft capable of providing same; sufficient energy to accomplish the mission; Earth-normal atmosphere at .8-1 bar (12-14 psi), 20-25 degrees Celsius (68-77 degrees Fahrenheit); and a fully closed atmosphere, most likely without any weather.

While physical, chemical, and mechanical systems have been used to handle life support on past and current space missions, bioregenerative elements will likely become common in future missions, especially long-duration missions on the planetary or interstellar scale. This includes farming to provide food as well as plants grown for their oxygen-producing and aesthetic qualities. These systems could include hydroponics, LEDs, and solar lighting. Chemicals needed to maintain or replenish these systems such as hydrogen, oxygen, carbon, and nitrogen, could come from the interstellar medium.

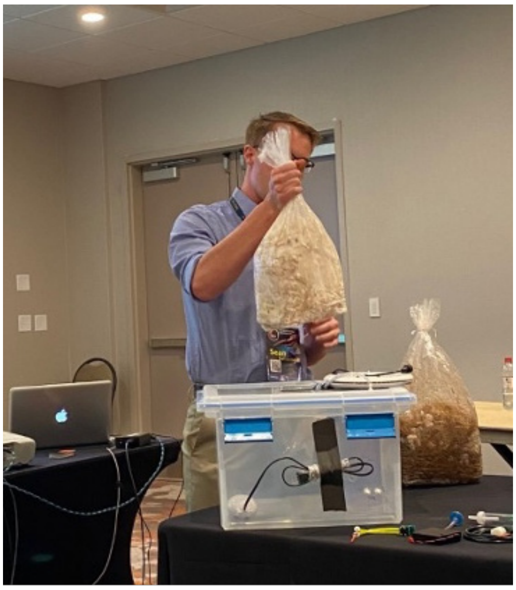
Food production on interstellar missions could include vertical farming, fermentation, and cell cultures in photobioreactors while food assembly could be accomplished using 3D printing and robot-attended vertical farming. Many of these types of systems are already being invested in by venture capitalists today to ensure food security here on Earth.

Other technologies in development today include growing mushrooms in fermenters or phototrophic and heterotrophic (no light required) bioreactors along with cultivated meat grown at the cellular without the need for actual bovines present. Algae and fish are other likely food sources.

A primary food source being investigated by Gellenbeck is fungi, specifically the oyster mushroom. At 40% protein by dry weight, containing all 9 essential amino acids, and possessing a fast growth rate, mushrooms could serve as an ideal “comfort food” compared to other alternatives such as meal worms or crickets. The oyster mushroom, which typically grows on field decay on Earth, grows aggressively, is good at fighting off other microbes, and is good at breaking down other organic matter.

The primary needs for all of these systems will be water, energy, and nutrients, with the water and nutrients being recovered and reused with as close to 100% efficiency as is possible. Artificial intelligence (AI) systems could be employed to monitor and maintain these sensitive systems.

Bioregenerative systems will be necessary in long-duration space missions and worldship efforts because it would be impossible to store all of the food or fresh air necessary to feed the entire crew or population for the duration of their flight. For example, the carbon dioxide removal system on the International Space Station must be replenished every six months. However, biologically based systems are not without problems. Like mold, mushroom spores go airborne and can grow elsewhere on a ship. The US Occupational Safety and Health Administration (OSHA) found parts of Biosphere 2 to be “unlivable” after being opened due to mold, spores, and allergens.



Gellenbeck showing a bag full of oyster mushrooms from an experiment performed at the HI-SEAS analog habitat.

The presenters also highlighted SIMOC – Scalable, Interactive Model of an Off-World Community – an online learning simulation of an off-world habitat using bioregenerative life-support systems. SIMOC (simoc.space) is designed to educate students about balancing O2 and CO2 levels in simulated habitat based on human and plant production. It will also incorporate data from the SAMS facility once it's operational.

Day 2 September 25

2.1 Keynote: Esther Dyson

Esther Dyson, investor, philanthropist, and daughter of physicist Freeman Dyson, participated in a Zoom-based "fireside chat" with Stephen Fleming, Chairman of the Tucson symposium. She discussed her experiences as a backup astronaut and astronaut trainee with Space Adventures in Russia.

Her experience with Space Adventures came about through her connection (investment) in Space Adventures to be a backup astronaut to Microsoft executive Charles Simonyi at a reduced price. She did not get to fly to the International Space Station, but she did get the six-month cosmonaut training experience.

She observed that space is shifting from large, monolithic government projects to risk-focused commercial enterprises. The environment is primed to grow, she said, but lots of companies will fail or be swallowed up in the process.

Dyson's cosmonaut training included riding in the centrifuge up to 8 gravities; experiencing wilderness training (with observers less than a kilometer away); and lying in a plaster-of-Paris mold to make her custom-built spacesuit. She noted that the Russians deliberately try to get the participants sick on their parabolic "vomit comet" flights, with the cycles being called "provocations."

She shared several curious stories about her time in Russia, including the time Charles Simonyi was bitten

Dyson during wilderness training—

the worst thing for her was losing a contact lens

Dyson's caption for this photo of her spacesuit fitting was, "What do we do with her now?"

Dyson with astronaut Cady Coleman. The Space Adventures participants were kept separate from the NASA astronauts undergoing training, but the two groups still socialized. They also had a lot of guests who were their "observers."

by a rabid dog and another story she heard about a cosmonaut who hid a sausage on a spacecraft.

Asked what she thought the space community could learn from the internet, she responded, "Money isn't inherently dirty, but you need to watch the impact of government power, too…The thing with money is that people get addicted to stuff that is extremely lucrative, but it leads to bad things. Profits are what sustain the business; you need a sense of mission, but you need to be able to pay bills, too."

She decided that the best analogy came from an author who said, "Money in business is like sex in marriage—it's necessary, but more sex does not make a marriage better, and more money isn't necessarily better in a business. When you get addicted to the money rather than the mission, that's when trouble starts."

Dyson observed that there are two interpretations of the Outer Space Treaty. The American view is that what is not forbidden is permitted whereas the Asian and European view is that what is not permitted is forbidden. She believe this conflict of visions should be resolved sooner rather than later. She was in favor of human spaceflight, however. "We're part of the universe; we shouldn't go mess up everything else, but we should travel, we should explore, we should be aware of consequences, but I don't think it helps the universe to leave Mars untouched. We want the grownups to run things, but we are the grownups. We all have to show up and figure out some reasonable way to go forward. Those who venture first get to be part of the discussion. There's some balance between who gets their first and claiming parts of planets."

During the audience Q&A, Dyson stated that the biggest business opportunities in space right now are communications, data collection, surveillance (roads, pipelines, weather); logistics; space tourism; space manufacturing to establish things in space and make things better on Earth; 3D printing in space; and synthetic biology. Amplifying her comments on synthetic biology, she said, "If we're going to terraform Mars, we need synthetic biology for food, waste processing, etc. We may end up doing careful editing of our ourselves as well…The implications for solving environmental problems on Earth might be the most interesting."

Asked whether she'd go if Elon Musk offered her a seat on the first or a later trip to Mars, Dyson said, "No, I'm in the middle of a ten-year project. The purpose of life isn't to click every box, but click the most interesting ones."

2.2 Is ET Lurking in Our Cosmic Backyard? – James Benford

Scientist James Benford believes that humanity should take a more direct approach to the search for extraterrestrial intelligence (SETI). Instead of seeking out mere signals from other civilizations, we should search for extraterrestrial artifacts (SETA). "It's at least as probable to be as successful in the near term. SETI's been around for 60 years." His primary argument for seeking objects rather than signals is that "Alien artifacts are the ultimate technosignatures. They can't be ambiguous like radio signals."

James Benford

In a paper, Benford cited the usefulness of co-orbiting objects such as Earth's Moon, as an ideal location for observing our civilization [1]. Using that logic, he believed that an artificial intelligence (AI) program should study over two million photographs from the Lunar Reconnaissance Orbiter (LRO), which has resolution down to approximately 30 centimeters (1 foot).

In addition to the Moon, he suggested that SETI start listening for signals from stars that have or might come within 10 light-years of Sol within 10 million years because Earth's atmosphere has been in chemical disequilibrium due to the presence of life for 2 billion years. Other places we could look for alien "lurkers" would be in orbital positions close to Earth, including the Sun-Earth and Earth-Moon Lagrange points along with other orbits where we have already detected objects. Those objects could be scanned using planetary radar painting and SETI listening. More promising or unusual candidates could be investigated using robotic probes, such as the Chinese probe being launched toward 2016 HO3 (469219 Kamoʻoalewa).

Summarizing the conclusions from his Drake Equation paper, Benson said, "If you're an early spacefaring civilization, you build beacons/radiators. If you're a superior civilization with fast interstellar travel, then you send lurkers because you'd get information back. If costs don't matter, you'd certainly send lurkers because the data return is greater."

[1] Benford, James. "Looking for Lurkers: Co-orbiters as SETI Observables," The Astronomical Journal, 20 September 2019, Vol. 158, Number 4 iopscience.iop.org/article/10.3847/1538-3881/ab3e35.

2.3 Breakthrough Propulsion Study – Assessing Interstellar Challenges and Prospects – Marc Millis

Under a NASA grant, Millis and his colleagues have attempted to create a catalog and database of all known interstellar propulsion concepts to impartially compare concepts against differing priorities for future missions. The goal was to make fair comparisons; include system-level factors, such as what type of mission the propulsion system was designed to support; and include technology readiness level (TRL) and research plans. The intended database would offer read/write access for propulsion professionals and summaries for the general public.

Using a three-stage plan, the group hoped to pursue the following path:

1. Understand: What are the right questions?
2. Get answers to those questions
3. Publish and analyze answers and recommend priorities

Figures of merit for comparing the various proposed systems included mission capabilities (payload capacity, mass, power, communication data rate, time on target, information obtained, etc); mission expense (including mass and energy); schedule (mission duration and anticipated launch year); and risks (TRL of least-ready elements, system information completeness, and theoretical limit of the system compared to the required performance). Comparisons among the various propulsion types ultimately depend on the expected mission performance.

Of the planned databases , the team has completed the first iteration of Mission-vehicle concepts and has written questions for propulsion performance, independent of mission; research needs and technology readiness; and infrastructure capacity growth baselines. The team is not actively collecting data at present. Although the group has received incomplete data on many of the propulsion concepts, the questions they ask cover submitter information and concept identifiers; mission destination and purpose; mission schedule; in-space mass and infrastructure requirements; mission architecture (delta-v and mass for departure, mid-course, arrival, and return); main propulsion specifications; secondary propulsion specifications; along with additional details, such as mission goals, payload specifications, design priorities, and TRLs.

Between December 2019 and May 2021, the group managed to determine the minimum question set for propulsion concepts; obtain a database contractor; establish the data collection methods, display, and assessment dashboards; and run trials with subject matter experts. However, the study team encountered lots of missing or incorrectly entered information, which hampered their ability to make progress and meaningful comparisons between systems. Once funding resumes, the team needs to complete databases for propulsiona, research, and infrastructure; complete the analysis tools in co-operation with NASA; and create online access tools for the database.

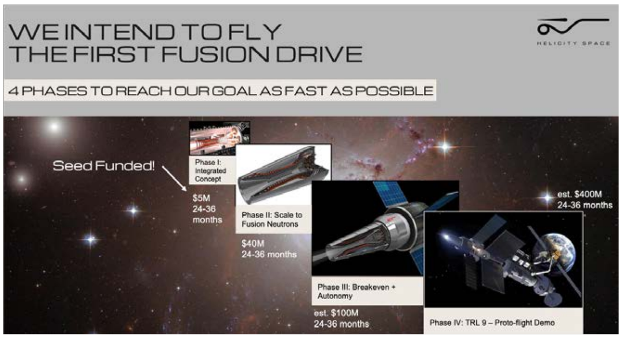
2.4 An Overview and Plan for an Interstellar Mission Study with the novel Helicity Drive Fusion Propulsion Concept – Alan Stern

As principal investigator of the New Horizons mission, Helicity Space Corporation (www.helicityspace.com) advisor Alan Stern noted that even as the fastest spacecraft yet flown by human beings, the New Horizons spacecraft would take one million years to reach Alpha Centauri. “Clearly we need better propulsion,” said Stern.

The system Helicity is developing would be high powered (100 kW to 1 GW), compact, clean, scalable, reusable, and agile. It will not include any radioactive devices, would be suitable for human missions, and would be thrusting continuously.

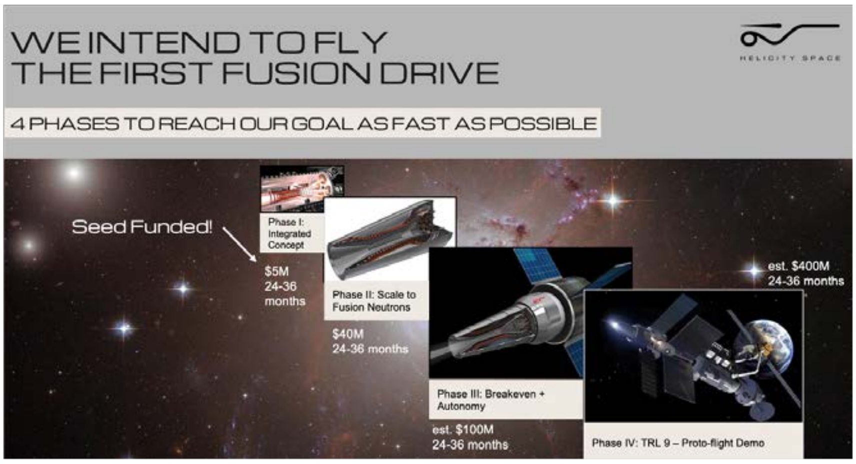
Alan Stern

Helicity Fusion Drive



Helicity Fusion Drive - phases

Stern describes the Hecility drive as "putting an afterburner on an electric drive and turning it into a fusion system." A series of jets emit their particles, which are then fused into a hotter, single jet using magnetic, peristaltic compression. The system would be scaled up by adding more fusion guns. A small unit would use 6 or 15 jets, a medium-sized unit would use 21 jets, and a large unit would employ 31 jets. Extra-large units could have as many as 172 jets.



Helicity Drive - scaling

At present, Helicity is developing a fully integrated proof-of-concept system, which will achieve greater than 100 electron volts and particle acceleration of 50-100 kilometers per second (km/s) in 100-500 microseconds. Using deuterium as its initial propellant (with an aim to use helium-3 in the future), the Helicity drive's 172-jet unit could generate thrust ranges of $4*10^3$ to $71*10^3$ Newtons at an average specific impulse of $7*10^3$ to $135*10^3$.

What these numbers mean in practical terms is that a spacecraft using the Helicity drive could reach the edge of the solar system and travel by Kuiper Belt objects in .3-.6 years and the solar gravitational lens focal line (550-1,000 Astronomical Units/AU) in 7.7 to 11.5 years.

Flying aboard a Falcon Heavy or Space Launch System (SLS) class of launch vehicle, a Hubble-size payload using the Helicity drive could conduct serious science missions within the Oort Cloud or provide telescopic images of exoplanets at the gravitational lens distance. As Stern put it, “We’re all about going faster and farther.”

2.5 Overview of the NASA Innovative Advanced Concepts Program – Dr Ronald Turner

Ronald Turner is NIAC’s senior science advisor for NASA’s Innovative Advanced Concepts (NIAC) program, which operates under the agency’s Space Technology Directorate. NIAC is responsible for investing in early-stage innovation, partnerships and technology transfer, and Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) programs. Their goal is to provide “A program to support early ties of innovative, yet credible, visionary concepts that could one day ‘change the possible’ in aerospace.” Proposals to NIAC are meant to fund “exciting, unexplored, credible, relevant” concepts that are in the very early stages of what is known to be physically possible. They are what NASA would call very low TRL (technology readiness level) ideas.

The Phase I grant opportunities, released in June, amount to $175,000 for a 9-month study that enables the investigator(s) to fund concept definition and initial analysis. The Phase II grants, released in October, can be as much as $600,000 for 2 years to further development, conduct mission analysis, and identify a technology development path forward, including potential spin-offs. While not as common, the Phase III opportunities released in December fund concepts for up to $2 million to help transition Phase II concepts with the highest potential impact into something resembling real hardware.

Phase I studies usually result in a credible final report while Phase II studies build on work identified in Phase I. Phase III efforts have identified a NASA partner ready to fund the idea. Phase I and II studies have gone almost equally to NASA people, academia, and the private sector. Phase III study funds have gone mostly to academia.

So what types of studies does NIAC fund? Obviously NIAC invests in topics relevant to NASA’s mission. These include space transportation systems, such as nuclear, solar sails, plasma, and beamed energy; human systems such as life support and habitats; in-situ resource utilization (ISRU) activities for lunar, asteroid, and atmospheric mining; robotics; and structures.

Turner also provided insights into how individuals or organizations can become a NIAC Fellow. Prospective candidates submit a Step A proposal in early June. Assuming it is accepted, they are invited to submit a Step B proposal in late September. After going through two review panels, recipients are announced in early February, at which point they can start working on their project. The NIAC website is www.nasa.gov/niac; questions regarding the process should be emailed to hq-niac@mail.nasa.gov. Turner stated that “Subject matter expertise is an advantage to innovation. Creativity is enhanced by diverse perspectives. And the most interesting solutions are not found in the answer section in the back of a book.”

2.6 Wind-Pellet Shear Sailing – Jeff Greason

Engineer and entrepreneur Jeff Greason offered another alternative propulsion method for interstellar travel, observing that the effort is difficult because the power levels are so high and it is difficult to bring the propellant with you.

Looked at as an energy problem, Greason stated that bringing a 1,000 kg (2,200 pound) payload to .2 c would require 1.8e18 joules or approximately 60 gigawatt-years of power. According to Greason's calculations, such a power level would require approximately 120 kilograms of antihydrogen. Alternatively, a fusion rocket operating at a 500,000-second specific impulse would require a wet mass of 162,000 tonnes (178,574 US tons).

Another alternative, beamed momentum propulsion via particles or photons requires the beam to have enough range to cover the accelerating "runway" (flight path). Beam power scales with ship mass at a value of mass * velocity cubed. Similarly, a "sailbeam" employing guided macroscopic propellant pellets makes the range longer, but the power requirements are still immense and the beam must still be paid for somehow. Another alternative, the "fusion pellet runway," uses slower pellets to carry the fusion energy. However, the drag of the pellets still has to be accounted for, and the mass of the pellets increases for velocities greater than the fusion exhaust velocity.

Greason's solution is not to carry the power supply on the spacecraft.

Rather than accelerating the craft by bouncing many pellets off of a surface to transfer momentum, this new concept relies on a radically different way to think about inertial frames of reference!

Greason would lay out a fusion pellet runway of slow pellets ahead of the spacecraft. This necessitates two separate pieces: a pellet pusher and the pellets themselves. Greason et al hypothesized that the pellets need not be made from exotic materials, either. Nanoparticles, aerographite spheres, or buckyballs (C60) are all candidates to act as particles. These particles would use their difference in velocity, relative to the interstellar wind, to transfer momentum into a forward moving craft. The particle pusher itself could take on many forms, though three particle accelerators were proposed. Among them, they force particles out of an acceleration tube either via a magnetohydrodynamic thruster (repurposing another space thruster concept), a scramjet accelerator, or a linear accelerator spitting out small ions.

The talk wrapped up with a mission concept outline, detailing where reasonable numbers could be approximated and where order-of-magnitude ballpark guesses had to be made against rough mission costs. The initial numbers paint a curiously promising overview, and future work is warranted by the team.

2.7 Synthetic Biology as the Enabling Technology for NASA's Missions – Lynn Rothschild

Dr Rothschild, a senior scientist at NASA Ames Research Ctr, sees the human needs for interstellar travel—cargo upmass and volume; cost; storage; reliability; flexibility; power; and self-sustainability—and has identified a potential solution, one that could "create the ultimate circular economy." This "ultimate black box," as she calls it, would be programmable; self-replicating; self-repairing; modular; able to sense something as small as a molecule; contains no petroleum or electrical input; and has atomic-scale perception: life itself.

In Rothschild's concept, humanity would design new biological functions and systems not found in nature for material production and bioprinting. These living tools would include the inner, natural mechanisms of bacteria and fungal mycelia. She calls her approach "mycotecture." Fungal mycelia, she pointed out, is low-mass, inexpensive, flame retardant, potentially self-healing, and compostable.

Using sunlight to power photosynthesis, biology could fill multiple needs beyond Earth, including material production for fabrics, circuit boards, clothing, filters, medical devices, sensors, power generation and storage, and other items. The primary design effort would program the existing DNA machinery of cells to manufacture other materials or products we need. And unlike nanotechnology, which requires clean rooms to operate, Rothschild says that biological systems do not. The trick to getting cells to do our bidding is forcing DNA to have an amino acid mismatch along its helical ladder; for example, a cytosine-cytosine mismatch allows you to incorporate/extract metals.

Rothschild also sees biotechnology as a critical method for building and generating pharmaceuticals, especially items such as antibiotics, which have a limited shelf life. Another problem with on-demand pharmaceuticals is predicting what a crew in space would need. To bring large supplies of everything would not be practical. It's an upmass issue. Instead, a crew would program bacteria to make materials. Such testing should be done in space, on the International Space Station, Moon, or Mars, before we try something like interstellar travel. As a starting point, EuCROPIS the German space agency, DLR, is planning to launch a satellite that will test food production in space using synthetic biology.

Beyond the applications already mentioned, Rothschild identified other uses for synthetic biology, including recycling metals, ISRU, aeronautics, green aviation, biofuels, novel materials, and biomimetics.

2.8 The Solar Shield Concept: Current Status and Future Possibilities – Ken Roy

In addition to the terraforming discussion on the 24th, Ken Roy presented a geoengineering approach to solar radiation management to mitigate or reverse global warming. First proposed by James T Early from Lawrence Livermore National Laboratory, concepts like this have also been called planetary sunshades or "Dyson Dots." The shield would cool the Earth by blocking some of the sunlight reaching it. Such a shield, massive in its scale, would need to be placed between the Sun and Earth sunward of the Sol-Earth L1 Lagrange point, about 2.44M kilometers from Earth.

To decrease worldwide average temperatures by the levels recommended by the Intergovernmental Panel on Climate Change (IPCC), the sun shield would need to be 3.4 million square kilometers, with a mass of anywhere from 21.2 to 127.1 x 10^6 tonnes, and would require ~235,000 SpaceX Starship launches. Greater temperature goals would require even larger devices and correspondingly more launches, as depicted in the following table.

Required Cooling	**1°C**	**1.5°C**	**2°C**
Required Shield Area km2	3,420,000	5,130,000	6,840,000
Mass of Shield 106 tonnes	21.2 to 127.1	31.8 to 190.1	42.3 to 254.1
Total Starship Launches 16% Reflective 6 g/m2	235,000	353,000	471,000
Total Starship Launches 90% Reflective 37 g/m2	1,412,000	2,118,000	2,824,000

Total Requirements to Reduce Average Global Surface Temperatures

The technologies to make a global sunshade possible are already being tested and flown. Solar sail spacecraft have flown before, and NASA plans to launch the Solar Cruiser mission as a technology demonstrator. The 1,700 m^2 (~18,000 ft^2) sail will fly to the Earth-Sun L1 position to demonstrate station-keeping capabilities, close to where the sunshade would need to be placed.

While the IPCC recommends using carbon capture technology to reduce global temperatures 2-3 degrees Celsius, the global sunshade could result in a 1-degree cooling of the planet even with high carbon emissions. Of course to get the sunshade deployed will take a concentrated, global, and large-scale effort, including 200-1200 Starship launches per week between 2035 and 2080. And while critics of the sunshade worry about the atmospheric effects of that many flights, Roy stated that the cooling effect from the sunshade is greater than heating from launches. One way to overcome this concern, however, would be to consider building the sunshade infrastructure in space: the Moon or the asteroids.

Overall, Roy sees the sunshade as a win. It would enable humanity to protect our biosphere; buy time for the transition to a carbon-free economy; and offer the keys to solar system by demonstrating the fabrication and assembly of large-scale space structures. Current work regarding the sunshade are being pursued by the Planetary Sunshade Foundation (www.planetarysunshade.org).

2.9 FarView – An In-Situ Manufactured Lunar Far Side Radio Observatory – Ronald S Polidan

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Robert Polidan, an astrophysicist and former chief technologist for NASA Goddard Space Flight Center, is pursuing an ongoing NIAC study to develop a low-frequency (5-40 MHz) radio telescope comprising 100,000 dipole antennas dispersed over 120 km² of the Lunar far side. The antennas, which would be manufactured in situ, would be in an excellent location to conduct radio astronomy, blocked from the Earth's extensive radio noise.

While the project is still in the preliminary phase (NIAC Phase I), the study eventually will define a workable architecture and identify the technologies necessary to make it come about. The effort is focused more on the systems than the specific technologies, which are being developed under separate studies.

The science goals of the FarView telescope are to conduct interferometric measurements of three-dimensional fluctuations in the hydrogen "dark ages" signal (ie hydrogen from the "dark" period in the billion years following the Big Bang). This effort will test the standard cosmological model from the onset of structures forming in the universe. The telescope would also study radio emissions from coronal mass ejections (CMEs); monitor auroral radiation from the magnetic fields on Uranus and Neptune; detecting radio emission from other stars' CMEs as well as the magnetic fields of nearby potentially habitable planets; and monitoring radio transient objects such as Fast Radio Burst objects.

FarView will be made possible through two key technologies: a regolith processing facility (RPF) and vapor deposition technology. The RPF would use molten regolith electrolysis (MRE) to convert raw lunar regolith into metal and oxygen, which would then be refined as needed. The vapor deposition technology, which is an outgrowth of the Wake Shield Facility mission from the Space Shuttle era, would use the metals developed in the RPF to manufacture the dipole antennas and power cables.

FarView's 100,000 dipoles will be distributed in a sub-array architecture, meaning they will be established in a pattern of 150-200 clusters, each containing 500-650 antennas distributed across the 120 km² area. Construction will begin with the landing of the RPF and multiple manufacturing rovers. Additional RPFs and rovers will land in the future to reduce travel time, improve logistics, and improve system redundancy. The rovers will pick up aluminum ingots the RPF creates, drive to the subarray site, and begin manufacturing the antennas and related power cabling. Additional rovers will manufacture solar arrays and batteries for each subarray. The rovers will also serve as maintenance machines should a failure occur at one of the antennas. Polidan stated that an arrangement like this could enable FarView to operate for 50 years.

Despite the presence of less aluminum, more iron, and less solar radiation, Polidan believes that the MRE process also could be used to extract metals on Mars, though the solar arrays would need to be twice the size as the lunar units. Another advantage of building on Mars is that the atmosphere contains carbon dioxide, which makes obtaining oxygen easier. However, because Mars does have an atmosphere, the vapor deposition process would not work because it requires full vacuum to operate.

Long-term, Polidan sees the FarView system benefitting both scientific and engineering endeavors on the Moon. The telescope, out of sight from Earth's radio noise, will provide a new science window onto the universe. With it, we will be able to collect data on the pre-stellar universe and the first stars, along with radio and magnetic phenomena around other stars and exoplanets, as well as our own sun.

2.10 Deceleration of Interstellar Spacecraft Utilizing Antimatter – Gerald Jackson

Jackson proposes an alternative method for decelerating a “chipcraft” probe destined for Proxima Centauri, using antimatter-induced fission for propulsion and onboard electrical power. The proposed 10 kg dry mass probe would be decelerated into orbit around Proxima Centauri, eventually settling into orbit around Proxima b. After a 10-year burn, the acceleration stage is directed toward a fly-by through the inner Alpha Centauri binary solar system. Jackson sees a way to build support for the mission by integrating early science returns into the mission, akin to the Voyager probes visiting the outer planets before collecting data about the heliopause region of space 40 years later.

The key problem with taking along antimatter as a propellant is sublimation—the material just evaporates if left alone too long, even if contained. Jackson proposes solving this by coating an antihydrogen “snowball” with antilithium as well as a 1-micron-thick coating of aluminum. The problem with antimatter storage is that it is unstable in interstellar space. Galactic cosmic rays are considered to be the trigger. Using Jackson’s unique system, antiparticles would fly back and forth between the spherical antilithium surface and the titanium chamber wall. Using this approach, there would be a loop gain of (anti)particle production and the antimatter storage would be stable.

The voyage using Jackson’s system could last anywhere from 56 to 200 years, depending on the vehicle’s cruising speed (.0225 - .1 c), propulsion power (2.4-40 MW), and antimatter mass (35-590 grams).

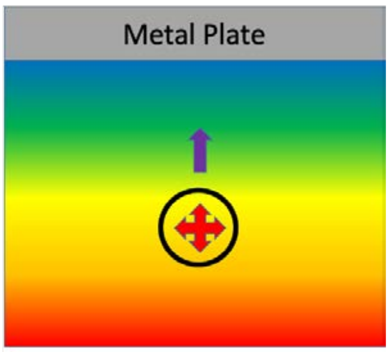
Stating that Voyager would not have been funded if the only mission was heliopause physics, Jackson believes that an exoplanet mission will need shorter-term goals to gain public approval and funding. One suggestion was to launch monthly Chipcraft Flybys to astronomical targets of interest within a 0.1 AU radius. Additionally, instead of accelerating the entire spacecraft, the initial goal was to emit and accelerate gram-scale chipcraft out to the Oort Cloud. Eventually Jackson’s team would like to build a 2-meter telescope with a mass less than half a kilogram. An initial test would be to develop a telescope with a primary mirror with a .3-meter diameter and a mass of .5 kg. One promising class of passive observations involve sensing plasma perturbations of the interstellar medium via long-wavelength electromagnetic emissions. Going forward, Jackson’s team sees early-mission results as the key to conducting decades of revolutionary astrophysical science.

On the antimatter production side, Jackson and his team hope to minimize project risk by experimentally proving storage steps with normal matter. This would mean starting with storage issues such as sublimation and levitation, which are inexpensive, then work up to more expensive studies such as a nucleosynthesis facility. The team also will continue studies of other mission capabilities and technologies, including communications, computing, navigation, and scientific instrumentation. This will all lead to a NIAC Phase II grant application to move the various parts of the project forward.

2.11 Using New Physics to Get to Alpha Centauri in a Human Lifetime – Mike McCulloch

In the process of identifying an alternative explanation for why galaxies do not fly apart given their rate of rotation, Dr Mike McCulloch has theorized a possible new method of in-space propulsion.

The theory McCulloch has articulated substitutes an alternative theory of inertia that he calls quantised inertia (QI), which he stated derives from the action of Unruh radiation at the quantum level. His theories state that when an object accelerates, for example to the right, a dynamical (Rindler) event horizon forms to its left, reducing the Unruh radiation on that side by a Rindler-scale Casimir effect, whereas the radiation on the other side is only slightly reduced by a Hubble-scale Casimir effect. This produces an imbalance in the radiation pressure on the object, and a net force that always opposes acceleration, like inertia.



McCulloch, M.E., 2018. Propellant-less propulsion from quantised inertia. Sp. Explor, 7, 3.

If this is so, then McCulloch believes that an object with high accelerations in it, shown as a circle in the image at right, sees Unruh waves (red). A metal plate above damps the Unruh waves (blue area). The object would then move down the Unruh Gradient – upwards. The end result being a reactionless propulsion method that would counter the force of gravity.

McCulloch is in the process of working on a grant from the US Department of Defense's Defense Advanced Research Projects Agency (DARPA) to make the measurements of QI more exact and to develop a method for showing whether it can, in fact, counteract gravity and serve as a form of reactionless thrust.

A team working with McCulloch has performed an experiment using laser light inside a loop of fibre-optic cable, which experiences Unruh waves. Damped by a metal plate below, the loop accelerates down the Unruh gradient (toward the plate). McCulloch stated that the observed force/power ratio was .08 Newtons per kilowatt of power, which is better performance than typical ion drives. This thrust could be enhanced up to 8 N/kW.

Employing a similar, much larger coil powered by a 100 kW SAFE-400 fission reactor, a 567-kilogram, 2-meter-long spacecraft with transmitter antenna could generate a propulsive force of 800 N, accelerating at 1/3 g for 3.7 years and achieving .5 c. McCulloch's QI spacecraft would be able to reach Proxima Centauri in 12 Earth years.

2.12 Controllable Mass Propellantless Propulsion Drive: a Gedankenexperiment – Matthew Gorban

Another mind-stretching, physics-bending alternative drive was presented by Matthew Gorban, a physics student from Baylor University. While offered as a Gedankenexperiment (thought experiment), Gorban's approach offered up an interesting alternative to direct propulsion.

Starting with the idea of a controllable-mass object (CMO) hanging on a spring, Gorban asked the audience to imagine this object achieving a high or low mass state depending on its position. Starting from a position in its high-mass configuration, the object would tend to move upward once changed to its lower-mass state. Then, when it reaches its highest vertical point, the CMO would switch to its higher-mass state until it reached the lowest extreme in its cycle.

Would such a system violate the conservation of momentum or the conservation of energy? Gorban says no. On the momentum side, the CMO's mass changes occurs at the extremum positions; the velocity is zero, but the mass can be changed. When it comes to the conservation of energy, mass change itself violates energy conservation except when energy is pumped into the system. Since energy is being added to the system, this system would not represent a "perpetual motion" machine.

Now imagine a two-ended spring, with CMOs on each end. On the forward end is a CMO at its higher-mass state and at the other a CMO at its lower-mass state. Starting from the point where the objects are at their maximum distances from each other, they are then released and allowed to compress toward each other, with the higher-mass object pulling the lower-mass object forward. When they reach their closest approach again, the forward object becomes the lower-mass object, with the heavier mass pushing it from behind. The net movement is in the original forward direction, causing the two-mass object to move through space akin to an inchworm.

How fast could such a system move? It would depend on the conditions of the spring between the two objects, preferably a long spring with a high spring constant and a large displacement. However, theoretically, you could move it past 500 m/s, which is the speed of Voyager 1.

Where will Gorban take this Gedankenexperiment? He will use the system to facilitate a quantum model, looking to change the effective mass of objects via the Casimir effect. It might be possible to increase the efficiency of the system using additional masses. It might be possible to develop enclosed CMOs, providing a spring system as a propulsion mechanism for a spacecraft. Gorban stated that he needs to rigorously address locality arguments regarding mass changing, answering such questions as: Does the mass change need to be a local effect? Can mass be exchanged between two CMOs at the extremum positions? And: Can mass be exchanged via a third-party (ie a spaceship)? As with any Gedankenexperiment, he gave the audience plenty to think about.

Day 3 September 26

3.1 Keynote: Avi Loeb

Like James Benford, Astrophysicist Avi Loeb thinks we're looking at the search for extraterrestrial intelligence incorrectly. He began his talk by saying, "When you're not ready to discover extraordinary things, you will never find them."

Given that about half of all sun-like stars host Earth-like planet in their habitable zone, Dr Loeb believes we need to embrace a little cosmic modesty, stating that there are more Earths in the universe than grains of sand on Earth.

He said that AI systems can behave as autonomous probes that outsmart us and can survive over a billion years of interstellar travel. 3D printing of copies can allow them to replicate. Over a billion years, they could populate all habitable planets in the Milky Way, including the Solar system. Given that possibility, Loeb believes we must search for equipment sent by other civilizations that preceded us. Believing that we shouldn't repeat the arrogance of intellectuals in Galileo's time, Loeb observed that, "Denying the possibility of other civilizations doesn't make them go away."

To forward the progress of SETI, Loeb has founded The Galileo Project (projects.iq.harvard.edu/galileo), which is designed to seek evidence of extraterrestrial artifacts. Among the objects the Project is seeking are alien telescopes, which could be circling Earth in polar orbit. A meter-size telescope could obtain megapixel-sized images of human-sized objects at a distance of a mile at the diffraction limit. The Project will also seek images of high-resolution, multi-detector unidentified aerial phenomena (UAP) to discover their nature. Loeb called for the scientific community to evaluate the evidence of the UAPs identified in the United States Defense Department's report on the subject.

As one of the astronomers who helped capture images of 'Oumuamua ("Scout" in Hawaiian), discovered October 19, 2017, Loeb was a bit disappointed by what he regarded as a bad artist's rendering of the object's shape. The light-curve modeling of 'Oumuamua suggested that it was a disc or cigar-shaped, but Loeb stated that a disc shape more likely. Given that the object seemed to generate no detectable outgassing or rocket-like effect nor any cometary tail; wasn't expected to be found; brightness changed by a factor of 10; generated no heat or infrared signature; and deviated from a Keplerian orbit, it is at least conceivable that it was artificial.

He also argued that many alternative explanations for 'Oumuamua's unique characteristics made no sense. It could not be a cloud of dust particles, for example, because a cloud could not maintain its integrity. It could not be an iceberg of molecular hydrogen: "We never saw hydrogen, but it would have evaporated." Nor could it be a nitrogen iceberg because there is not enough nitrogen in free space. Loeb concluded, "If it's something we've never seen before, we might as well consider the possibility that it's artificial." Along with space objects near Earth, Loeb suggested that we seek out industrial pollution, city lights, Dyson spheres, coherent light, or light sails near other stars, along with relics or megastructures. His hope is that finding the relics of more intelligent cultures would inspire us to ignore our small differences and co-operate as equal members of the human species.

3.2 Communications Challenges for the Exploration of Nearby Star Systems with Low Mass Probes – Philip Mauskopf

The Breakthrough Starshot (BTS) program was discussed multiple times during IRG. Dr Philip Mauskopf, is the program's principal investigator from Arizona State University. The concept of operations for the BTS is to launch a computer-chip-sized spacecraft attached to a sail powered by a ground-based array of lasers. Flying at a cruise speed .2 c, it is expected to reach Proxima Centauri within 20 years of launch. Mauskopf focused on the communication aspects of the mission: How do we get the data back?

The mission's main communication goal is for Earth to receive ~100 kilobyte images from 4.24 light-years away. The most likely tool would be optical (laser-based) communications, which soon will be demonstrated on NASA's Psyche mission. Some of the challenges include identifying a power source, making navigational and course corrections, and acquiring images during the system flyby.

As a point of comparison, NASA's New Horizons mission transmitted its Pluto flyby data from a distance of 30 AU (.005 light-years). The onboard transmitter was a 12-Watt X-band radio with 2.1-meter Cassegrain antenna, and data was received on Earth using a 70-meter Deep Space Network (DSN) antenna for 12 months at a data rate of 1 kilobits per second (kbps). Additionally, the closest approach New Horizons made to a planetary body was 15,000 km at a speed of .00004 c.

Starshot hopes to make its closest approach to a planetary body at less than 1 AU (depending on what they find) at a speed of .2 c and at a distance of 2.7e5 AU or 4.24 light-years. The intended downlink rate will be 0.1-10 bits per second and, like New Horizons, it is expected that it will take approximately one year to downlink at least one image from the flyby. The distance factor alone will mean that the signal strength and data rate will be 8 orders of magnitude lower than New Horizons. The key FOMs are signal-to-noise ratio (SNR) per kg and SNR per watt. Starshot requires an 8-9 order of magnitude communications improvement to be successful.

Another point of reference for Starshot communications is the Deep-Space Optical Communications (DSOC) on board Psyche mission. Mauskopf believes that it should be possible to get 250 Mbps data rate from Psyche. To meet Starshot's communication needs will require a 7-orders-of-magnitude improvement over DSOC. However, if changes are made across several parameters, it should be possible to make 7 to 11 orders of magnitude improvements over DSOC. Those parameters—and the potential orders-of-improvement—appear in the table at right.

Change in assumptions from DSOC to Starshot	Parameter	Orders of magnitude gained from DSOC to Starshot
DSOC estimate for bandwidth is conservative → Optimize signal encoding and detection	B = Bits per photon	1-3
Effective collecting area for DSOC is 10 m^2 → Design low cost 1 km x 1 km receiving station	A_{dishes}	4-5
Use 2.2 meter diameter light sail to direct the light towards vs. 0.22 meter DSOC aperture → Design transmitter optics	D_{sail}	2
Increase on-board power from 10 mW to 100 mW → Power generation/storage	P_{emit}	0-1 (extra)
Total		7-11

To achieve these goals, the Starshot team will need to develop and refine theoretical concepts and system designs for sending and receiving data transmissions from Alpha Centauri; develop and design subsystem components that meet Starshot's transmitter requirements for size, weight, and power; and develop and design subsystem components for a Starshot receiving station that meet cost and performance requirements.

3.3 On Moving Faster Than Light – Gabriele Rizzo

Physicist and futurist Gabriele Rizzo believes that faster-than-light propulsion—he used the Star Trek term "warp drive"—could be moving from a theoretical exercise to an engineering problem.

Rizzo emphasized that he was discussing moving faster than light, not traveling through space at those velocities. The goal would be to create a local distortion of space-time, as described by theorists like Alcubierre.

Computer simulations of space-time around a ship using warp drive are needed, he stated, but also that events inside the warp bubble cannot influence events outside of it. Therefore, there would not be any time-travel paradoxes of the sort seen in science fiction. On the downside, no communication signals can reach within the ship in the bubble and because the ship would be operating within event horizons, they would see a black wall if they looked outside.

What moves traveling by space-time distortions from theory to practice is recent work by Dr Erik Lentz at the University of Göttingen, who posited a new class of warp called a "soliton," which maintains its shape and moves at constant velocity. Such a warp, which would only imply positive energies (as opposed to "negative energy" theories suggested elsewhere), which could enable faster-than-light travel. Solitons' space-time configurations create space-time warps with metrics that obey a hyperbolic relation. This predictable configuration would enable it to be powered by conventional energy sources rather than sources with exotic negative energies [2].

Report by Joseph Meany joseph.meany@irg.space

Gabrielle Rizzo gave a rousing lecture on achieving faster-than-light (FTL) travel, akin to sci-fi "warp speed." Warp, otherwise referred to as a self-reinforcing curvature of spacetime, creates an isolated "bubble" which envelops the ship that moves through spacetime. Warp travel has long been one of the dreams of the astrophysical community, but remains largely relegated to theoretical discussions and does not share a strong spotlight with the other more concrete propulsion methods. Dr Rizzo addressed a number of issues plaguing the practical achievement of FTL travel, providing ways of analyzing the problem that Alcubierre's warp drive required negative energy to obtain the desired spacetime geometry and the creation of horizons around the payload. This horizon isolates objects within, and the shape of the bubble's horizon is dependent on the speed at which the bubble is moving within spacetime. Dr Rizzo did mention that the bubble could also move at "coordinate time" rather than in relativistic time. Recently, an article by Lentz in Classical and Quantum Gravity offers a novel construction to avoid resorting to negative energy, moving the warp drive problem from an existential, fundamental point to an engineering issue. Astronavigation must be plotted out ahead of time, akin to the "hyperdrive calculations" of the Millennium Falcon in Star Wars, since the isolation within the warp bubble also means that the craft is essentially sensor blind while travelling within warp. The trajectory of the warp bubble cannot be affected from within the warp bubble and cannot be steered reactively, but by modifying charges on the bubble the path is effectively steered. By overcoming the negative energy problem, it then makes sense to revisit some literature about FTL astronavigation, and investigating the use of warp bubbles also for subluminal travel and not just for superluminal speed.

[2] Additional source: www.eurekalert.org/news-releases/642756

3.4 Cryopreservation of Organisms in Space in Preparation for Interstellar Travel – Jekan Thangavelautham

Dr Thanga began his talk discussing humanity's motivations for leaving Earth, including extinction-level events such as volcanic eruptions, plagues, environmental disasters, and other planet-wide problems. Such events have pressed us to hope for or seek "Earth 2.0."

In talking about actual interplanetary and interstellar travel, Thanga stated the need to balance ethical and moral considerations for the people going. Human factors for the journey would include resources, mission/trip time, loss of mission, rigidness of laws/rules, reactions of future generations, and relativistic effects upon return. Interstellar ships, however, are vulnerable to any number of hazards. Limited resources could heighten tensions within the crew; civil disobedience could create problems; and there are always potential chaotic, unplanned situations that could occur. A human crew venturing to other solar systems will require biodiversity and medicine to survive. It is hard to separate humans from their surrounding ecology; how much biodiversity can we take with us? Cryogenics could slow aging and reduce consumables; however, it requires high-level robotics and artificial intelligence systems to monitor effectively.

An interstellar mission will require plenty of resources to keep the crew and passengers well fed. Generations may pass before reaching the destination, and younger generations might lose zeal for the mission. On the social side of things, shipboard rules that are too strict might lead to disobedience and civil strife while rules that are too lax could lead to splintering and social separation.

To address the long-term social and life-support issues, Thanga proposed developing a concept platform for testing the viability of cryo-preserved animals, plants and fungi cells in space and lunar environments. In addition to the long-term goal of interstellar travel, such long-term preservation also could be used to facilitate a "lunar ark" for preserving samples of Earth life as well as medical applications by helping us learn how to increase quality of life.

Thanga envisions the lunar ark as a global biodiversity repository on the Moon's lava tubes, which would remain untouched for 3-4 billion years. Such an "ark" would be more cost-effective than trying to protect all the endangered species any other way or creating an entire artificial ecosystem to keep them alive. The idea would be to save them until technologies advance enough to re-introduce the species. Thanga called it the biodiversity equivalent of a modern global insurance policy!

On the cryogenics front, cryo-preservation of individuals cells including eggs, sperm, and stem cells all might be necessary for interstellar travel. In theory, cold storage of life would be possible for decades or even hundreds of years. However, long-duration degradation is not well understood, though the technology is maturing. Simply freezing people or other life would cause ice crystals to damage them internally. Newer techniques use cryo-protectants, a form of an anti-freeze that fills in the internals of the body. Nevertheless, there is general agreement that large-scale, long-term application of this technology is daunting.

An alternative to cryogenic preservation would be to institute a state of torpor in the human body, which is similar to hibernation adapted to humans. The body temperature is brought down to 10°C, at which point the body slows down and operates with a very low metabolism. The technique is used in emergency rooms to save patients from crises for days.

In non-human cases, the Judean date palm was brought back from extinction, resurrected after 2,000 years, and an arctic flowering plant was resurrected after 32,000 years of hibernation. Cryo-frozen mouse sperm and eggs frozen on ISS for 6 years were returned to Earth, fertilized, and the offspring are now living healthily.

Torpor has several advantages for an interstellar mission. The spacecraft would not need to be as complex with the crew in hibernation for most of the journey. Humans operating at a low metabolism would produce savings in terms of consumables and onboard living space. Also, hibernation could be viable for years. However, the human crew would still age over the course of the journey, albeit more slowly. Also, the limit of using hibernation techniques like torpor would seem to be within 100 years. An alternative might be augmenting human beings to incorporate the capability of some sea creatures, which can keep their blood from freezing.

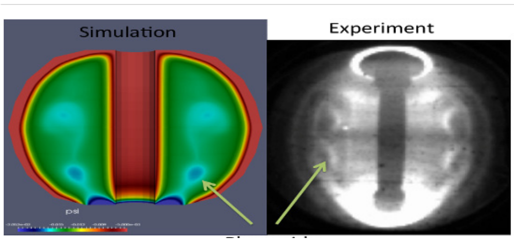
3.5 Reconnecting Plasmoid Propulsion – Fatima Ebrahimi

Focusing on speed and fuel efficiency as the key problems in interstellar travel, Dr Fatima Ebrahimi proposed another unique approach: the reconnecting plasmoid thruster, which accelerates plasma to the Alfven velocity in the same way the sun ejects solar flares when magnetic field lines reconnect, and the magnetic energy is converted to kinetic energy.

Ebrahimi's approach uses magnetic reconnection to create thrust (similarly to solar flares) and accelerate plasma to a high and scalable velocity, with specific impulse (ISP) up to 50,000 seconds. More importantly, she has conducted a proof-of-principle experiment at 10 MWe at the National Spherical Torus Experiment (NSTX), though only of short duration. She envisions such a system having large, continuous, and adjustable thrust in the range of a tenth to tens of newtons using a wide range of power sources, including solar, fission, or fusion systems.

The tests performed to date have involved passing plasma through a magnetic field. Passing the plasma physically through the field creates the same effect as magnetic field lines on the Sun twisting, bursting through the surface in a teardrop-shaped bubble until the magnetic field lines then reconnect, and the plasma (now called a plasmoid) left in the bubble is propelled outward.

According to Ebrahimi, the ISP potential for this plasmoid-type propulsion is high and highly scalable, from ~ 2,000 to 50,000 s and capable of generating thrusts from ~ 1 - 100 N using power levels from 0.1 to 10 MW.



In her experiment at NSTX, plasmoids formed and accelerated upward, which matched a magnetohydrodynamic computer simulation predicting the phenomenon. In a thruster configuration, the top will open to space to let the plasmoids escape. While these images serve as proof of principle, the team has not yet performed an experiment in a specifically propulsion-based environment.

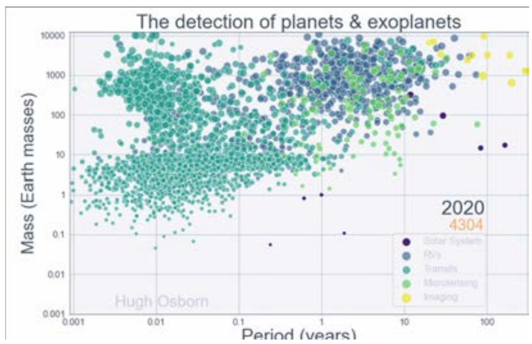
3.6 Understanding the Closest Worlds: Orbital Architectures of Exoplanets within 15 Parsecs – Jeremy Dietrich

Jeremy Dietrich, a PhD candidate at the University of Arizona, has taken a statistical approach to finding Earthlike worlds in other star systems. He noted that there are at present over 4,000 confirmed exoplanets and 86 systems within 15 parsecs of Sol. Even with 1,500 stars within that sphere, we are limited by what our current instruments can tell us. It is likely, Dietrich said, that many planets are still missing from our catalogue of known worlds. He believes we can study star systems as a population using statistics.

DYNAMITE, the program he developed for this purpose, provides integrated analysis of planetary systems by collecting specific, incomplete data; matching that data with statistical distributions and models gathered from exoplanet populations; making predictions for the presence and parameters of additional planets in a given system; and using the analysis as a model to guide follow-up observations and prioritize targets for characterization.

Given the information about the star systems known to date, he was able to remove a known planet from an observed system and have DYNAMITE predict the existence of that planet.

He has gone on to analyze other nearby stars as well. The model supports the likelihood of an unconfirmed planet around Proxima Centauri in a 5.68-day orbit along with an additional planet in the habitable zone. Tau Ceti has four known transiting planets, and the model predicts three more. GJ 667 c, an M-type star in a trinary system, hosts four confirmed planets, two in the habitable zone with the model predicting three more, one of them in the habitable zone. L98-59, an M dwarf with many close-in planets, could have an additional planet at the inner edge of the habitable zone. There are others.



In sum, while there are 86 exoplanet systems with 153 confirmed planets within 15 parsecs, there are a significant number of them in the temperate zone, meaning they are potentially habitable worlds. There are many intriguing exploration targets, and the more we learn, the better Dietrich's model will get at identifying the presence of other worlds as well.

3.7 The Interstellar Communication Relay (What if SETI Succeeds. Now What?) – Brian McConnell

Brian McConnell foresees the eventual development of—and need for—an online hub that would allow millions of people to access signals from confirmed extraterrestrial intelligence. The Search for Extraterrestrial Intelligence (SETI) has been mostly a small-scale effort, run at remote sites by subject matter experts and with limited connectivity to the outside world. Such will not always be the case once intelligent signals are confirmed.

Artificial radio signals could be recognized quickly or take time to confirm; however, optical SETI (OSETI) confirmation could occur very quickly due to a lack of interference with conventional radio frequencies. The initial phase of detection would be to rule out non-ET causes and then determine how the signal is encoded or modulated. The initial phase of confirmed SETI or OSETI communication would involve a small amount of data confined to the SMEs at first, who would be concerned with deciphering the message; a more distributed information analysis effort, focused on the meaning of the signal, would come later.

The information analysis phase would involve professional and citizen scientists across multiple disciplines. To support this sort of effort, McConnell says that a signal-sharing system would need to be scalable for millions of concurrent users; resistant to denial-of-service attacks; include a revision history; and have operating costs that scale with use. Several cloud-based services could meet these types of requirements, including Github and Amazon Web Services.

The Interstellar Communication Relay mentioned in the title of the presentation would be a scalable, cloud-based repository for data extracted from an ET signal or artifact. McConnell stated that such a relay would serve four types of user communities:

- Tier 0: signal processing experts, via on-site connectivity to receiving systems (eg, searching for weaker side carriers in the raw data)
- Tier 1: remote signal processing experts, working with reduced data products delivered via Internet (or sneaker net)
- Tier 2: information analysis, this is a data stream of states extracted via demodulation
- Tier 3: derived data products (eg, decoded images, etc)

However, sharing SETI or OSETI signals with the general public would not be without risks, McConnell cautioned. Passive SETI is widely assumed to be low risk compared to active messaging to extraterrestrial intelligences (METI). McConnell states that such contact could be highly disruptive to the culture, with con artists and cultists stepping in to create false narratives or alternative explanations for the “meaning” of the messages. The potential for fraud and misinformation is a good reason to have solid information infrastructure in place.

3.8 Power Generation from Interplanetary and Interstellar Plasma and Magnetic Fields – Geoffrey A Landis

Physicist and author Geoffrey Landis made two Zoom appearances at IRG. In this presentation he discussed a work developed with Matt Wetzel-Long about providing power for a Starshot-type, interstellar ship-on-a-chip probe. At present, no existing power sources meet the strict mass limit requirements.

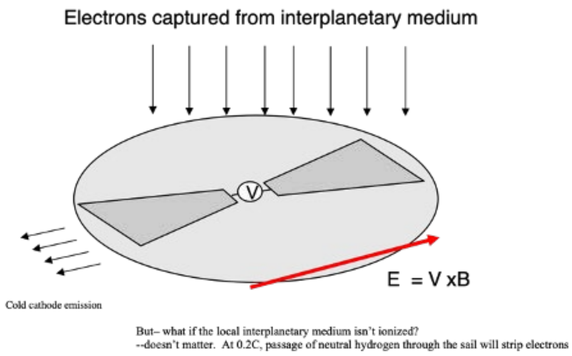
A baseline for the interstellar probe would include a 3-gram payload, a sail diameter of 4 meters, an acceleration of up to 15,000 g, cruise velocity up to .2 c, and a flight time of 20 years. The time spent within 1 AU of a target planet would be approximately 5,000 seconds. The authors set their arbitrary mass constraint for the power system at 1 gram, with a total energy output of around 300 kilojoules (kJ).

Electrical power required is needed to collect and transmit data back to Earth. Assuming laser/optical-based communications, the system would send a downlink of its data for up to one year after its flyby, though these requirements could change. The system could require higher peak power for brief periods, requiring the need for an ultra-efficient capacitor; however, the authors did not examine this possibility at this time. Landis did state that power level could be traded off against duration of use. Higher power for shorter duration would amount to 100 mW for 0.1 year, 1 W for 3.6 days, and so forth.

While many approaches to power are possible, weight is the critical figure of merit. The paper Wetzel and Landis pursued investigated generating power by passing through the plasma and magnetic environment of the target star at relativistic speeds. Since the speed is very high, power can be generated even at relatively low magnetic fields.

Voltage induced by passing through a magnetic field generates power from the motion of the spacecraft through the target star's environment. Using the magnetic field of the target star, power can be generated by the vxB potential of the spacecraft's movement in the star's magnetic field. This is similar to the "electrodynamic tether" tested by the Space Shuttle in the 1980s. However, for this to work, the current loop must be closed. In this case, the current must be closed through the ambient plasma. This could be done using the potential difference induced by the sail moving through the heliospheric (and interstellar) magnetic fields (HMF and IMF).

Movement through the HMF can be modeled using the Parker spiral theory, which states that a star's magnetic field would be configured as a spiral as it switches from north to south, rotates, and expands outward into the surrounding solar system. The sail would encounter different bands of the spiral as it passes through the system. In a similar manner, the sail could obtain power during its cruise through the ambient interstellar medium, which is primarily neutral and ionized hydrogen, with a few percent helium.



Landis and Wetzel concluded that harvesting energy during passage through the Proxima Centauri system is particularly difficult. Partly this is because Proxima is such a dim star and partly because the sailcraft would pass through the system (and magnetic field) in minutes, making it hard to generate power fast enough. Additionally, stars change: they have magnetic and plasma events making their magnetic field inconstant, and Proxima Centauri has orders-of-magnitude changes in its magnetic field. The best approach might be to pick a different (more sunlike) target star.

3.9 Alpha Centauri: Getting There – and What to Expect When We Do – S Pete Worden

Former NASA Ames Research Center Director and now Chairman of the Breakthrough Initiatives, S Pete Worden provided a status on the organization's projects, including the Breakthrough Starshot.

The Breakthrough Initiatives offer the world's largest science prizes: $3 million each. Often called "The Oscars of Science," the organization has given prizes to eminent scientists such as Jocelyn Bell-Burnell, who first discovered pulsars in 1967.

In 2015, Breakthrough Initiatives board member Yuri Milner announced the funding of the Breakthrough Initiatives, which are designed to investigate the presence of life in the universe. Among the questions the initiative will seek to answer are:

• Is there intelligent life elsewhere?

• Is there any other life in the universe?

• Can we travel between the stars?

The Breakthrough Listen program will be seeking technosignatures using space and ground systems. The group is also partnering with the 500-meter Aperture Spherical Radio Telescope (FAST) in China; the MeerKAT array in South Africa; and the Parkes Observatory in Australia.

One signal passed the initiative's basic test as a possible alien technosignature. However, the signal then drifted and disappeared. It took 2-3 weeks before the story was leaked to the media. Even so, the Breakthrough organization was able to test all of its analysis and outreach procedures.

The Breakthrough Watch initiative aims to identify and characterize Earth-sized, rocky planets around Alpha Centauri and other stars within 20 light years of Earth, seeking oxygen and other "biosignatures." That work is being conducted by the Very Large Telescope and Extremely Large Telescope in Chile. So far, they have detected a giant planet around Alpha Centauri A.

Breakthrough Starshot, of course, is the project to send a 1-gram "ship on a chip" via laser-powered sail to Alpha Centauri at .2 c to determine if there are life-bearing planets in that system. This is achievable, Worden said. There are already "chip sats" orbiting Earth. However, the laser array is a big challenge: how do you build 200 GW array for $10 billion? The current power requirements for the Starshot chip-ship are 14 kJ at 20 milliwatts, with a 1 W peak. These needs are driven by communications: 100 kbits sent during the year after encounter.

Breakthrough is also interested in where else life could be in our solar system. They have completed a study to go to Venus in 2023, where some biogenic gases have been detected.

Worden concluded on a positive note: "In 50 years, we might have our first image of another world."

3.10 Bussard's Fusion Ramjet: the Impossible Dream – Geoffrey Landis

Dr Landis's second presentation discussed the likely downsides of a staple of science fiction novels: the Bussard ramjet. This hypothetical spacecraft invented by physicist Robert Bussard would use a magnetic scoop to funnel interstellar hydrogen into a fusion reactor for propulsion.

Noting that we need interstellar flight shorter than centuries, fusion is the obvious choice for providing power. Deuterium fused with tritium would generate 4 atoms of helium plus a neutron, with .375% of the rest mass converted to energy. Such an approach could work; however, tritium is radioactive, the thrust output is slow (.087 c), and at present we can't do controlled fusion.

Another problem with the Bussard approach is that even though the fuel is free, you couldn't accelerate forever due to material limitations of the scoop. The scoop itself could not be material; it would need to consist of electromagnetic fields. Bussard also calculated the availability of interstellar hydrogen to be ~0.001-.05 hydrogen ions per cubic centimeter. The actual numbers, however, have turned out to be 4-6 orders of magnitude worse.

Fuel, however, turns out to be the least-important problem, in Landis's view. For one thing, there are no known or projected fusion methods that use hydrogen atoms as fuel. Also, fusion must occur in milliseconds as atoms pass through the throat. The ramjet would be collecting charged particles that can't be slowed down.

An alternative would be put the fuel on a "runway" of fuel pellets launched ahead of the spacecraft before flight. The "runway" of fuel pellets could be deployed by a dedicated craft that drops fuel pellets at predetermined locations along the flight path. Each fuel pellet would contain the fusion fuel and locator beacons. The fuel pellets would require a small amount of propulsion capability as well to maintain a predetermined location.

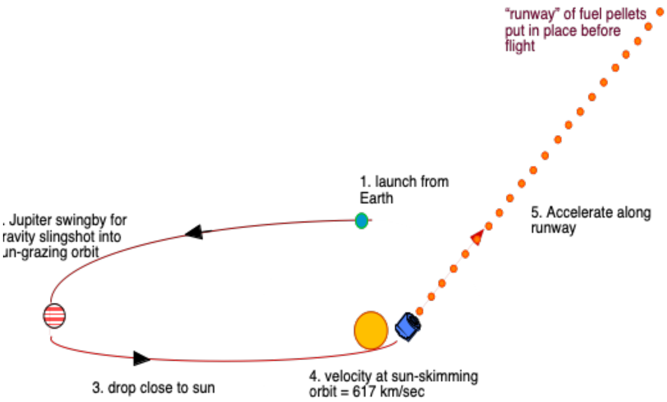
Another option, proposed by physicist Jordin Kare, would be "impact fusion," where the vehicle acquires fuel pellets on the "runway," then uses impact fusion. Fusion could be achieved at the temperatures produced by impact at interstellar velocities. If a small pellet carried on the vehicle impacts a pellet of fusion fuel, the impact releases enough energy to ignite a fusion reaction. The vehicle thus achieves high net thrust through a series of successive microexplosions.

Of course even this approach to a Bussard-type starcraft is not without problems. What is the actual impact fusion threshold? What is its fuel? How do you start the vehicle, given that it needs to be moving at high speed to collect hydrogen? How do you navigate to ensure that the pellet streams achieve a centered impact when closing at hundreds of kilometers per second? While Kare suggested impact fusion could occur at 200 km/second, this number is optimistic, as it assumes the fusion particles are already compressed by lasers or other methods. The current target temperature of deuterium-tritium fusion research to achieve a thermalized plasma is ~4500 eV per particle, corresponding to 657 km/sec.

Landis believes it would be better to use a proton/boron fusion reaction, as proposed for terrestrial applications. While it is roughly six times harder to ignite than DT fusion, boron requires lower energy per unit mass. The fuel also could be diborane, B2H6, which is liquid at slight pressure. D-T or D-^{3}He would work, but they requires a cryo-cooler for the pellets.

Boron is an easily stored fuel in the form of frozen boron hydride ("borane"), unlike the cryogenic storage needed for liquid deuterium and tritium (or the even lower temperatures for liquid deuterium and helium). The resulting exhaust product is charged, allowing it to be confined and directed with a magnetic nozzle. This reaction is more difficult to ignite than the D-T reaction typically proposed for terrestrial fusion. Since boron has a charge +5, the Coulomb barrier is approximately five times as high, requiring five times the energy to ignite. However, since boron is 11 times more massive than hydrogen, the boron atoms carry 11 times more energy than hydrogen atoms at the same velocity. This means that the impact fusion threshold is only slight increased over D-T. This produces an exhaust velocity capable of bringing the vehicle to 4.5% of the speed of light…if everything ran perfectly.

The impact propulsion method requires the ship reaches a speed greater than the minimum impact-fusion ignition velocity before thrust can initiate. Kare proposed starting the ship using electromagnetic acceleration ("rail gun") of fusion fuel packages into a stationary ship, but this is problematic. More reasonably, according to Landis, the ship and the pellets each have half the initiation velocity and travel in opposite directions. This can be accomplished with a clever trajectory design using conventional means.



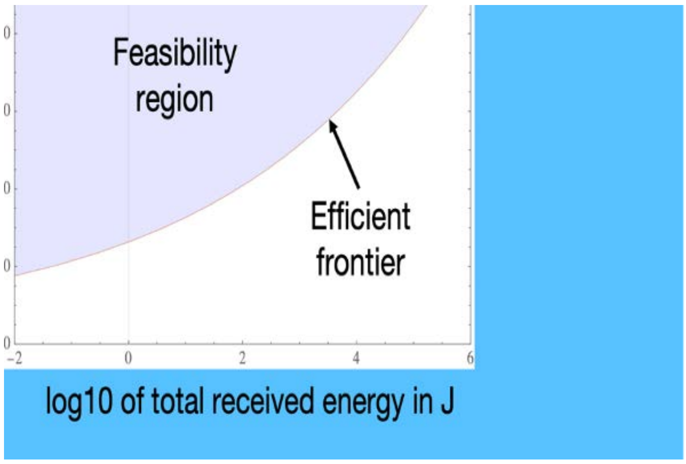
A gravitational slingshot by Jupiter would put a pellet-dispensing spacecraft in a highly-elliptical heliocentric orbit that would pre-position the stream of pellets. This can be accomplished with conventional chemical propulsion. The spacecraft itself then follows the same orbit around the sun, but in the opposite direction, resulting in a relative velocity of double the escape velocity at the that solar distance.

The peak velocity of a sun-skimming orbit would be close to solar escape velocity, 617 km/sec. By impacting the vehicle traveling the opposite direction, the pellets would yield a relative velocity of 1,234 km/sec, well above the assumed 657 km/s impact fusion threshold. Once the reaction is ignited, the spacecraft accelerates into the pre-emplaced pellet stream and out of the solar system. Bussard's interstellar ramscoop, then, is not utterly a dream, but much more difficult than originally conceived.

3.11 Mass and Propulsion Implications for Interstellar Scientific Observation by Flyby – David G Messerschmitt

In an effort to maximize scientific return and ensure crew safety on interstellar missions, Dr David Messerschmitt and his collaborators are looking at ways to optimize missions by type, contrasting between launch/landing missions and flybys. They determined that launch-landing missions, incorporating actual surface landings, need to maximize spacecraft speed while flyby missions need to be slowed somewhat to maximize data collection. While most speakers at IRG focused on maximizing speed, Messerschmitt said that it's important to look at stakeholder wants and needs, catalogue assumptions, and perhaps learn that we don't need to go nearly so fast.

The team assumed that flyby missions have a science principal investigator (PI) that cares about speed of data return but doesn't necessarily care about the probe's speed. Mapping data latency (time from launch before all data is received) against the log of energy required, Messerschmitt identified a realm he calls the "feasibility region."



The feasibility region has a lower boundary: the "efficient frontier," along which the mission is doing the best job for the PI. The goal is to have the lowest latency for given energy, or conversely, the maximum energy for a given latency. Different missions have different requirements. The "efficient frontier" assumes a fixed probe mass and speed.

Messerschmitt foresees the very first interstellar probe as being an engineering evaluation. That sort of mission we would want back as soon as possible, with not a lot of data expectations attached to it. On later missions, incorporating more complex instrumentation with lots of data coming back, mission planners would be willing to accept longer latency.

Another alternative to optimizing power would be to vary the transmission time; however, by transmitting longer the vehicle touches the efficient frontier only once. Beyond the efficient frontier, the probe can't transmit as much because data loss increases with distance. If the vehicle moves to higher mass, the probe slows down and the curve moves up and to the right. If we want more data back, we should increase mass and reduce the vehicle's speed. Latency increases as a ¼ power of the mass. As the curve moves to the right due to higher data rate, the loss rate goes down over time because the probe is moving slower. Messerschmitt assumes that transmission time will be 1/10 travel time.

The key takeaways from this analysis of flyby missions were: to increase received energy (data volume) with a minimum impact on latency, the probe should be slowed; a slower probe also benefits scientific data collection; a higher-mass probe is easier to design and fabricate; an efficient mission means that transmission time is 1/10 travel time; and increased received energy or launch energy bring with them strong economies of scale. In the end, a flyby mission benefits from a somewhat slower probe.

3.12 Dynamic Soaring as a Means to Exceed the Solar Wind Speed – Andrew Higgins

(postponed to P36)

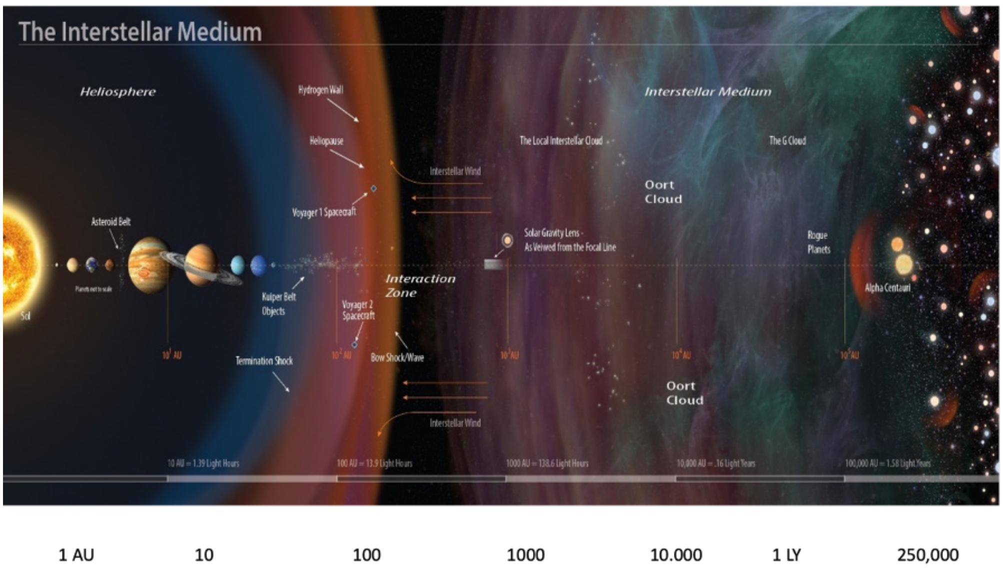
3.13 Visiting an Exoplanet – Louis Friedman

Planetary Society founder Louis Friedman addressed some of the challenges involved in reaching and studying an exoplanet. On the plus side, there are probably billions of exoplanets in our galaxy, many of which are potentially habitable or in the "habitable zone." One of those planets is within 10 light-years of Earth, 11 with 20 light-years, and 23 within 50 light-years, according to the NASA Habitable Exoplanet Catalog. In short, there is lots of exploration to be done.

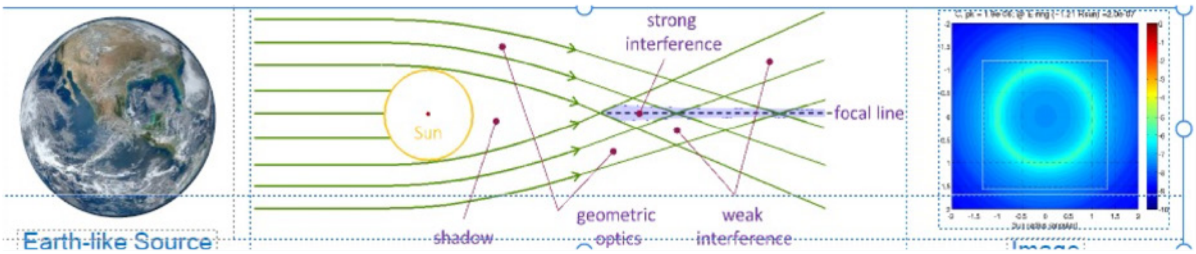
The key point of using all this engineering, said Friedman, is to search for life. We might go there virtually or actually go ourselves. To do so with people right now is currently "a bridge too far," according to Friedman, because practical interstellar flight requires massive amounts of external energy. Even the Breakthrough Starshot requires 200 gigawatts to launch 1 gram within 20 years or 1 kilogram within 100 years…and that is merely to the closest star. To do interstellar travel on a large scale will require decades of technology, financial, and social development.

To travel there virtually would mean using telescopes with high-resolution images, which is more realistic. The largest telescope (10.4 m) yields 1.5-million-mile resolution for Alpha Centauri. A 90-kilometer-diameter telescope would provide a 1-pixel view of a terrestrial planet 30 parsecs away. Magnifying an exoplanet using a 2-meter telescope at the solar gravity lens point 600-900 astronomical units away would increase resolution 100 billion times, offering kilometer-scale resolution of planets within 50 light-years.

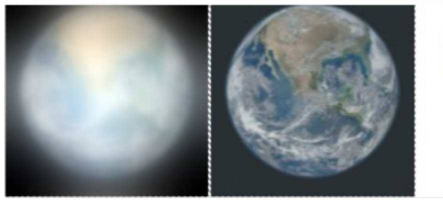
Therefore, according to Friedman, the only practical means to get multi-pixel, kilometer scale images of a likely habitable or inhabited world is using the solar gravity lens.



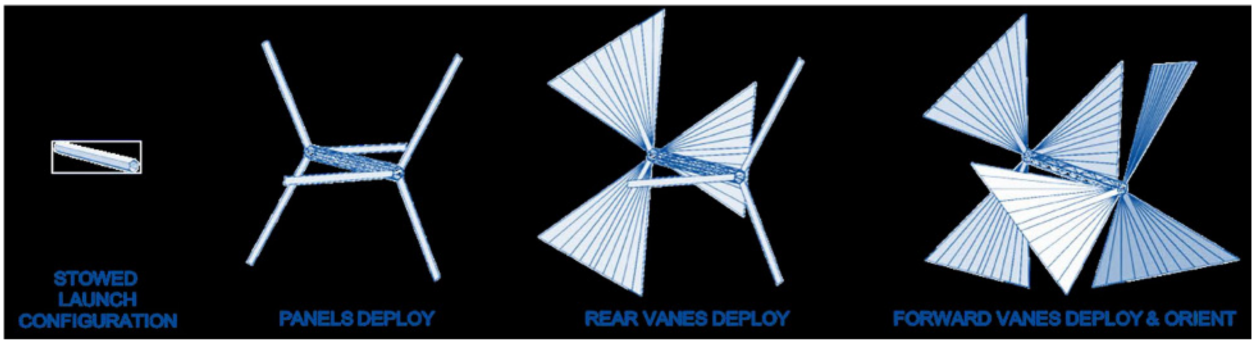
Just getting to the solar gravity lens (SGL) point will be difficult, and that is 1/500th of the way to Alpha Centauri—still longer than anywhere we’ve been so far.



S. Turyshev, NIAC Phase I, II, III Study of Direct Multi-Pixel Imaging Using the Solar Gravity Lens



The SGL focal line extends outward from 547 AU. To reach that distance with practical missions requires achieving velocities of greater than 20 AU per year. Unless we use nuclear or ultra-close solar flybys, a solar sail-propelled microsat would need to have less than 100 kg mass. Solar sails, Friedman believes, are more feasible than nuclear propulsion or a chemically powered “sundiver” vehicle.



L-Garde Smart Space Technology is developing a solar-sail spacecraft design with multiple sails that can be packaged on a smallsat. The individual vanes provide a lot of control capability. The spacecraft could ride share on an existing mission. Its mission trajectory would take it spiraling inward toward the Sun, then deploying its sails/vanes and using the Sun’s close proximity to propel it outward at a velocity of 20 AU per year.

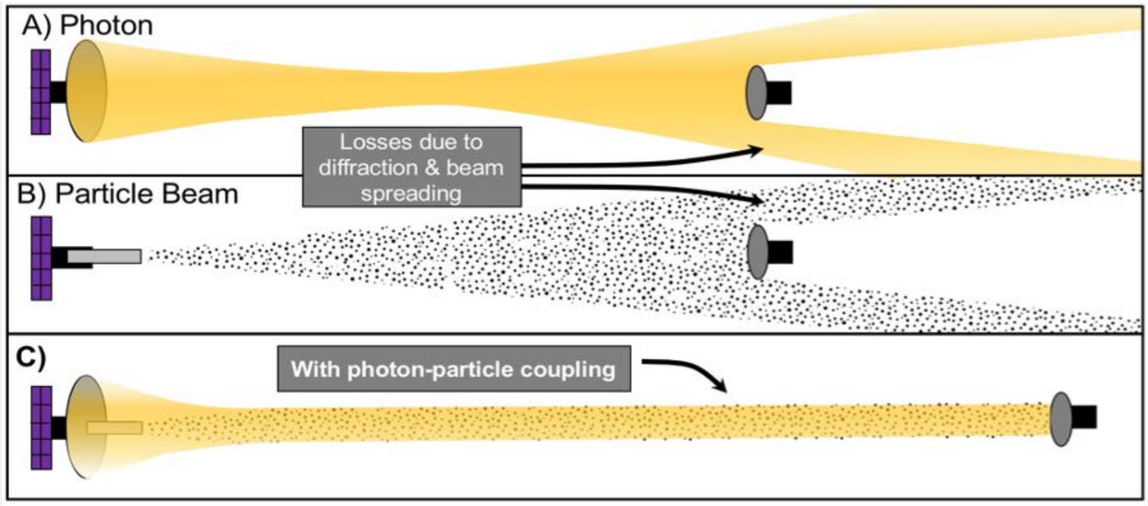
There could be a smaller test mission first, to test out the technology. That mission would travel at only 6 AU/year, but it would still fly faster than Voyager 1. The goal of that first mission would be to prove the “sundiving” maneuver; future missions would improve performance and add science payloads. Once the ability to fly to SGL distances is proven, Friedman said that similar methods could be used to fly interstellar missions.

3.14 Phenomenology and Capabilities of Mutually Guided Laser and Neutral Particle Beams for Deep Space Propulsion – Chris Limbach

Researchers at Stanford and Texas A&M University led by Dr Chris Limbach are looking at yet another unique propulsion concept under NIAC grants: a combined laser and neutral particle beam for propelling a sailcraft. The team is developing the interaction between the two types of beams and tailoring that interaction to enable them to do more.

The advantages of a combined laser/particle beam include a small transmitter size (1 m^2 vs more than 10^6 m^2 for the proposed Breakthrough Starshot program); the ability to maintain long acceleration distance, on the order of .1 AU; and high thrust-to-power efficiency. The challenges to this technology include a complex design, both for the transmitter and the spacecraft; locating the particle beam in space; and the feasibility of the mission requirements.

Using a process called photon-particle coupling, the particles would be used as an optical wave guide while the laser envelops the particle beam.



One key problem with both lasers and particle beams is diffraction or scattering when encountering other objects or particles. However, diffraction is inevitable, even in vacuum. The team is working on a smaller transmitter and more focused beam that would provide a higher thrust-to-power ratio capable of accelerating a 1 kg sail .5 AU in an hour.

The combined technologies exploit resonant characteristics of the laser material, performing “particle trapping” through optical forces. Using ultra-low-temperature physics, the team discovered that particles were intensified and trapped by the beam when their thermal energy was less than the potential depth of the laser’s wavelength.

In essence, the team discovered a new laser-based, kinetic damping mechanism that could play a role in stabilizing beam propagation through vacuum, resulting in key dimensionless beam parameters being identified: η, V^2, τ, all of which influence stability of co-propagation. The team also developed a physical model for high-fidelity simulations for beam propagation across millions of kilometers. They observed more than four times the expected propagation vs diffraction. Dynamical heating seems to be the primary limitation to this technology. The team needs to investigate further a variety of initial conditions to achieve >100x improvement.

4 September 27, 2021

4.1 Keynote: Mark Shelhamer, ScD

Keynote speaker for the final day of the conference was Mark Shelhamer, Sc.D. Johns Hopkins University and Chief Scientist for NASA’s Human Research Program (HRP) from 2013 to 2016. Addressing human factors, Shelhamer discussed known risks, troubling trends, and key areas for research.

Shelhamer noted that few of the IRG talks considered the human element in missions. He said: “You ignore the human element at your peril. You can debate whether you’ll send people or robotic probes, but if it’s important to send people, you have to figure out how to accommodate them so they can do their jobs. But people also become part of the system when they encounter anomalies. People shouldn’t be an afterthought. They can take care of unforeseen circumstances.”

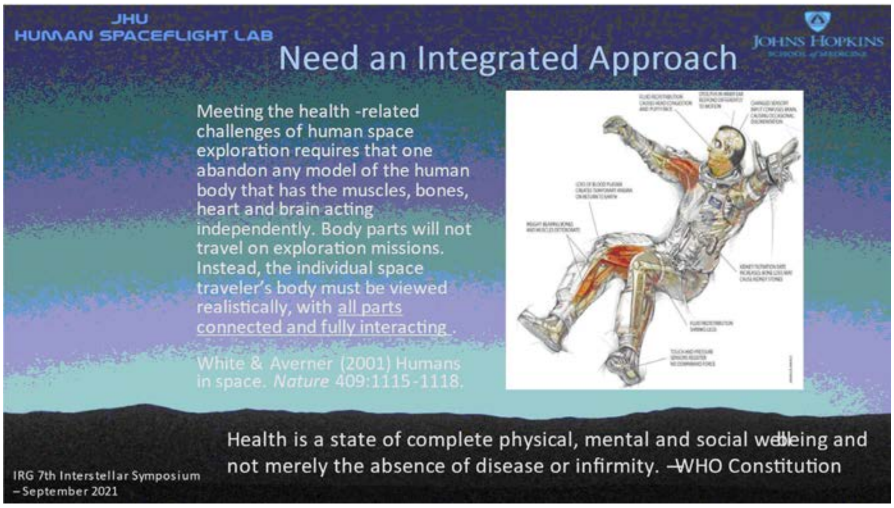
Known risks to humans in space include altered gravity and related physiological changes; distance from home and associated implications for medical care; hostile environment outside and closed environment inside with accompanying problems such as CO2 levels and inadequate nutrition; isolation and confinement issues like sleep disorders and team dynamics; and space radiation.

Troubling trends observed during and after International Space Station (ISS) missions include kidney stones; human-system interaction challenges; immune function changes related to T-cell function and cytokine profile along with latent herpes virus reactivation; gut microbiome alterations; sleep disorders; heart arrhythmia; and even the potential for behavioral emergencies. And radiation-related problems, Shelhamer said, were “a mess,” meaning NASA doesn’t have ways to cope with them yet. However, NASA has never had to cancel a mission or deal with major medical issues due to radiation.

Longer missions, with increasing independence from Earth, will involve more on-site medical care. For a three-year mission to Mars, on-site would be the only care available. Longer missions mean limited resources (for example, constraints related to mass, power, volume, medical expertise, and shelf life of pharmaceuticals and consumables); absence of ground support; limited information and time pressure when dealing with medical emergencies; and the increased importance of recognising early warning signs of potentially serious medical conditions.

HRP involves, in part, looking at the soft, squishy, intangibles in a hardware-centric, technocratic environment. Many risks must be tracked based on likelihood and consequence.

Take, for example, potential for behavioral issues. When a group of astronauts had their attitudes tracked in journals, the entries revealed an increase in crew conflicts and a decrease in positive attitude by mission quarter. Because we lack sufficient analogs in isolated, confined environments, it’s difficult to determine whether these findings are significant. In any case, there are some troubling indications regarding personal interactions:



NASA Bioastronautics Roadmap (defunct)

Serious interpersonal conflicts have occurred in space flight. The failure of flight crews to co-operate and work effectively with each other or with flight controllers has been a periodic problem in both US and Russian space flight programs. Interpersonal distrust, dislike, misunderstanding, and poor communication have led to potentially dangerous situations, such as crewmembers refusing to speak to one another during critical operations, or withdrawing from voice communications with ground controllers.

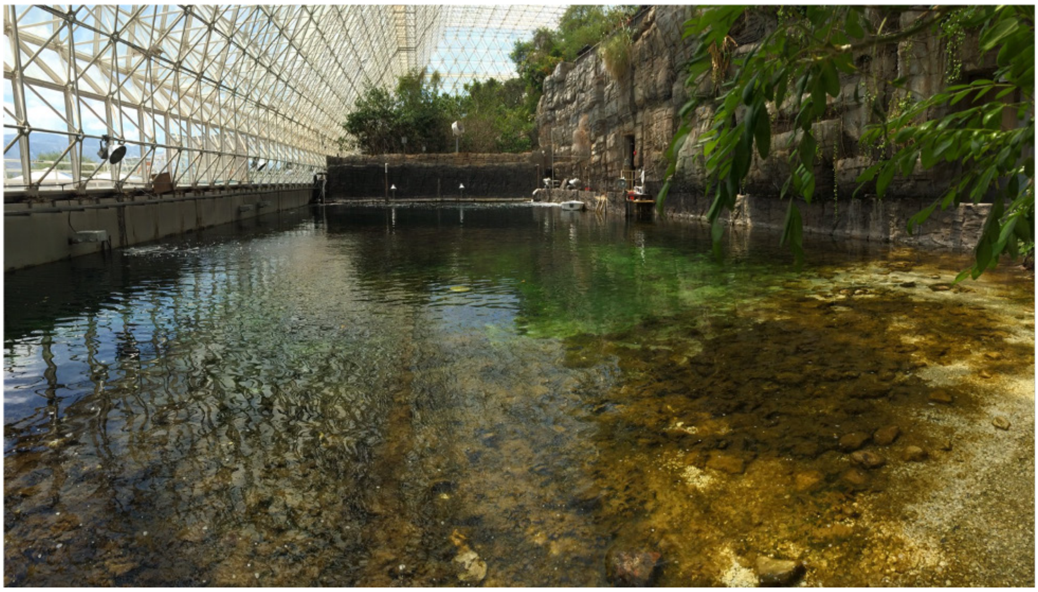
Bottom line: long-duration space missions will require an integrated approach to crew health.

Shelhamer emphasised the need for an integrated approach to HRP, taking into account the interactions of systems within the human body, among crewmembers, and between crews and mission control. Hopefully, Shelhamer concluded, we can draw on insights from complex network theory. “We need more research on mission resilience.”

4.2 SAM: Construction of a High-Fidelity Hermetically Sealed Mars Habitat Analog at Biosphere 2 – Kai Staats

Kim Staats is the Director of SAM (Space Analog for the Moon and Mars) at the Biosphere 2 facility, which is now run by the University of Arizona. SAM will study human factors, along with bioregenerative life-support systems.

Biosphere 2 remains the world's largest indoor ecological experiment. The SAM study will be conducted in a smaller facility on the property where the concept of bioregenerative life-support was first tested. Staats said that analog studies affect how we prepare for becoming interplanetary or interstellar travelers. There have, in fact, been quite a few of them, from Antarctica to Hawaii to Russia.



The SAM simulation started in January 2021 after an extensive refurbishment. While Staats stated that, "We're not going to have greenhouses on the surface on Mars," he did note that the team doing the refurbishments changed the lighting and transparency of the greenhouse windows to match Mars conditions. The team of volunteers replaced the greenhouse's air handlers and rebuilt the artificial "lung" that modulates air pressure. The "Mars yard" for the facility will be over half an acre (2,023 m^2).

Shipping containers will be used as crew living space. The first sealed test of the revitalized structure began on June 29, during which the team monitored oxygen, temperature, and pressure within the habitat. Participants in the project will also undergo "space" training in a neutral buoyancy lab and gravity offset rig.

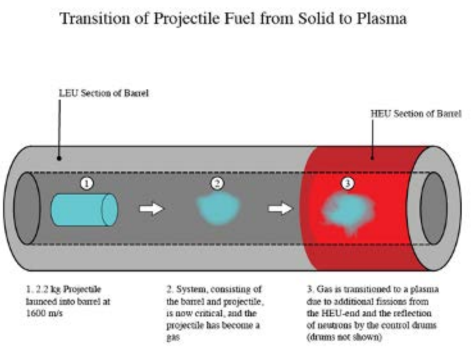
The SAM activity also ties into SIMOC, the Scalable, Interactive Model of an Off-World Community, which is an online learning simulation of an off-world habitat using bioregenerative life-support systems (simoc.space). The intention is to integrate SAM data into SIMOC as part of a live data feed. The team is also looking to build an artificial intelligence system to manage plant growth.

The principal science objectives at SAM will be to transition from physicochemical (machine-based) to bioregeneration (plant-based) life support systems; transform simulated regolith into soil; conduct a study of the microbiome of the built environment; test pressurized suits in entry, exit, and EVAs in a half-acre Mars yard, complete with boulder field and lava tube; and conduct advanced computer models and simulation.

There will be more to come after the restoration of the test module (January-June 2021). Crew Quarters, the initial Mars Yard, and Mission Control Center will be constructed from October 2021 through March 2022, with the first research teams entering in May 2022. In the last half of 2022, the team will have completed a covered 6,400 sq-ft scaled Mars crater, gravity off-set rig, synthetic lava tube, miniature Neutral Buoyancy Lab, and half-acre (2,023 m^2) outdoor Mars yard. Finally, in 2023, the team will develop astronaut training courses and curricula.

4.3 Pulsed Plasma Rocket – Developing a Dynamic Fission Process for High Specific Impulse and High Thrust Propulsion – Troy Howe

Troy Howe from Howe Industries LLC discussed his pulsed plasma rocket (PPR), which is being developed under NASA's NIAC program. Similar to the 1960s Orion program, the PPR uses thermonuclear explosions to propel a spacecraft with extremely high performance characteristics. The propulsive blasts are controlled neutronically, not with explosives or other implosion. Instead, it operates by firing a moderated High-Assay Low-Enriched Uranium (HALEU) projectile through an unmoderated HALEU barrel. The projectile and barrel together form a critical assembly, but only the projectile turns into a plasma. Rotating drums within the barrel can raise or lower the criticality of the HALEU. The PPR is designed to provide 5,000 seconds ISP and 100,000 N thrust, delivering a 18,500 kg payload to Mars on a 106-day round trip and a 20-day stay on the surface.



When operating, the PPR employs a moving wave of neutrons, which follows the projectile but distributes over the length of the barrel.

An HEU sleeve at the end of the barrel supports fast expansion from gas to plasma, while a control drum pulse flashes at the end of transit to support fast expansion from gas to plasma.

Howe stated that it is important to keep the barrel from melting, as peak heat generation moves along the barrel with the projectile. Barrel mass is significantly greater than projectile mass, and the time between firings (1 Hz) allows for active cooling. Photonic interactions between plasma and barrel are mitigated by a cooled sapphire shield. Contact between plasma and barrel is avoided by rapid ionization and capture by the nozzle.

Strong electric currents circulate through cooled copper wires within the nozzle to create a magnetic field. Ionized plasma particles get trapped along field lines, with the nozzle's geometry favoring ions moving outward, away from the ship.

Once deployed, a projectile is accelerated up to 1.6 km/s using an electromagnetic launcher. The fission process raises the projectile's temperature to 1 eV. Electrical power is reclaimed from heat in the barrel, with an active cooling system transporting heat to a conversion system. The PPR can produce electrical power even when not firing because the drums can drive the barrel to achieve critical mass. The average power generation when firing is 201 MW, with the average power usage being 5 MW when the unit is firing.

Howe stated that this system cannot get to another star, but it could improve performance. A PPR-powered kick stage could get a vehicle up to 51 km/s for solar system departure or the system could be developed for a generation ship.

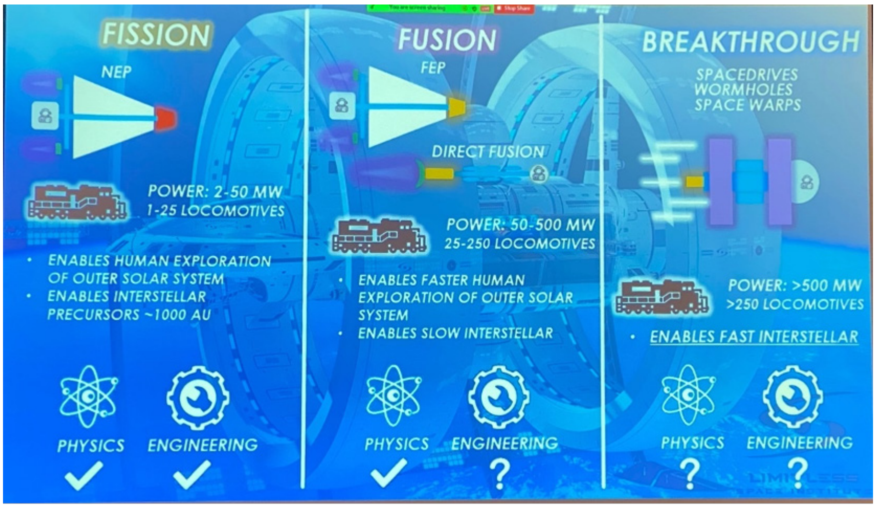
4.4 LSI Overview and Eagleworks Research and Development Activities – Harold "Sonny" White

The Limitless Space Institute (LSI) is a nonprofit educational organization focused on funding research and development for interstellar travel. They also conduct university partnerships, student programs, and educational outreach to facilitate those ends. Harold "Sonny" White is director of LSI's Advanced R&D.

White acknowledged that LSI is a little ahead of the curve when it comes to developments in human spaceflight, as we are just now trying to get humans back to the Moon and on to Mars. To get to other stars will require incredibly fast velocities and significant advancements in power and propulsion.

A space architecture based on nuclear electric propulsion would enable human exploration of the outer solar system as well as interstellar precursor missions out to 1,000 AU. Fusion-based power would enable faster human exploration of the outer solar system and slow interstellar missions. What is needed for fast interstellar transport are "breakthrough" technologies, akin to space drives, worm holes, "space warps," and other exotic propulsion systems.

White shared some of LSI's partners, which include DARPA, Massachusetts Institute of Technology, CalTech, Axiom Space, University of Alabama in Huntsville, Frankfurt Institute for Advanced Studies, UC Davis, and others. LSI has funded studies into dynamic vacuum research, which is exploring the implications of the dynamic vacuum model, in terms of power, increased negative vacuum energy density, communications and sensors, and thrusters.

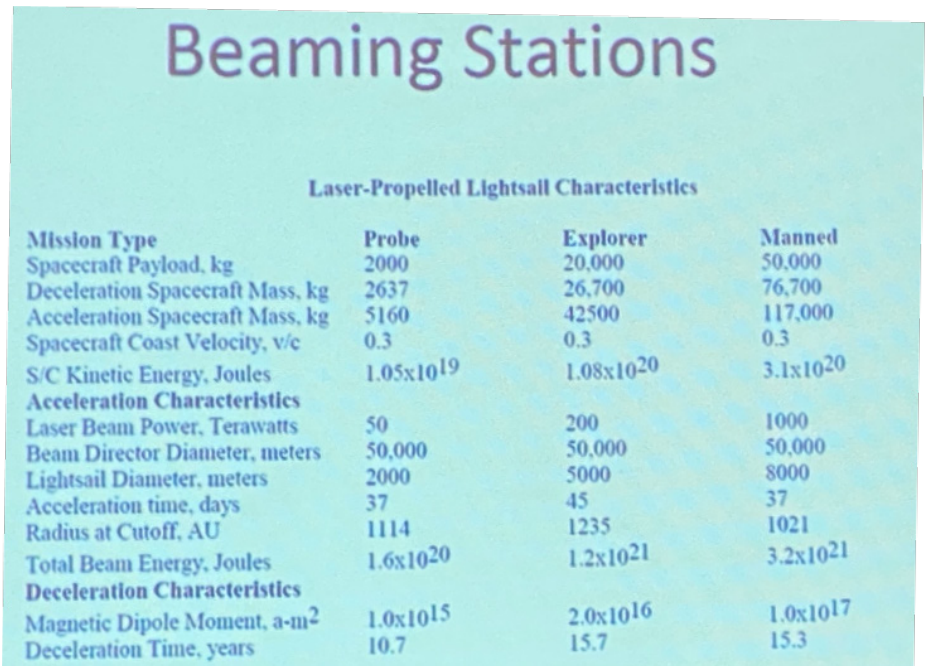


LSI has two award categories for its Interstellar Initiative Grants, each with a ~12 month period of performance: the Tactical grant has a primarily theoretical focus and will issue grants for up to $100k; the Strategic grant incorporates empirical objectives and will issue grants for up to $250k. Awards were announced on September 1, with the funded topics including: beamed energy propulsion; origami photonic crystal sail fabrication and test (maintain reflectivity of solar sail); four fusion propulsion projects; two space drive projects; and mathematics of traversable wormholes. LSI wants to issue its Interstellar Initiative Grants every two years.

4.5 A Gravitational Wave Transmitter – Gregory Benford

Physicist and author Gregory Benford used his talk to suggest potential novel technosignatures for detecting extraterrestrial intelligence, focusing on what we can observe (not necessarily what is possible). In seeking radiators of light, we could look for beacons, deliberate transmissions, propulsion stations, ambient radiation from starships, waste heat from starships, waste heat from Dyson spheres, or other very large instruments. Using neutrinos as a detection source, we might detect starships, beacons, or deliberate beaming of communications. And using gravitons, we might detect beacons from very advanced civilizations. Observable starships could include magsails, nuclear-powered, and antimatter-powered ships up to 1,000 light-years away. Benford said that it is difficult to determine the constraints on advanced civilizations.

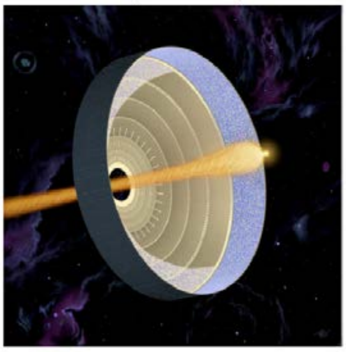
If a civilization were to launch an interstellar sailcraft, their masses, beam power, and distance could vary greatly, as seen in the chart below.


Beaming Stations

Laser-Propelled Lightsail Characteristics

Mission Type	Probe	Explorer	Manned
Spacecraft Payload, kg	2000	20,000	50,000
Deceleration Spacecraft Mass, kg	2637	26,700	76,700
Acceleration Spacecraft Mass, kg	5160	42500	117,000
Spacecraft Coast Velocity, v/c	0.3	0.3	0.3
S/C Kinetic Energy, Joules	1.05×10^{19}	1.08×10^{20}	3.1×10^{20}
Acceleration Characteristics			
Laser Beam Power, Terawatts	50	200	1000
Beam Director Diameter, meters	50,000	50,000	50,000
Lightsail Diameter, meters	2000	5000	8000
Acceleration time, days	37	45	37
Radius at Cutoff, AU	1114	1235	1021
Total Beam Energy, Joules	1.6×10^{20}	1.2×10^{21}	3.2×10^{21}
Deceleration Characteristics			
Magnetic Dipole Moment, a-m^2	1.0×10^{15}	2.0×10^{16}	1.0×10^{17}
Deceleration Time, years	10.7	15.7	15.3

Power outputs could range as high as 10^{25} watts and generate enormous luminosity.



Shkadov thruster (Don Davis)

“If you see it, you’ve got a ship coming, and they’ve got a big budget.”

Enormous, big-budget artifacts could include an “Einstein ring,” where a civilization uses a black hole to power a transmitter; a “black hole bomb beacon,” which would harvest the energy out of a black hole; a gravitational wave transmitter; a rotating black hole w/Jovian mass; or a “ship star,” which would focus energy of a star into a jet, and be detected from sunlight from its inner shells. This last item Benford and Larry Niven have written about in science fiction format.

Benford concluded with the following thoughts:

1. Starships will be hard to see unless they are coming at you.

2. Advanced civilizations may take advantage of astrophysical “augmenters,” such as lensing with stars, neutron stars, and black holes.

3. They might produce anomalies in astronomical observations, both electromagnetic and neutrino and gravitational waves.

4. A high-level civilization might use superradiance.

5. A really advanced civilization might build a gravitational wave transmitter.

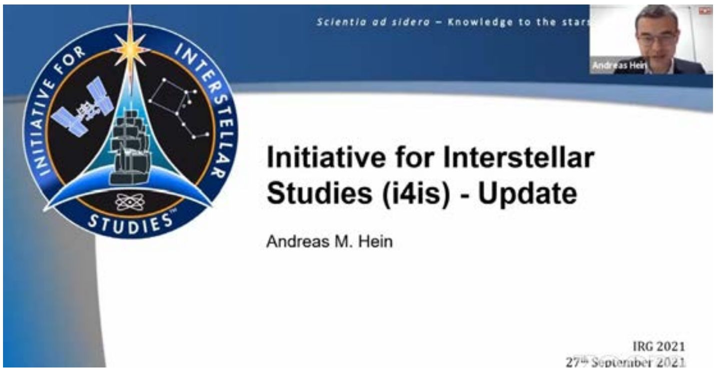
6. We might detect lensing of traversable wormholes and gravitational wave shocks from warp drives.

7. We could detect planetary engineering without a Dyson Sphere.

On the sociological side, Benford pointed out that in human history the only large structures we’ve built that have lasted millennia have been religious in nature. If we can find starships, we’d have to encounter civilizations very different from ours. The goals of long-lived civilizations will be profoundly different from ours if they’re able to send out messages that wouldn’t be received for centuries. “If you think big, you must also think long.”

4.6 i4is (Institute for Interstellar Studies) Update – Andreas Hein

Andreas Hein from i4is provided an update on the organization's activities. These included Project Lyra, Project Dragonfly, the Andromeda Probe, and AttoSat development.



i4is's research activities included investigating a Venus astrobiology balloon fleet; missions to interstellar objects; a first engineering concept of a near-term self-replicating probe; a state-of-the-art paper on world ships, along with several concept studies; and a concept for swarm-based communications, which would consist of a fleet of ships at interstellar distances, acting as signal transmitter to enhance interstellar communication [see *The downlink from swarming micro-probes* in this issue].

Research and education continued on attosats (spacecraft massing 1-10 grams). i4is developed a teaching module on ChipSat while conducting hardware development on AttoSat as well. They also collaborated with the International Space University on education modules about interstellar travel and worldships.


The Royal Institution of Great Britain
Credit: Gryffindor+Wikipedia

i4is conducted interstellar-related outreach in the UK, US, Nigeria, and Vietnam, concentrating on students aged 13-15 and 16-18. The program is called "Skateboards to Starships." [first run at the Royal Institution, London].

And, of course, i4is continued to put out its quarterly magazine, Principium, which averages 80-90 pages an issue.

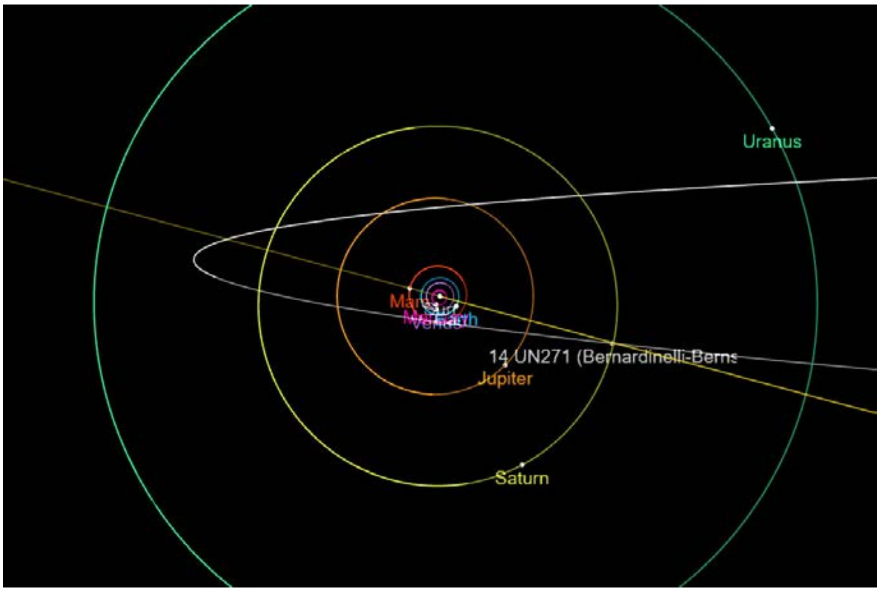
About The Authors

Bart Leahy is a Freelance Technical Writer (heroictechwriting.com) based in Florida. He has supported the Interstellar Research Group (IRG/TVIW) as a Volunteer Outreach Writer since 2015, where he has served the organization as workshop rapporteur, media planner, article writer, and IRG Facebook page administrator. He holds a BA in English from Northern Illinois University and an MA in Technical Writing from the University of Central Florida. His book *Heroic Technical Writing: Making a Difference in the Workplace and Your Life* shares insights on the professional and personal sides of technical writing.

Joseph Meany is a Postdoctoral Research Associate at the Savannah River National Laboratory and an internationally recognised leader in graphene and 2D nanomaterials. He is Secretary to the Board of Directors of the Interstellar Research Group (IRG/TVIW). He holds a PhD in Analytical/Organic Chemistry and an MSc in Chemistry from the University of Alabama. His first degree was a BSc from Keene State College.

News Feature: The journey of Bernardinelli-Bernstein

John I Davies

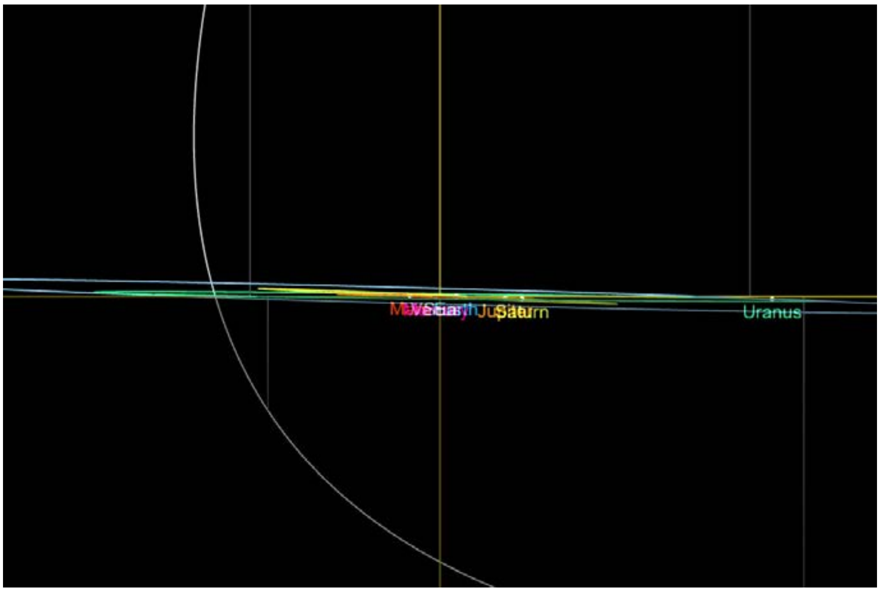


PLAN

Here is a plan view of the Solar system with planets in their almost perfectly circular orbits all lying close to the ecliptic plane but BB diving through with its closest approach to the Sun, perihelion, between the orbits of Saturn and Uranus.

Credit:JPL

The giant comet C/2014 UN271 (Bernardinelli-Bernstein) is diving towards the ecliptic, the fairly flat plane where most Solar System objects live. The NASA Jet Propulsion Lab (JPL) tracks and predicts its journey, alongside many others [1]. JPL allows us to see the classic plan and elevation of its trajectory - showing how Bernardinelli-Bernstein (BB) deviates from the Solar System norm by approaching almost at 90 degrees to the ecliptic. At about 150 km diameter[2] it may well be the largest comet we have ever observed.



ELEVATION

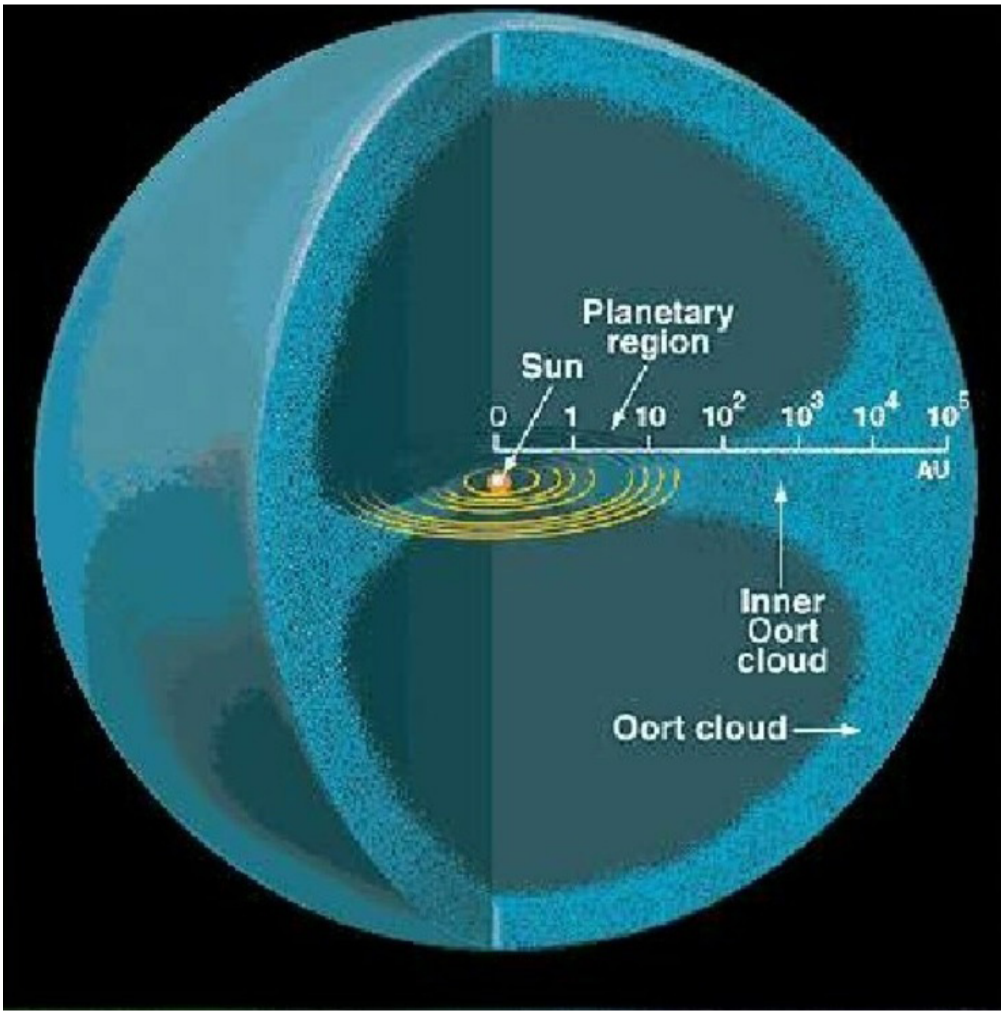
And here is the corresponding elevation of the Solar system with planets in their orbiting almost perfectly into the ecliptic plane. BB approaches from above and passes through the the ecliptic plane at almost 90 degrees.

Credit:JPL

[1] JPL Small-Body Database Browser, C/2014 UN271 (Bernardinelli-Bernstein) - ssd.jpl.nasa.gov/sbdb.cgi?sstr=2014%20UN271;orb=1;cov=0;log=0;cad=0#orb

[2] "Assuming a typical albedo, its diameter of ≈150 km implies a mass 10× larger than Hale-Bopp, and capable of gravitationally binding many of the larger particles ejected from other comets." *C/2014 UN_{271} (Bernardinelli-Bernstein): the nearly spherical cow of comets,* Bernardinelli et al Sep 2021 arxiv.org/abs/2109.09852

BB comes from the outer Oort cloud, like most long-period comets and outer Oort cloud objects lie in a rough sphere around the Sun rather than in the nice flat plane of the ecliptic.



The inner and outer Oort cloud.
www.slideshare.net/whitmers/oort-cloud-v2-adam

Credit: Adam Anderson

Missions to intercept and even rendezvous with BB are possible, as Adam Hibberd and John Davies explained in articles in Principium 34, August 2021 [1]. BB's perpendicular trajectory makes a rendezvous challenging but a flyby mission much easier. The 90 degree plane change is just more deltaV from the point of view of Tsiolkovsky's "tyrannical" rocket equation. As Adam explained in this article, two Rendezvous Missions, a simple direct mission requires a deltaV of at least 20 km/second – about twice that required to place an object into low Earth orbit – and you first have to get your rocket and probe out there. However Adam suggests economising on rocketry using a powered gravitational assist around Jupiter.

We will, of course, be keeping Principium readers up to date on the progress of BB, what we learn about it and what mission possibilities there are.

[1] *News Feature: Mission to 2014 UN271 using OITS*, John I Davies, Principium 34 page 38
i4is.org/wp-content/uploads/2021/08/News-Feature-Mission-to-2014-UN271-using-OITS-Principium34-print-2108231132opt-6-1.pdf

and

2014 UN_{271} Spacecraft Missions, Adam Hibberd, Principium 34 page 42
i4is.org/wp-content/uploads/2021/08/2014-UN271-Spacecraft-Missions-Principium34-print-2108231132opt-7-1.pdf

Become an i4is member

Patrick J Mahon

If you like what you see in Principium, and want to help us do more, why not become a member?

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

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

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

Members have access to exclusive benefits, including:

- regular member-only talks on interstellar topics;
- early access to selected Principium articles before public release;
- regular newsletters keeping you up to date with the latest interstellar news;
- videos of i4is lectures and presentations; and
- copies of our corporate publications, including our annual report.

Recent highlights of the i4is talk programme (recordings of which are available on the members' section of the website) include:

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

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

More details of the benefits of membership are on the i4is members' page, also in this issue of Principium.
If you would like to join, please go to i4is.org/membership.
Join i4is and help us build our way to the Stars!

Interstellar News

John I Davies reports on recent developments in interstellar studies

ISOs in the neighbourhood?

Our Centauri Dreams ally Paul Gilster (www.centauri-dreams.org) draws our attention to a recent letter in the Monthly Notices of the Royal Astronomical Society, *Interstellar objects outnumber Solar system objects in the Oort cloud* [1]. Avi Loeb is the indefatigable champion of the thesis that at least some interstellar objects (ISOs) are artificial. Here he and his Harvard colleague, Amir Siraj, aim to show that the detection of Borisov implies that interstellar objects outnumber Solar system objects in the Oort cloud, whereas the reverse is true near the Sun due to the stronger gravitational focusing of bound objects. They suggest that this hypothesis can be tested with stellar occultation surveys of the Oort cloud.

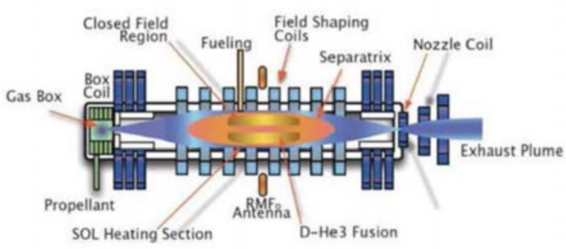
Kezerashvili on a Deuterium-Helium 3 fusion drive

Professor Roman Kezerashvili (City University of New York) is a major contributor to interstellar studies. In his recent paper [2] he advocates a Direct Fusion Drive (DFD) design as a fast way of reaching Solar System objectives such as Mars (around 100 days one way) and Titan (around two years return). This work has been reported in several issues of Principium [3], presented at our FISW workshops in New York 2017 and Gloucestershire UK 2019 - and in JBIS V72 #2 Feb 2019, *Direct Fusion Drive for Interstellar Exploration*, S A Cohen et al - and Acta Astronautica, V178, Jan 2021, *Exploration of trans-Neptunian objects using the Direct Fusion Drive.*

Seligman, Laughlin et al on ISO composition

Darryl Seligman and Gregory Laughlin have been active in interstellar object (ISO) studies since very soon after the discovery of 1I/'Oumuamua by the STARRS telescope. In this latest paper they and colleagues examine the various theories of the appearance and observed properties of the two ISOs found so far [4]. For 2I/Borisov they conclude that it is simply an interstellar comet not significantly different from one of our own long period comets if it strayed into another solar system. For 1I/'Oumuamua (aka "1I") they find all current theories wanting in different respects.

They cite a number of studies which note the relatively low incoming velocity of 1I and deduce that it must have had relatively few gravitational perturbations and thus must be a relatively "young" object. They suggest that the upcoming Vera Rubin Observatory (formerly the Large Synoptic Survey Telescope - LSST), by detecting objects up to three magnitudes dimmer than Pan-STARRS, will detect enough 1I-like objects to deliver a representative population study. We shall see!



Schematic of a DFD with its simple linear configuration and directed exhaust stream. A propellant is added to the gas box. Fusion occurs in the closed-field-line region. Cool plasma flows around the fusion region, absorbs energy from the fusion products, and is then accelerated by a magnetic nozzle. Figure from *Nuclear and Future Flight Propulsion - Modeling the Thrust of the Direct Fusion Drive S J* Thomas, M Paluszek, S Cohen, A Glasser, AIAA 2018-4769 (2018).

Credit (image and caption); Cohen et al - FIG. 1:

[1] *Interstellar objects outnumber Solar system objects in the Oort cloud,* A Siraj, A Loeb - open publication arxiv.org/abs/2011.14900

Monthly Notices of the Royal Astronomical Society: Letters, Volume 507, Issue 1, October 2021, Pages L16–L18, doi.org/10.1093/mnrasl/slab084 Published:23 August 2021

[2] Exploration of the solar system and beyond using a thermonuclear fusion drive, arxiv.org/abs/2108.01689# August 2021

[3] *News Feature: Foundations of Interstellar Studies Workshop 2019*, Principium 26, August 2019,

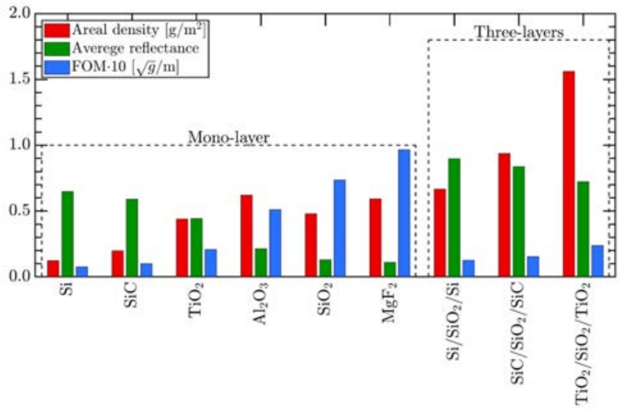
page 9. IAC20 report. *Exploration of trans-Neptunian objects using the Direct Fusion Drive*, Principium 30, August 2020, page 32, and Principium 31, November 2020 page 43. *Direct Fusion Drive for the Gravitational Lens Mission*, Principium 30, August 2020 page 68. *A Titan mission using the Direct Fusion Drive (DFD)*, Principium 31, November 2020, page 22.

[4] *Constraints on the Occurrence of 'Oumuamua-Like Objects*, W Garrett Levine, Samuel H C Cabot, Darryl Seligman, Gregory Laughlin, 25 Aug 2021 arxiv.org/abs/2108.11194

Red-shift of lasers powering a sailcraft

In *Directed Energy Accelerated Lightsails*, Santi et al [1] (a team including Philip Lubin [2]) presents results of a study of the problem of red-shift of the lasers powering a sailcraft as the craft accelerates away from the lasers. They note that "the reflector needs to be broadband enough to allow a modest or perhaps large dynamic range of received wavelengths". This alongside materials and layering, thermal stability of the lightsail, mechanical strength and sail mass per reflecting area will determine the performance of the sailcraft. They conclude that, for a 1,064 nm laser source, TiO_2 as a single layer, or multilayer stack with SiO_2, as a second material looks most attractive. Best propulsion efficiency is achieved by single layer, multilayers offer advantages of thermal control and stiffness. However a longer wavelength laser source could expand the choice of potential materials having the required optical characteristics.

They derive a figure of merit function FOM(ρ_s, R, A) where ρ_s is the area density of the sail, R is its reflectance and A is absorption. See bar graph of various material combinations.



Bar graph of material combinations

Areal density (red bar) and (average) reflectance (green bar) of selected lightsail structures considered, as grouped by the number of layer. For each group, the value of the FOM increases from left to right.

Credit: Santi et al

IRG Eridani Award 2021

Congratulations Dr Albert A Jackson

At the 2021 Symposium of the Interstellar Research Group in Tucson Arizona (see our Lead Feature) the IRG made the IRG Eridani Award 2021 to Dr Albert A Jackson.

Al is a veteran of interstellar studies and has been professionally engaged in space endeavours since his work with the Apollo programme.

We would like to add our congratulations to a friend and colleague of i4is.

[1] *Directed Energy Accelerated Lightsails*

Giovanni Santi et al, Nature journals preprint www.researchsquare.com/article/rs-943018/latest.pdf

[2] Professor Philip Lubin, UCSB, will be familiar to Principium readers. Lead author Giovanni Santi is at Università di Padova, and other team members are at Istituto di Fotonica e Nanotecnologie, Padova, Istituto Italiano Tecnologie, Genova, Istituto di Elettronica, Ingegneria dell'Informazione e delle Telecomunicazioni, Padova and Osservatorio Astronomico di Padova

Microbial Habitability of Rogue Planets

Rogue planets are planets without host stars. They have been known to exist for some time, see *Rogue planet wanders into view* in Principium 7, November/December 2013. In a recent paper, Dirk Schulze-Makuch, Technische Universität Berlin, and Alberto G Fairén, CSIC-INTA, Madrid [1] look at their microbial habitability and suggest they may be vectors for panspermia. They identify two types of rogue planets, sub-brown dwarfs and “rocky” rogue planets, with only the latter capable of hosting or carrying life. They discuss factors such as water (liquid or ice) and energy sources (given no solar energy) including chemical, photosynthesis from hydrothermal light or the occasional passing star, direct hydrothermal energy and temperature gradients - and, more speculatively, osmotic gradients, magnetic fields, or radioactivity.They cite work on the possible conditions on rogue planets and suggest that even planetary collisions are not necessarily fatal to all life and thus could result in panspermia effects.

Searching for Kardashev III civilisations

Supported by a grant from the National Natural Science Foundation of China, Professor Michael Garrett and Zhaoting Chen have been considering a potential identifying factor for Kardashev Type III civilisations (KIII) [2]. Their paper [3] argues that since KIII have, by definition, energy requirements that are likely to generate strong excess waste heat emissions in the mid-infrared (MIR) and low levels of optical radiation then they will differ from a wide range of galaxy types which adhere to the infrared-radio correlation (IRC). This has been found to apply to both star-forming and non-star-forming galaxies over a wide range of orders of magnitude. They conclude that the small number of galaxies which deviate from the IRC may be candidates for investigation both as possible KIII and to determine what natural mechanisms might result in this deviation. They identify three characteristics a galaxy hosting a Type III civilisation might be expected to have: (1) extremely red MIR colours, (2) high values of the IRC parameter q, and (3) unusually low optical/IR luminosity ratios.

Examining the available candidates they remain cautious, there are clearly some slightly "fishy" looking cases but no smoking gun. They suggest that more work along these lines "...can place very strong constraints on the incidence of Type III civilisations in the universe".

[1] *Evaluating the Microbial Habitability of Rogue Planets and Proposing Speculative Scenarios on How They Might Act as Vectors for Panspermia,* Dirk Schulze-Makuch, Technische Universität Berlin, Alberto G Fairén, Centro de Astrobiología (CSIC-INTA), Madrid, in the journal *Life*, 2021, 11(8) www.mdpi.com/2075-1729/11/8/833/htm

[2] See Robert Kennedy's *Guest Introduction: A Modest Proposal for Photometric SETI* in Principium 11 for more about the Kardashev scale of civilisations. Also articles by Dmitry Novoseltsev in P18, P23, P27, P29 and David Gahan in P32. Earlier related work by Mike Garrett was reported in P23 (*SETI radio surveys of the distant Universe*), There is a useful Wikipedia entry at en.wikipedia.org/wiki/Kardashev_scale

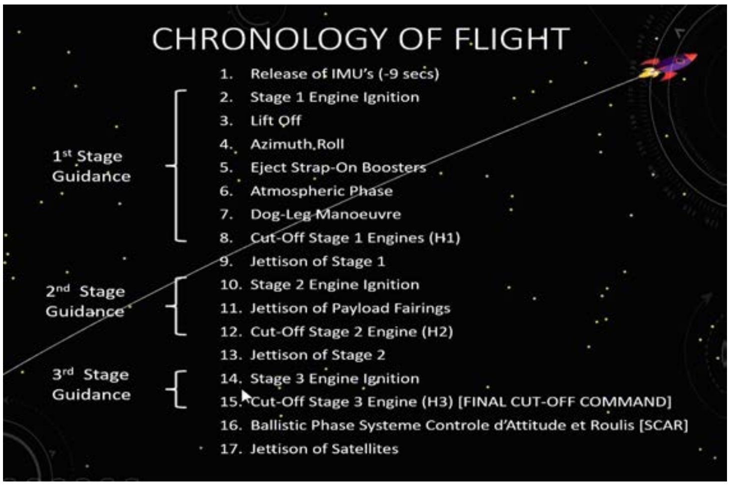
[3] *Searching for Kardashev Type III civilisations from High q-Value Sources in the LoTSS-DR* (MNRAS Preprint 14 August), H. Chen (National Astronomical Observatories, Chinese Academy of Sciences, Beijing,) and M A Garrett (Jodrell Bank Centre for Astrophysics, University of Manchester) arxiv.org/abs/2108.06597

Adam Hibberd at BIS West Midlands

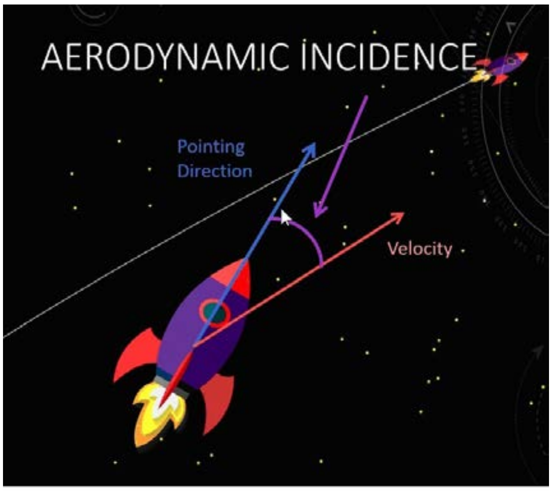
The West Midlands group of the British Interplanetary Society is one of its most active. Our i4is colleague Adam Hibberd recently took members through the basic dynamics of some of his earlier professional work, long preceding his vital contribution to i4is Project Lyra. This was the Ariane 4 rocket, the immediate predecessor of the current Ariane 5 heavyweight - due to launch the JWST next month. We can't show his brilliant animations in our magazine but here are a couple of snapshots.

Amongst the BIS members present were a number of rocket engineers with decades of experience, notably at the UK Westcott establishment - these days a test site for the Reaction Engines air-breathing rocket, Sabre. Their enthusiasm for Adam's presentation was readily apparent!

An earlier version of Adam's presentation was given to i4is members as part of our talk series on 8 June 2021 and is available in the members' area of our website.



Snapshots from animation by Adam Hibberd



"Hycean worlds" better hab-zone candidates than Earth?

Researchers from the Institute of Astronomy, University of Cambridge, have investigated a new class of habitable planets, "Hycean worlds" [1] composed of water-rich interiors with massive oceans underlying H_2-rich atmospheres which they suggest can be candidates for habitability and may be abundant in the exoplanet population. They may exist in a wider habitable zone than Earth-like planets and easily detectable by the James Webb Space Telescope (JWST).

Avoiding the "Great Filter"

The "Great Filter" is a class of explanations for the absence of detectable extraterrestrial intelligences, the Fermi Paradox. It is speculated that, at some point before detectability, intelligence or simply life is extinguished. If the probability of this is high enough then the Fermi Paradox is resolved.

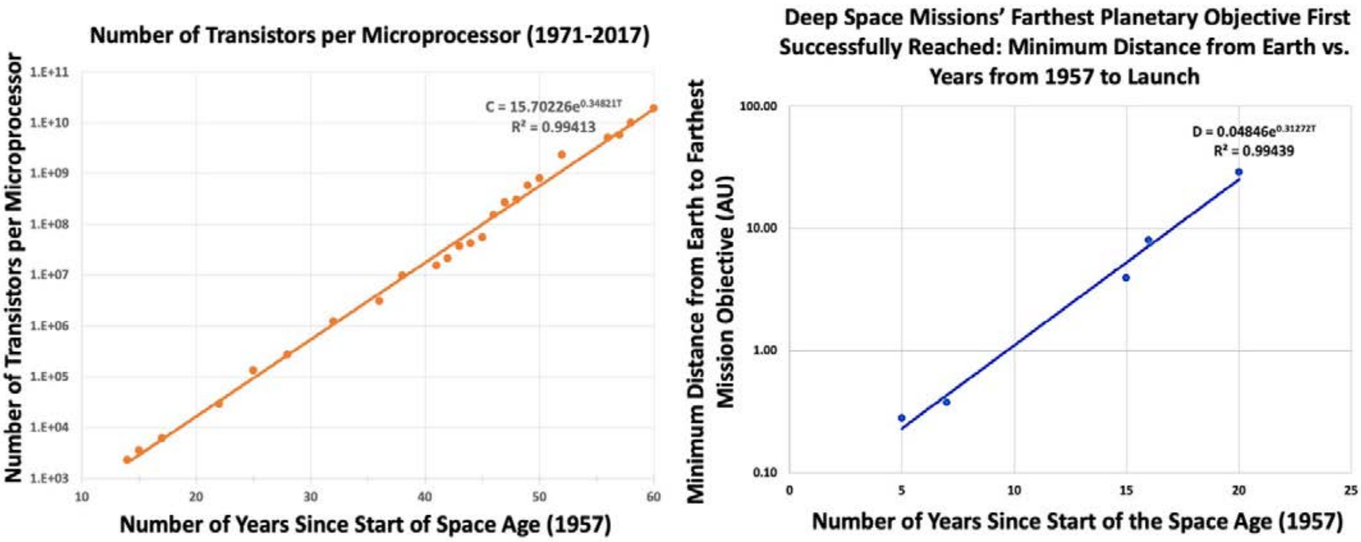
A team at JPL has been looking at how our own species might avoid this. In their paper *Avoiding the "Great Filter": A Projected Timeframe for Human Expansion Off-World* [2], they use the history of space exploration to extrapolate to the earliest possible launch dates to Solar System and interstellar destinations. They suggest the first human-crewed missions to Mars, Asteroid Belt objects and moons of Jupiter and Saturn before the end of the 21st century and launches of human-crewed interstellar missions within 40 light-years being possible during the 23rd century, with intragalactic missions by the end of the 24th century.

They suggest that computational power will be the limiting factor and use a transistor-neuron/synapse

[1] *Habitability and Biosignatures of Hycean Worlds*, Madhusudhan et al, The Astrophysical Journal, Volume 918, Number 1, August 2021 open publication:arxiv.org/abs/2108.10888 "Hycean" is a contraction of 'hydrogen' and 'ocean'.

[2] *Avoiding the "Great Filter": A Projected Timeframe for Human Expansion Off-World*, arxiv.org/abs/2108.01730, Jonathan H Jiang and Kristen A Fahy (Jet Propulsion Laboratory, Caltech), Philip E Rosen (Energy Industry Engineer - Retired, USA)

analogy to drive the required extrapolation. They set this against distances achieved by probes to date and in future. They are sceptical about the application of Moore's law given the physical limits to packing circuitry on semiconductor chips but nevertheless assume that human ingenuity will achieve a roughly exponential growth of computing power.



Left: Computational power - number of transistors per microprocessor - log scale
Right: Probe distance - first robotic flybys by objective minimum distance from Earth - log scale
Both versus years since start of the Space Age (1957) - linear scale
Image credit: Jiang et al

On this basis they present log-linear graphs setting probe distance and computational power against years since the start of the space age in 1957. They do not imply that "correlation implies causation" but the parallel is striking. They make similar comparisons between robotic and crewed missions but the data points for the latter are, of course, much more sparse.

Having derived empirical equations from the above they suggest a method of bringing these together and, taking a date of 2038 for the first crewed Mars landing, they derive a table of destinations and dates.

Tables for LookUp Data on Pre-Chosen Destinations and Projections for Earliest Possible Mission Launch Dates

Destination	Moon	Mars	Asteroid Belt	Jovian System	Saturn System	Proxima Centauri	Tau Ceti	Trappist System	4 kpc from CoMW
Dist. from Earth (AU)	0.0026	0.3763	1.5587	3.9501	8.0412	265,486	752,526	2,562,570	882,424,035
1st Flyby	1959	1964	1972	1972	1973	Not Yet Launched	Not Yet Launched	Not Yet Launched	Not Yet Launched
1st Robotic Lander	1966	1975	Not Yet Launched	Not Yet Launched	1997	Not Yet Launched	Not Yet Launched	Not Yet Launched	Not Yet Launched
1st Human Landing	1969	2038	Not Yet Launched	Not Yet Launched	Not Yet Launched	Not Yet Launched	Not Yet Launched	Not Yet Launched	Not Yet Launched
Actual and Calculated Projections for Calendar Year of Launch from Earth of First Successful Mission Type and Destination and Corresponding Computational Power Requirement									
Launch Year of 1st Successful Flyby Mission	1959	1964	1972	1972	1973	2007	2010	2014	2032
Year Computational Power First Achieved	1948	1964	1968	1971	1973				
Launch Year of 1st Successful Robotic Landing	1959	1975	1979	1982	1984	2018	2021	2025	2043
Year Computational Power First Achieved	1959	1975	1979	1982	1984	2018	2021	2025	2043
Launch Year of 1st Successful Human Landing	1969	2038	2064	2076	2086	2254	2270	2290	2383
Year Computational Power First Achieved	1969	2038	2064	2076	2086	2253	2269	2289	2381

Actual and projected timing of first successful robotic and human missions for selected destinations within the Solar System and interstellar space. Credit (image and caption): Jiang et al

The objective of the researchers is "...to provide a timeframe for humanity to become a multi-world species through off-world colonization that would logically follow on the heels of earlier human landings" and thus avoid a future "Great Filter".

Laser Communication using the Solar Gravitational Lens

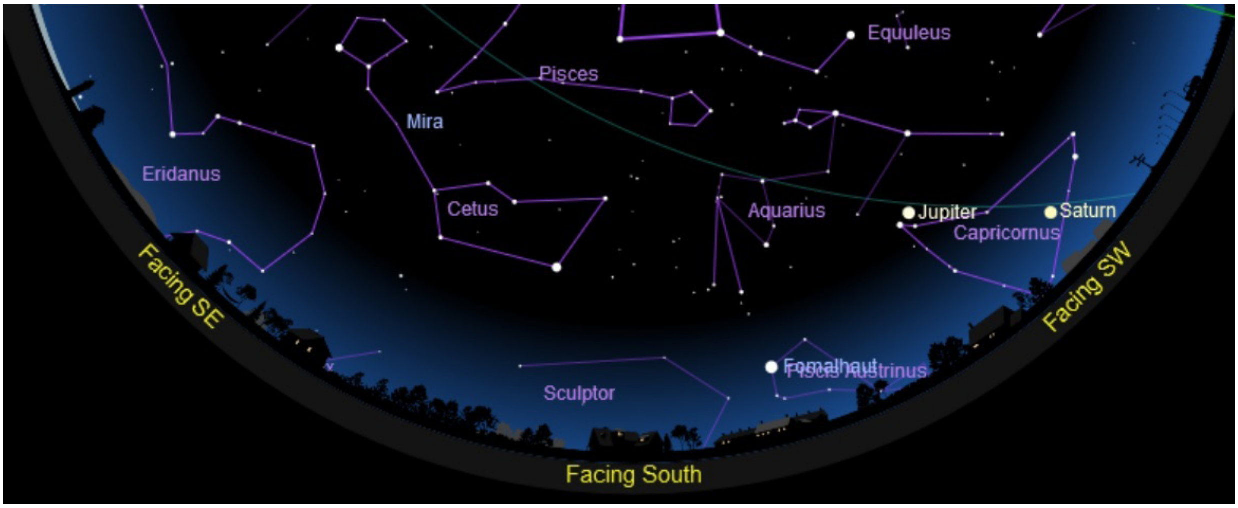
If we are to send probes to the nearest stars the greatest challenge may not be the speed required to reach them in a reasonable time but to communicate, if only one-way, with our probes.

Principium has reported on this in several issues, most recently in this issue in the feature, *The downlink from swarming micro-probes*. We have also reported on the potential use of the solar gravitational lensing point at 542 AU or greater distance, about 1% of a light year away, as an extremely powerful telescope.

In the paper, *Laser Communication with Proxima and Alpha Centauri using the Solar Gravitational Lens* [1], researchers tested the possibility that transmissions are already being made from focus points on the Earth-Sun radius and thus would be detectable at Earth. In the case of four nearby stars, Tau Ceti, Proxima Centauri, and Alpha Centauri AB, the beam would miss Earth because the directions to them do not lie in the plane of the ecliptic but any sub-optimal focusing of the beam might still generate a detectable signal. The researchers modified a Schmidt telescope of aperture 0.28 m (11 inch) using a custom-designed prism.

This very detailed work presents a new means of doing SETI but it also provides foundation information for future potential use of gravitational lensing for communications from our own interstellar probes and, longer term, communications to more capable probes we may send later.

It's worth noting that if you look along the ecliptic plane by taking a line between any two planets you can eavesdrop on signals from probes to stars on that line if you have a good enough telescope!



Where might we find signals intended for ETIs using our own Solar Gravitational Lens?
Look between Jupiter and Saturn. You may just be able to intercept signals to stars on that line.
Image credit: Sky and Telescope.

Sending a spacecraft to 2I/Borisov

Another i4is Project Lyra paper, *Sending a spacecraft to interstellar comet 2I/Borisov,* will appear in the December issue of Acta Astronautica [2]. This was first announced in Principium 33, May 2021. For a launch in 2027 a 765 kg mission could reach 2I in 2052 (using the NASA Space Launch System and Parker probe heat shield technology). Alternatively SpaceX Falcon Heavy could deliver 202 kg. Challenges include Borisov's high hyperbolic excess speed (around 32 km/s) and high orbital inclination with respect to the ecliptic (44°). It's notable that 1I/'Oumuamua is not travelling so fast but its trajectory has been much closer to Earth - see our front cover visualisation of its closest approach to the Earth in Principium 20, February 2018.

[1] *Laser Communication with Proxima and Alpha Centauri using the Solar Gravitational Lens*,

Geoffrey W Marcy (Center for Space Laser Awareness, USA), Nathaniel K Tellis (RocketCDL), Edward H Wishnow (Space Science Laboratory, University of California, Berkeley) arxiv.org/abs/2110.10247. Accepted for publication in the Monthly Notices of the Royal Astronomical Society October 2021

[2] *Sending a spacecraft to interstellar comet 2I/Borisov*, Adam Hibberd(i4is), Nikolaos Perakis (Technical University of Munich and i4is) Andreas M Hein(i4is), Acta Astronautica V189, December 2021. Open publication: www.researchgate.net/profile/Adam-Hibberd/publication/354593769_Sending_a_spacecraft_to_interstellar_comet_2IBorisov/links/61448f19a3df59440b922ef3/Sending-a-spacecraft-to-interstellar-comet-2I-Borisov.pdf

A chronology of Principium

Principium is now in its 10th year so maybe it's time to put our issue creation dates on public record.

#	Date	Year	pages
1	Tue Dec 4	2012	13
2	Thu Jan 17	2013	14
3	Sat Feb 23	2013	14
4	Mon Apr 22	2013	16
5	Mon Jul 22	2013	20
6	Wed Aug 7	2013	26
7	Wed Dec 18	2013	17
8	Wed Jul 30	2014	18
9	Sat May 9	2015	34
10	Fri Aug 7	2015	26
11	Sat Nov 7	2015	26
12	Wed Feb 10	2016	23
13-	Thu Jun 2	2016	28
14	Sat Aug 20	2016	32
15	Tue Nov 29	2016	36
16	Sun Feb 26	2017	36
17	Wed May 17	2017	40
18	Tue Aug 29	2017	44
19	Sat Dec 16	2017	44
20	Tue Feb 27	2018	40
21	Tue May 29	2018	40
22	Thu Aug 23	2018	48
23	Tue Dec 4	2018	44
24	Mon Feb 18	2019	40
25	Mon May 27	2019	56
26	Fri Aug 30	2019	56
27	Thu Nov 28	2019	44
28	Sat Feb 29	2020	52
29	Wed May 27	2020	60
30	Mon Aug 31	2020	96
31	Sun Nov 29	2020	92
32	Mon Feb 22	2021	88
33	Fri May 28	2021	76
34	Wed Aug 25	2021	56

- and here are our total pages per year- 2012 13 pages, 2013 107 pages, 2014 18 pages, 2015 86 pages, 2016 119 pages, 2017 164 pages, 2018 172 pages, 2019 196 pages, 2020 300 pages.

Will Interstellar Astronauts Be Human?

A recent paper asserts that the first, at least, will not [1]. The paper explores the biological and technological challenges of interstellar space biology, focusing on radiation-tolerant micro-organisms capable of cryptobiosis (a state of extreme inactivity in response to adverse environmental conditions), planetary protection and other ethical considerations of sending life to the stars.

They ask "Why should we develop the technology to send spacecraft into interstellar space?" and answer "the human drive to understand and explore" and that "the same technology we use to enable relativistic flight also enables a transformative range of possibilities for space exploration". The paper cites the NASA Starlight program for laser sailcraft as the leading initiative and examines the challenges of any future human interstellar flight. The robustness of some microorganisms such as tardigrades and C. elegans makes them attractive interstellar voyagers but modifying mammals to have similar characteristics is by no means a trivial undertaking! Experimental interstellar craft could carry a range of species as laboratory subjects.

The suggested motivations here seem to be rather modest. As a species we have always migrated and the settlement of the Pacific islands in just a few hundred years by what lofty Europeans and Americans once called "primitive peoples" is a powerful instance of this (see next page).

A real, albeit humble, warp bubble?

Sonny White (Limitless Space Institute) has published, with colleagues, more thinking which just may give us the access to the warp drive technology suggested by Miguel Alcubierre [2]. The setup consists of a standard parallel plate Casimir cavity and subsequently a toy model consisting of a 1 micrometer diameter sphere centrally located in a 4 micrometre diameter cylinder as a three dimensional demonstration. They find qualitative correlation suggesting that chip-scale experiments might attempt to measure tiny signatures illustrative of the presence of the conjectured phenomenon "a real, albeit humble, warp bubble".

[1] *The First Interstellar Astronauts Will Not Be Human*, Stephen Lantin et al, arxiv.org/abs/2110.13080. Lantin is at Department of Agricultural and Biological Engineering, University of Florida. Other authors are with a range of deparments at UCSB (including Prof Philip Lubin), UCLA Health Center and Ruhr-Universitat Bochum.

[2] *Worldline numerics applied to custom Casimir geometry generates unanticipated intersection with Alcubierre warp metric.* Harold White et al, European Physical Journal V81, #677 2021 epjc.epj.org/articles/epjc/abs/2021/07/10052_2021_Article_9484/10052_2021_Article_9484.html

SETI on fire

In *Strategies and Advice for the Search for Extraterrestrial Intelligence* [1], Jason T Wright has produced a how-to guide and potential roadmap. As he says, SETI is currently experiencing a resurgence and he surveys methods and potential types of evidence. And he notes the distinction between deliberate investigation versus the use of the vast amount of astronomical data accumulated for other purposes where SETI can be a "byproduct" (note that a chemical engineer will tell you that byproducts often rise in value to equal or surpass that of the original intended product).

Communicative signals he call "dispositive" since any signal that is sufficiently compressed in time or frequency must be artificial. Technosignatures would be unambiguous but their absence need not necessarily imply absence of an ETI.

He draws a useful distinction between targeted searching, imaging a signal or signature that an ETI might be expected to produce, versus simply searching for anomalies (the "that's funny" reaction that resulted, for example, in the discovery of pulsars).

He wraps up with some guidelines and a model plan for SETI research.

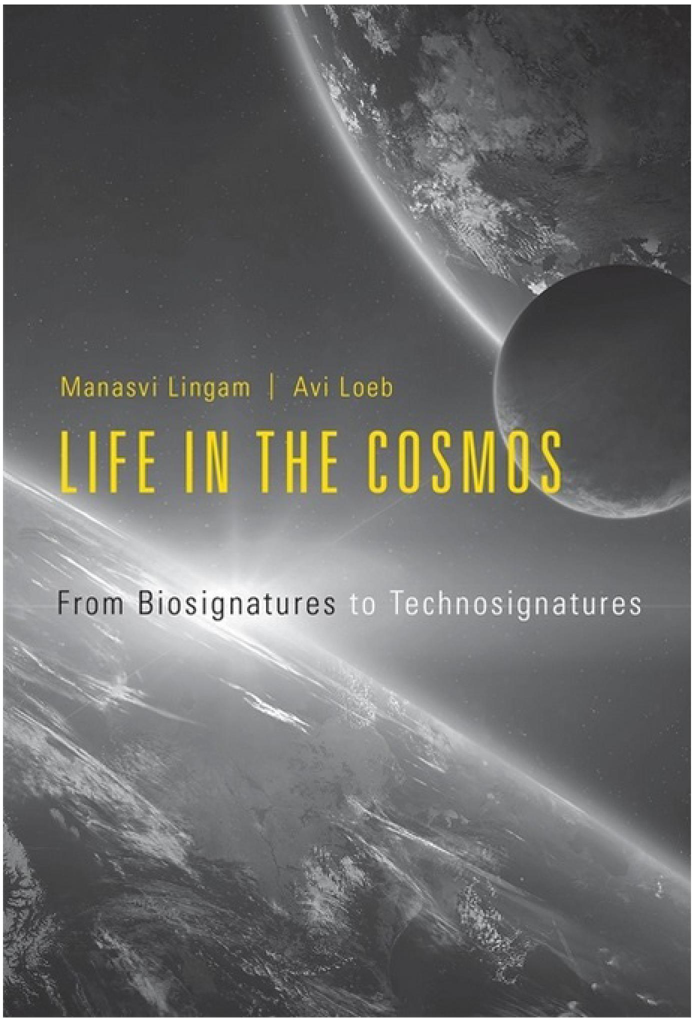
Jason is a professor of astronomy and astrophysics at Penn State, a member of the Center for Exoplanets and Habitable Worlds, and director of the Penn State Extraterrestrial Intelligence Center.

Jason has also produced *SETI in 2020* [2], which he characterises as a brief and subjective review of developments in SETI in 2020. He mainly reviews 75 papers and books published or made public in 2020. He identifies six broad categories: results from actual searches, new search methods and instrumentation, target and frequency selection, the development of technosignatures, theory of ETIs, and social aspects of SETI.

Life in the Cosmos: From Biosignatures to Technosignatures

Our interstellar colleague, Manasvi Lingam (Assistant Professor of Astrobiology, Florida Institute of Technology) has now published his book, written with Professor Avi Loeb, *Life in the Cosmos: From Biosignatures to Technosignatures* [3]. It is a very substantial (1088 pages) review of possible ETIs.

We look forward to reviewing it in a future issue.



[1] *Strategies and Advice for the Search for Extraterrestrial Intelligence*, Jason T Wright, Pennsylvania State University, July 2021, arxiv.org/abs/2107.07283

[2] *SETI in 2020*, Jason T Wright, August 2021 arxiv.org/abs/2107.07512

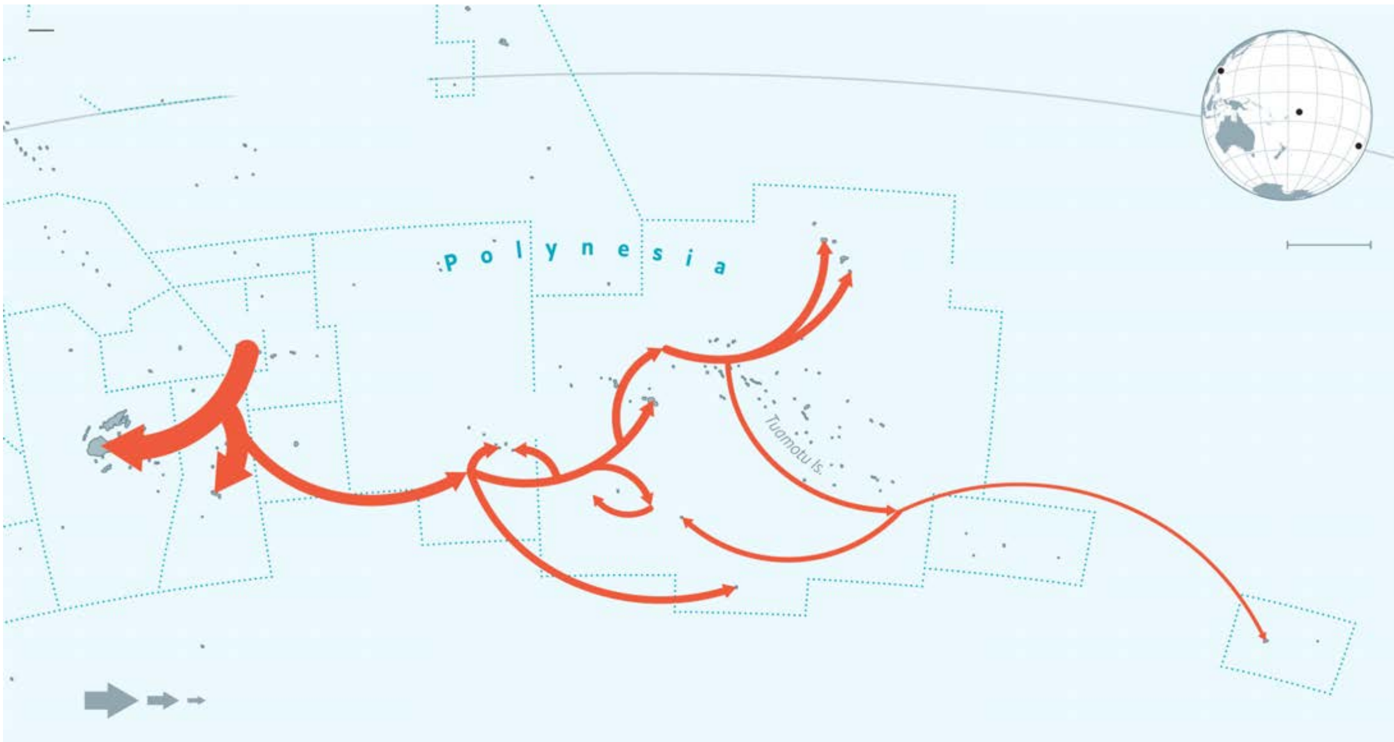
[3] *Life in the Cosmos: From Biosignatures to Technosignatures*, Manasvi Lingam & Avi Loeb, Harvard University Press, www.hup.harvard.edu/catalog.php?isbn=9780674987579

"Canoeing" to the stars

The Economist newspaper and Nature recently published *Settling the Pacific by canoe in a few hundred years - Paths and timings of the peopling of Polynesia inferred from genomic networks* [1], reporting recent research by a team stretching from Oxford and Stanford to the Mata Ki Te Rangi Foundation, Hanga Roa, Easter Island. They used genetic evidence to show that the Pacific was settled by canoe in the space of a few hundred years. It shows how the Pacific, one third of the area of our planet, was settled by humans using canoes propelled by wind and muscle between AD 830 and AD 1200, about 370 years. The straight line distance between Rarotonga and Easter Island is about 5,000 kilometres. If we double this for indirect travel then this might be approximated to 10,000 kilometres.

If our ingenious ancestors achieved this using vehicles capable of only a few tens of kilometres per day, settling many times along the way, then cannot our outward urge take us, at a few percent of the speed of light, to the stars in similarly feasible times?

More than 70 years ago Thor Heyerdahl respected the maritime capabilities of our ancestors enough to journey from South America to Polynesia on the raft, Kon Tiki, to support a theory of such staggering achievement. He seems to have got the direction reversed but his faith in the capacity of our species should hearten us. What was called impossible just after the Second World War was achieved by 1948 and modern genetics now shows that Heyerdahl's suggested migration, in the reverse direction, was achieved by humans in canoes over less than four centuries - and long before westerners even knew the Pacific existed.



The settlement of Polynesia Reconstructed from the genes of modern inhabitants.
Credit: The Economist / Nature

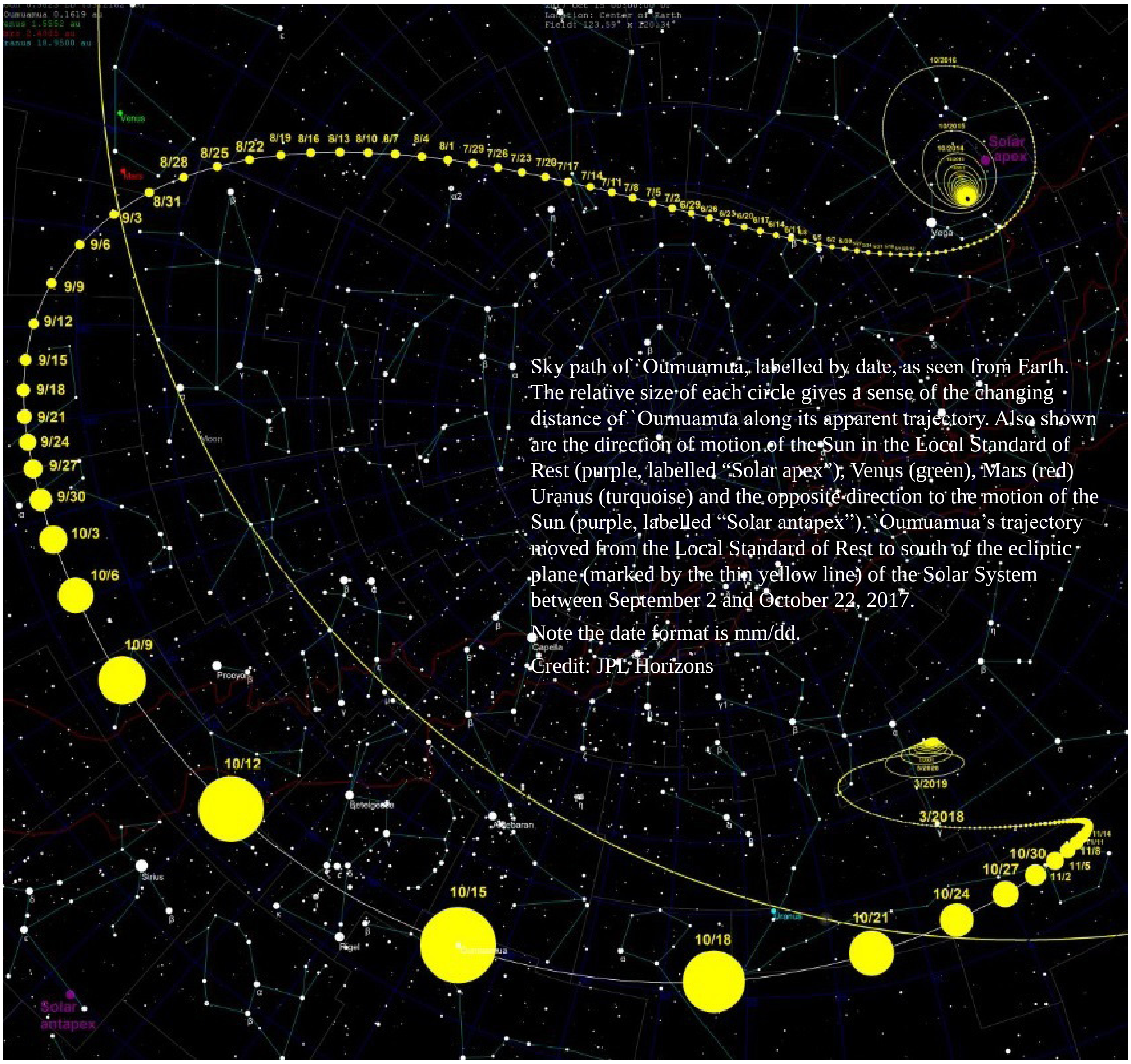
[1] *Genes reveal how and when humans reached remote corners of Pacific - The islands settled most recently have the least genetic diversity* www.economist.com/graphic-detail/2021/09/25/genes-reveal-how-and-when-humans-reached-remote-corners-of-pacific.

News Feature: Loeb on an Artificial Origin for `Oumuamua

John I Davies

Professor Avi Loeb remains resolute on an artificial origin for 'Oumuamua. He has long advocated the possibility of an artificial origin for this first known interstellar object (ISO), 1I/'Oumuamua, in the face of wide scepticism amongst his peers. For example the Principium piece, *An Interstellar Visitor: sorting the fact from the speculation* by Professor Alan Aylward in Principium 32, February 2021, page 53.

Neither Principium nor i4is has a collective opinion on this. Where we are, more or less, united is in the opinion that no entirely satisfactory explanation for the nature of 1I has yet been suggested. In the paper *On the Possibility of an Artificial Origin for `Oumuamua* [1], Professor Loeb again nails his colours to the mast of the good ship "Following the Evidence" and expands on his new Galileo Project, stating that each of the natural-origin models for 1I has major quantitative shortcomings and thus the possibility of an artificial origin for `Oumuamua must be considered. The project aims to collect data to identify the nature of `Oumuamua-like objects (more about it in *ET Technology - the Galileo Project* in Principium 34, August 2021, page 18). 1I appears not to have been diverted towards us by the gravitation of any specific star but conforms to the "galactic neighbourhood average" the Local Standard of Rest, illustrated by this visualisation of its trajectory.



Sky path of `Oumuamua, labelled by date, as seen from Earth. The relative size of each circle gives a sense of the changing distance of `Oumuamua along its apparent trajectory. Also shown are the direction of motion of the Sun in the Local Standard of Rest (purple, labelled "Solar apex"), Venus (green), Mars (red) Uranus (turquoise) and the opposite direction to the motion of the Sun (purple, labelled "Solar antapex"). `Oumuamua's trajectory moved from the Local Standard of Rest to south of the ecliptic plane (marked by the thin yellow line) of the Solar System between September 2 and October 22, 2017.

Note the date format is mm/dd.

Credit: JPL Horizons

[1] open publication: arxiv.org/abs/2110.15213 and lweb.cfa.harvard.edu/~loeb/Loeb_Astrobiology.pdf

He cites the shape, the anomalous acceleration and the absence of detectable outgassing. He has already a book in support of his views. In his book *Extraterrestrial: The First Sign of Intelligent Life Beyond Earth* (reviewed by Patrick Mahon in Principium 33, May 2021, page 34), Loeb states "a picture is worth 66 thousand words, the number of words in my book titled, Extraterrestrial, I would have never written this book if we had a megapixel image of `Oumuamua".

i4is, of course, has long advocated, and provided extensive evidence for, the feasibility of missions which might provide such a picture - and a lot more.

Professor Loeb cites four proffered natural explanations for the nature of 1I -

• Porous structure with a mean density a hundred times lower than air

• Fragments from tidal disruption

• An iceberg of molecular hydrogen

• A nitrogen iceberg chipped off the surface of a planet like Pluto around another star

- and aims to refute all of them.

His Galileo project will look for future `Oumuamua - like objects. He does not mention the possibility that we may wait a long time for such an object.

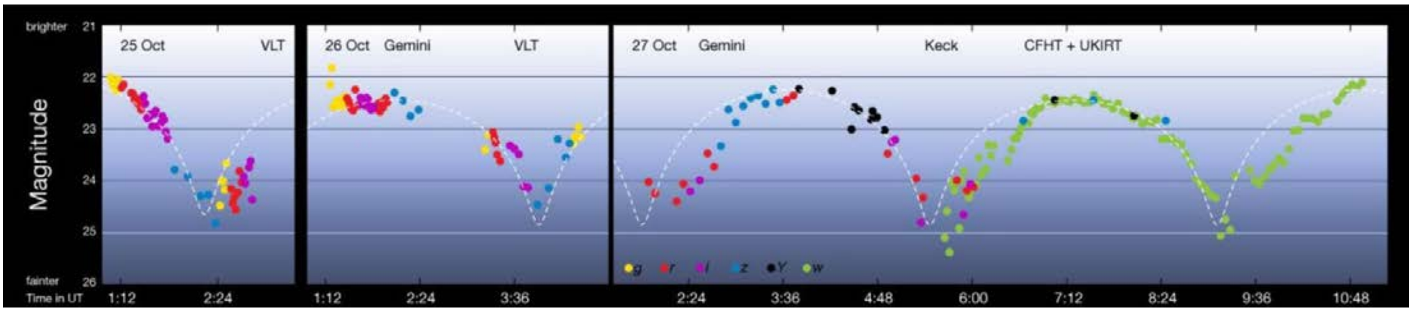


Figure 4: Variation in brightness of `Oumuamua as observed by various telescopes during three days in October 2017. Different colored dots represent measurements through different filters in the visible and near-infrared bands of the color spectrum. The amount of reflected sunlight changed periodically by about a factor of ten (2.5 magnitudes) as `Oumuamua rotated every 8 hours. This implied that it has an extreme shape which is at least ten times longer than it is wide when projected on the sky. The dashed white line shows the curve expected if `Oumuamua were an ellipsoid with a 1:10 aspect ratio. However, the best fit to the light curve from its tumbling motion implies a flattened, pancake-shaped configuration rather than an oblong, cigar-shaped object as commonly depicted in the media.

Image credit: ESO/K. Meech et al.

Caption credit: Loeb

Professor Loeb shows the light curve observed from `Oumuamua, see above, in support of his ideas about the shape of this ISO. Most researchers have come to similar conclusions so this is not controversial.

However he does not mention the regularity of the curve - which implies that the tumbling behaviour did not change. He does not mention that this also makes it unlikely that outgassing was responsible for the anomalous acceleration component in its motion unless a mechanism can be found which kept the resulting thrust vector exactly through the centre of mass.

Some of the natural object explanations suggest that objects like `Oumuamuawill appear soon but even if they are correct then their occurrence will be random and the mathematical distribution of Monsieur Poisson applies. Professor Loeb will be free to suggest that non-arrival supports his view since we cannot expect his suggested ETIs to conform to any particular statistics. The solution, a mission to the only `Oumuamua - like object we know, 1I itself, is staring us in the face!

News Feature: The Journals

John I Davies

Principium has been logging interstellar papers published in the Journal of the British Interplanetary Society (JBIS) for some years. In the last issue we also logged interstellar papers in Acta Astronautica (ActaA), the commercial journal published by Elsevier, with the endorsement of the International Academy of Astronautics. On this second occasion we have also aimed to capture ActaA papers since our last issue.

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

JBIS V74 #8 August 2021	**General Issue**	
Dry Space and Solar Sails: Resource Limits and Environmental Constraints on Near Future Space Industry	Stephen Baxter	-
Roadmap to Nuclear Gas Core Rockets	Colin Warn	Washington State University
JBIS V10 October 2021	**General Issue**	
Possible Space Mission To The Trans-Neptunian Object 2012 VP113	Vladislav Zubko & Andrey Belyaev	Russian Academy of Sciences & Bauman Moscow State Technical University

Zubko & Belyaev - trajectory to 2012 VP113 in 2026 using the EVEEJN-A scheme with the time of flight of 32.7 yrs.

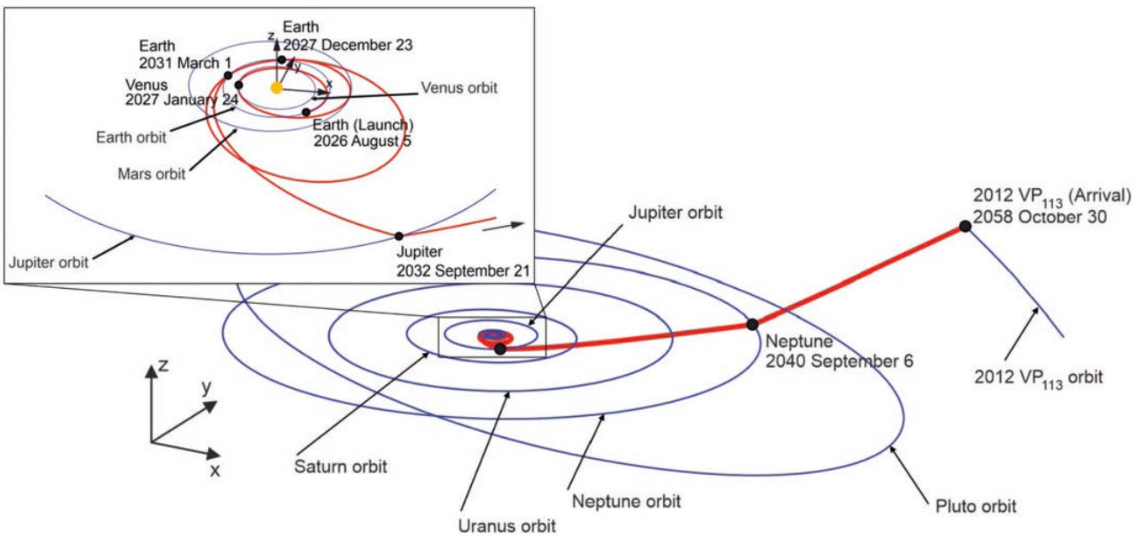


Fig.9 The trajectory to 2012 VP_{113} in 2026 using the EVEEJN-A scheme with the time of flight of 32.7 yrs.

Acta Astronautica

Two i4is papers in **bold** below.

<table>
<tr><td>Title</td><td>Number+date</td><td>Author(s)</td><td>Affiliation</td></tr>
<tr><td>Thinking ET: A discussion of exopsychology</td><td>#25 September 2021</td><td>Niklas Alexander Döbler, Marius Raab</td><td>Otto-Friedrich-Universität Bamberg</td></tr>
<tr><td colspan="4">Exopsychology concerned with extraterrestrial minds is proposed. Extraterrestrials are identified as high-order cognitive agents. A distinction between inadmissible and admissible anthropocentrism is useful. We must investigate the human representation of extraterrestrials. The concept of intelligence is not useful to SETI.</td></tr>
<tr><td>Sending a spacecraft to interstellar comet 2I/Borisov*</td><td>#14 September 2021</td><td>Adam Hibberd, Nikolaos Perakis, Andreas M. Hein</td><td>i4is</td></tr>
<tr><td colspan="4">Missions to Interstellar Object, 2I/Borisov, are studied. Chemical/High Impulsive Thrust Propulsion is assumed. A direct trajectory as well as a Jupiter/Solar Oberth Maneuver are examined. Viable missions are found using the NASA Space Launch System or the SpaceX Falcon Heavy.</td></tr>
<tr><td>Strategies and advice for the Search for Extraterrestrial Intelligence*</td><td>#22 July 2021</td><td>Jason T. Wright</td><td>Penn State University</td></tr>
<tr><td colspan="4">Overview of observational strategies for SETI. Rough map of the landscape of possible technosignatures. Discussion of the importance of and strategies for placing upper limits on technosignatures. Recommendations for those seeking to enter the field.</td></tr>
<tr><td>ESA F-Class Comet Interceptor: Trajectory design to intercept a yet-to-be-discovered comet</td><td>#16 July 2021</td><td>Joan Pau Sánchez, David Morante, Cecilia Tubiana</td><td>Cranfield University</td></tr>
<tr><td colspan="4">Comet-I mission aims to explore a Long Period Comet; ideally, dynamically new. Such a target will remain unidentified, possibly, even after launch. The paper analyses the orbital space that will be accessible for Comet-I S/C. Chemical, electric and hybrid propulsion systems are modelled in patched-conic. A Monte Carlo analysis shows a 95–99% of completing the mission within 6 years.</td></tr>
<tr><td>Metalaw – What is it good for?</td><td>#29 June 2021</td><td>Michael Bohlander</td><td>Durham University</td></tr>
<tr><td colspan="4">Metalaw, Cosmic ethics, SETI and Law, Hostile encounter, Discovery of ETI.</td></tr>
<tr><td>Modal Analysis of Electric sail</td><td>#7 May 2021</td><td>Todd D. Lillian</td><td>Purdue University</td></tr>
<tr><td colspan="4">Derivation of an analytical model for electric solar wind sail vibrations. Simple models accurately predict natural frequencies of electric solar wind sails. Hub and spoke electric solar wind sails can configured to be infinitesimally stable.</td></tr>
<tr><td>Near-term self-replicating probes - A concept design*</td><td>#2 April 2021</td><td>Olivia Borgue, Andreas M Hein</td><td>i4is</td></tr>
<tr><td colspan="4">Self-replicating probes may enable exponentially accelerating space exploration. We present a concept for a near-term self-replicating probe. At least 70% of its dry mass can be replicated. Operations would be limited to the inner solar system. A technology roadmap for achieving full replication and interstellar exploration.</td></tr>
</table>

* discussed elewhere in Principium.

The i4is Members' Page

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

The i4is Talk Series

The i4is Talk Series will return early in the new year. Rob Swinney is currently planning this. If you would like us to cover a specific topic then email Rob.Swinney@i4is.org or John.Davies@i4is.org.

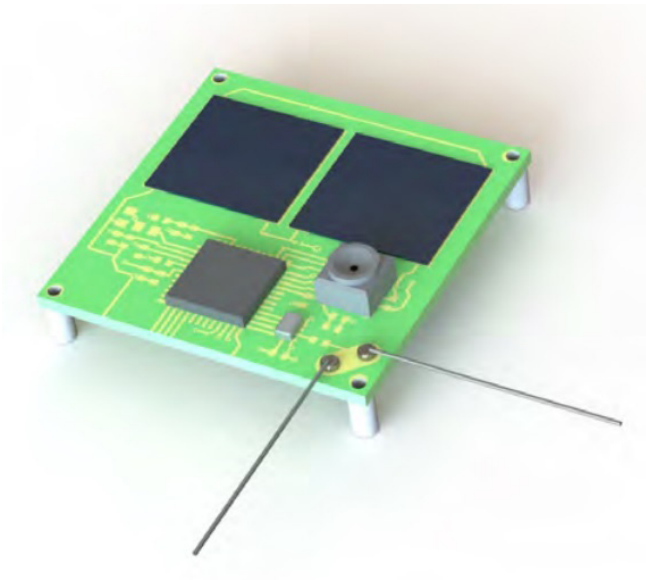
Members can access videos and presentations of all the past series via - i4is.org/what-we-do/education/talk-series.

Members' Newsletter

The latest *Newsletter: Writers Needed!* came to you on 13 November. If you would like to contribute or assist with editing then please contact the editor, Conor MacBride, via Conor.MacBride@i4is.org. Items in this issue included *Limitless Space Institute: Human Exploration of the Far Solar System and on to the Stars* and *Talk Series — Series 3 Videos.*

Helping to achieve interstellar objectives

As Tsiolkovsky remarked "Earth is the cradle of humanity but one cannot live in a cradle forever". Members of i4is are helping our species to take our first toddler steps and to envisage what we can achieve when we mature into an interplanetary and interstellar species. We appreciate your help and, if you have time, we would appreciate application of your personal skills to our endeavours. Contact any of us via our email addresses or simply use info@i4is.org - which is checked daily and forwarded to the appropriate member of the team.



Project Pinpoint

The technical team within i4is supports a number of projects by both management and finance. This includes hardware such as Project Pinpoint's current chipsat design above, instruments and software-defined radio for testing. More about this project in Project Pinpoint: Pushing the Limits of Miniaturization by Andrew Broeker in Principium 33, May 2021, or at i4is.org/wp-content/uploads/2021/05/Project-Pinpoint-Pushing-the-Limits-of-Miniaturization-Principium33-print-2105280923.pdf

72nd International Astronautical Congress 2021
The Interstellar Papers

edited by John I Davies

This year the International Astronautical Federation once more held the International Astronautical Congress in a geographical location, this year in Dubai. In this first of two pieces we report on items which are likely to be of special interest to Principium readers. Some are explicitly interstellar in topic but others are important in contributing to our interstellar goal including innovations in propulsion, exploitation of resources in space, deep space communication and control, enhanced and economical access to space, etc.

Our onsite reporter was i4is Contributing Editor Samar AbdelFattah of DM TECH (www.disruptivemobility.com).

Here you will find -

- Code - the unique IAC code and a link to the Abstract
- Paper title, Speaker, institutional Affiliation and Country
- Links to papers and videos on the IAF website (login required) and to open publication where found
- Remote reports by - Adam Hibberd & John I Davies

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

We will have more reports and background in our next issue, Principium 36.

At IAC 21

Images credit: Samar AbdelFattah

IAF reference	title of talk/paper	presenter	institution	nation
IAC-21,A3,IP,58,x65239	Optimum Location to Intercept Interstellar Objects with Build-and-wait Missions	Laia Lopez Llobet	International Space University (ISU)	France

IAF cited paper:

dl.iafastro.directory/gallery/file/IAC-21/A3/IP/IAC-21,A3,IP,58,x65239.pdf

IAF cited presentation video:

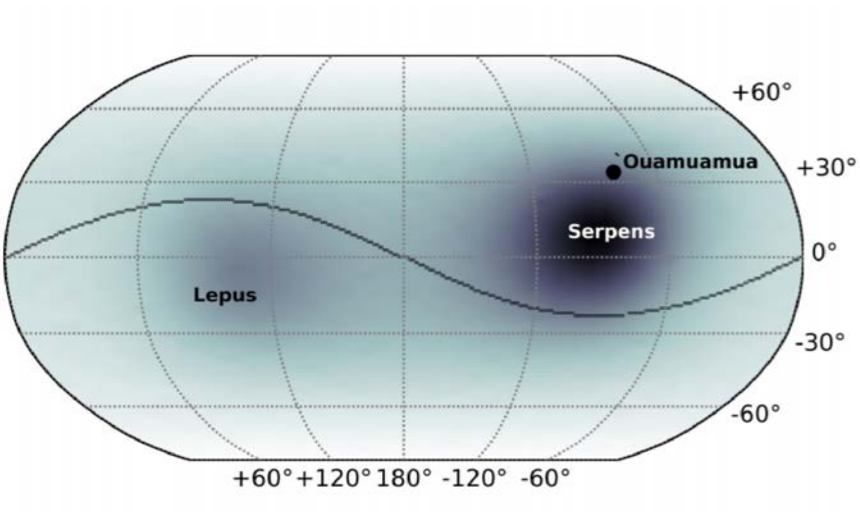
dl.iafastro.directory/gallery/file/IAC-21/A3/IP/IAC-21,A3,IP,58,x65239.lecture.mp4

Open paper: none found

Reported by: John I Davies

The ESA Comet Interceptor mission will launch in 2028 to the Sun-Earth Lagrange 2 position (joining the existing Gaia astrometry mission, the James Webb space telescope and others at this convenient quasi-stable point in the Earth-Sun system [1]). The Comet Interceptor will "lurk" until a suitable object, possibly an interstellar object (ISO), is spotted by one of the increasingly capable telescopes in place and planned for that time.

This study aims to generalise the problem of where best to locate a vehicle specifically intended to reach an ISO. It uses numerical analysis to simulate the potential trajectories of ISOs through the Solar System and calculates where they will intersect the ecliptic plane. The most likely incoming vectors are at the solar apex and anti-apex.



Entire caption credit: Lopez Llobet-

Fig. 3. Probability map from a heliocentric perspective representing the likelihood of ISOs approaching with a velocity vector parallel to the vector pointing from the Sun to a particular position in the sky. A higher probability is indicated with darker colors. The ecliptic is represented by a black line. The positions of 1I/'Oumuamua entering the Solar System and the constellations Serpens and Lepus have also been represented. These constellations are in the solar apex and anti-apex, respectively.

It uses MATLAB (in common with the work of Adam Hibberd for i4is Project Lyra - see multiple issues of Principium) to create the ISOs' trajectories. The trajectories are all hyperbolic with respect to the Sun, eccentricity >1, and the study considers eccentricities up to 9.

The study also examines the probability of ISO impact on the Earth and concludes that ISOs will average a hit every ten million years but with the caveat that only objects around the size of 1I/'Oumuamua or above are considered (so don't relax yet, an object half the size of 1I could do a lot of damage!). In fact the study suggests that Earth is near-optimally placed to intercept an ISO supporting the hypothesis that prebiotic molecules could have been brought to Earth by an ISO.

The study looks at costs and logistics and suggests that an ISO interceptor should probably be space-based, like the already planned ESA mission, but Earth based build-and-wait missions have advantages and should not be ruled out.

Authors: Laia Lopez Llobeta (ISU), Chris Welch (ISU), Andreas M Hein (i4is)

[1] To be clear, L2 is a dynamically unstable Lagrange point. A useful analogy is the top of a hill rather than the bottom of a valley. For example Gaia is not stationary but is in a "figure of eight" Lissajous-type orbit around the L2 point of the Sun-Earth system.

IAF reference	title of talk/paper	presenter	institution	nation
IAC-21,C3,IP,x65677	High-Temperature Photovoltaic Cells for Near-Sun and Interstellar Precursor Missions: State of the Art and Future Developments	Corentin Guemene	International Space University (ISU)	France

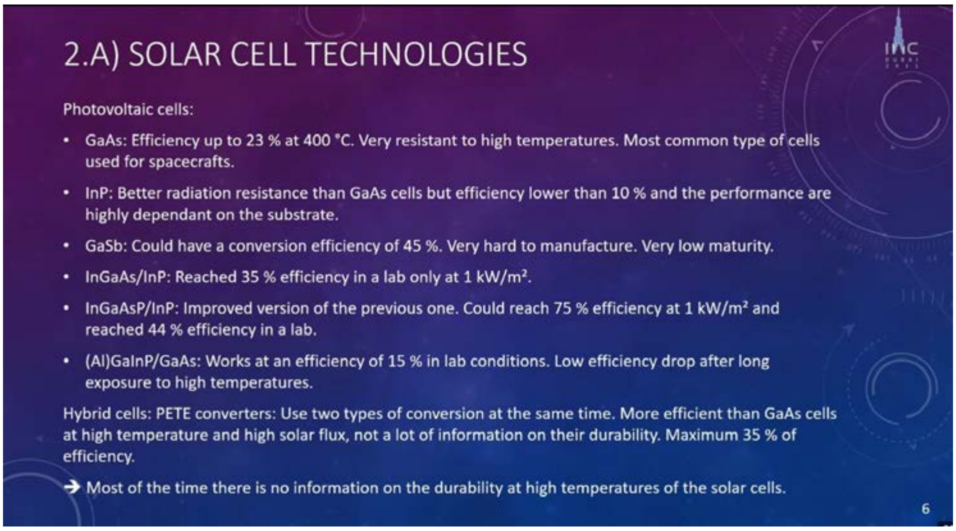
IAF cited paper:
dl.iafastro.directory/gallery/file/IAC-21/C3/IP/IAC-21,C3,IP,x65677.pdf

IAF cited presentation video:
dl.iafastro.directory/gallery/file/IAC-21/C3/IP/IAC-21,C3,IP,x65677.lecture.mov

Open paper: none found

Reported by: John I Davies

Missions close to the Sun are conveniently powered by the light of our local star. However, at the orbit of Mercury and closer, temperatures are challenging for current solar cells [1]. This study focuses on both these applications and on high-power electric propulsion with an external laser power source. Three missions are considered -



- Mercury orbiter
- Solar probe to study the Sun from close orbit
- Interstellar precursor mission to the outer Solar System and beyond

Solar cell technologies
Credit: Guemene

Existing material technologies examined include GaAs (Gallium arsenide), InP (Indium phosphide), GaSb (Gallium antimonide), multi-layer technologies (InGaAs/InP, InGaAsP/InP. (Al)GaInP/GaAs) and Hybrid Photon-Enhanced Thermionic Emission (PETE) converters (for example with a GaAs absorption layer and a GaAs photovoltaic cell).

Powering a spacecraft via external lasers is attractive because the craft need not carry large solar arrays (and can reach targets distant from the Sun) or a radioisotope thermal generator (RTG). The study identifies some challenges including a single optimum frequency (ie monochromatic) source, precise pointing and possible need for even larger photovoltaic arrays and laser sources, especially at low frequencies (ie long wavelengths).

The past MESSENGER craft, the current BepiColombo mission to Mercury and the projected Solar Probe+ are examples of the high temperature solar power application. The projected Solar Probe+ would study the Sun from 8.5 solar radii.

The study concludes with a discussion of the Technology Readiness Levels (TRLs) [2] of the various materials against several possible missions: Mercury, near-Sun, and interstellar precursor.

Authors: Corentin Guemene (ISU), Chris Welch (ISU), Rob Swinney (i4is), Angelo Genovese (i4is)

[1] Mercury is about 75 solar radii out, but probes which aim closer either for research reasons or to achieve gravity-assisted acceleration are planned to get much closer.

[2] Technology Readiness Level (TRL) - The ESA Science Technology Development Route sci.esa.int/web/sci-ft/-/50124-technology-readiness-level.

IAF reference	title of talk/paper	presenter	institution	nation
IAC-21,D3,1,7,x63937	Advanced Propulsion as a Cornerstone for Space Exploration and Interstellar Living	Tommaso Tonina	International Space University (ISU)	France

IAF cited paper:

dl.iafastro.directory/gallery/file/IAC-21/D3/1/IAC-21,D3,1,7,x63937.pdf

IAF cited presentation video:

dl.iafastro.directory/gallery/file/IAC-21/D3/1/IAC-21,D3,1,7,x63937.lecture.mp4

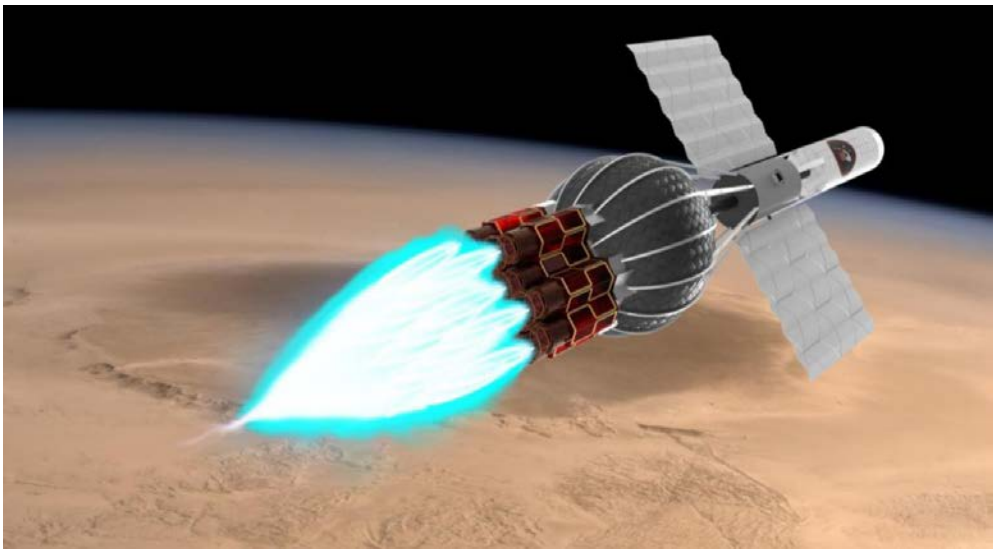
Open paper: none found

Reported by: John I Davies

Mission patch

Credit: ISU *Space Studies Program Team Project, Fast transit: Mars and beyond*

The bold ambition of this paper is missions accelerating at 0.2 g with a mid-journey flip to decelerate. Implying missions to Mars in 4-10 days using rocket having specific impulse (Isp) of 19,000 seconds a thrust/weight ratio of 2.94 using either Magnetic Inertial Confinement Fusion (MICF) with current TRL 2-3, or Antimatter Catalysed Fusion (ACF) with current TRL 2. They propose a large initial investment, likely through a Public Private Partnership (PPP), to demonstrate feasibility, delivering quick access to abundant raw materials as the return on investment. Achieving this would lead to a change in perception about accessibility of space travel. The team conducted interviews and discussions with key experts and a systematic review of the literature. They considered orbital mechanics and trajectories including an Earth-Mars cycler and the use of Lagrange points but settled on a direct Earth-Mars trajectory using the advanced rocket technologies MICF or ACF, settling on ACF and calling this "Fast Transit spaceflight". They also considered human factors, social ethical implications, the business implications of such a major undertaking and the legal issues - notably the dangers presented by such powerful rocketry. They present a highly ambitious roadmap and spin-off benefits for research missions and commercial applications.



Proposed spacecraft in transit near Mars - from -

International Space University Space Studies Program Team Project, Fast transit: Mars and beyond, Illkirch-Graffenstaden (France), 2019. -

:isulibrary.isunet.edu/index.php?lvl=notice_display&id=10798

Authors: Tommaso Tonina (ISU), Hamda Alshehhi (UAE Space Agency), Jason Dowling (CSIRO Australian e-Health Research Centre), Gustavo Jamanca-Lino (Colorado School of Mines), Erin Kennedy (Robot Missions Inc, Ontario), Yelyzaveta Kucher (ISU), Rijin K V (Indian Space Research Organisation), Itai Norber (ImageSat International NV, Israel)

IAF reference	title of talk/paper	presenter	institution	nation
IAC-21,E5,3,7,x66226	Virtual futuristic analogue missions to drive methodological innovation for clinical research for space mission and earth	Mona Nasser	University of Plymouth	UK

IAF cited paper:

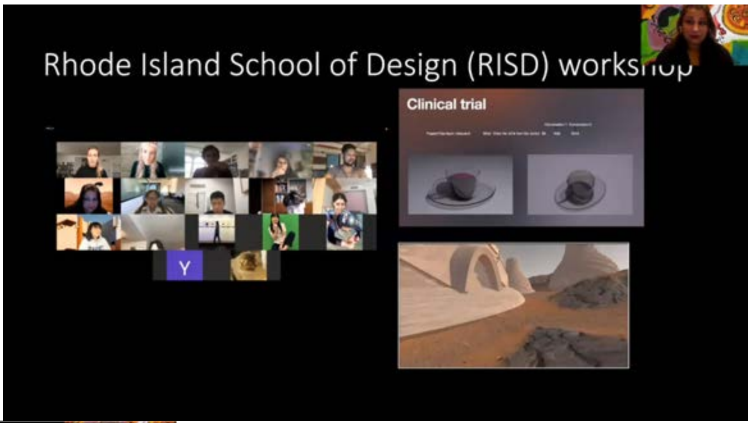
dl.iafastro.directory/gallery/file/IAC-21/E5/3/IAC-21,E5,3,7,x66226.pdf

IAF cited presentation video:

dl.iafastro.directory/gallery/file/IAC-21/E5/3/IAC-21,E5,3,7,x66226.lecture.mov

Open paper: none found

Reported by: John I Davies



The team piloted a series of virtual workshops using a futuristic sci-fi scenario for interplanetary and interstellar missions adapted for a virtual environment. They aimed for innovative approaches to the methods of clinical research in this context. In 2019, and 2020 they first conducted small groups of pilot hybrid workshops and moved on to four workshops with 20-30 people (engineers, lawyers, artists, clinical researchers, medics, geologists, other sciences and professionals). Having identified several limitations in current space medicine literature they immersed participants in a futuristic scenario, modulating participant tendencies to reinterpret the scenario presented into something more familiar. The team included a layer of meta-research which they termed "forensic backcasting" of scientific methods.

Some interesting results included participants starting to take an ecological approach to design clinical research and participants' confusion between risk and uncertainty. The team aim to extend their exercise to an interstellar scenario.

Venues included Torbay Hospitals (UK), the Cochrane Colloquium in Edinburgh, the office of Transtech (Plymouth, UK), the EDGE clinical trial conference in Southampton (UK), the International Space University and Rhode Island School of Design

Authors: Mona Nasser (University of Plymouth), Jacqui Knight (University of Plymouth), Agatha Haines (Rhode Island School of Design), Diego Maranan (University of the Philippines),

Ann Peeters (Space Ecologies Art and Design, Belgium), Prashanti Eachempati & Sumanth Kumbargere Nagraj (Manipal University, Malaysia), Mr Joshua Bernard-Cooper (UK)

IAF reference	title of talk/paper	presenter	institution	nation
IAC-21, A7,3,2,x67120	Comet Interceptor: A daring mission to a long period comet or an interstellar object	Dr Mohamed Ramy Elmaarry	Khalifa University of Science and Technology (KUST)	United Arab Emirates

IAF cited paper:

dl.iafastro.directory/gallery/file/IAC-21/A7/3/IAC-21,A7,3,2,x67120.pdf

IAF cited presentation video:

dl.iafastro.directory/gallery/file/IAC-21/A7/3/IAC-21,A7,3,2,x67120.lecture.mp4

Open paper: None found

Reported by: Adam Hibberd

This is an audacious combined ESA and JAXA F-class mission with a serious British involvement in the form of the Mullard Space Science Laboratory. Its whole raison d'etre is based on statistical predictions on three counts:

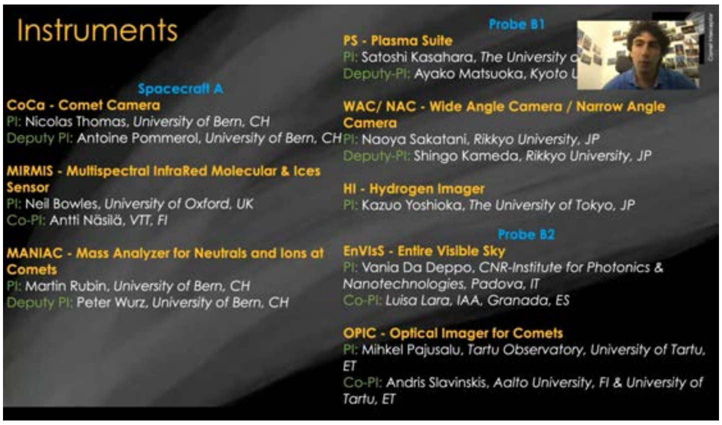
1. there are a sufficient number of dynamically new comets encountering the inner solar system
2. when the Vera C Rubin telescope comes into operation, it will be able to detect a sufficient quantity of them
3. there will be at least one which will be reachable by the spacecraft during its 3 year mission.

There is however a failsafe to the mission in that there are several short period comets which the mission designers have in mind and which would serve as a back-up if the statistical calculations are off-beam.

In simple terms Comet-I is a spacecraft capable of waiting in space for up to three years at a planned point, the Sun-Earth Lagrange 2 Point to be precise. There it will tag a free ride shadowing the Earth as it orbits the sun, counterbalanced perfectly by the forces from these two celestial bodies.

Once an appropriate 'dynamically new comet' (a comet possibly new to the inner solar system so in a relatively pristine condition - not eroded by the sun) is found by the Vera C Rubin, then at a suitable juncture the spacecraft will be sent a dispatch command from Earth to intercept this comet.

Relative velocities as high as 70 km/s are possible. Generally speaking, optimal intercept happens when the comet crosses the ecliptic, meaning the spacecraft need not apply much – or any – ΔV out of the ecliptic plane, where the Sun/Earth L2 lies of course. This 70 km/s figure makes sense because a comet arriving from approx. infinity would have a speed at 1 AU of 42 km/s. If one further supposes this is the worst case scenario (ie retrograde) and the s/c is travelling at Earth's speed of 30 km/s prograde, then these two speeds are additive, giving the 70 km/s (approx) stated in the paper.



Just before intercept, two smaller probes will be detached from the mother craft and study the comet in detail separately yet simultaneously and an image of the comet can be generated.

The relevance to i4is is the possibility that an ISO might be found in this three year span. If this happens then it would truly be a jackpot with implications regarding the potential scientific return which would result.

Authors: Mohamed Ramy El-Maarry, Geraint H Jones, Colin Snodgrass, Cecilia Tubiana, and the Comet Interceptor Team

IAF reference	title of talk/paper	presenter	institution	nation
IAC-21,A4,1,17,x63320	The Drake equation and SETI in the JWST era	Amri Wandel	Hebrew University of Jerusalem	Israel

IAF cited paper:

dl.iafastro.directory/gallery/file/IAC-21/A4/1/IAC-21,A4,1,17,x63320.pdf

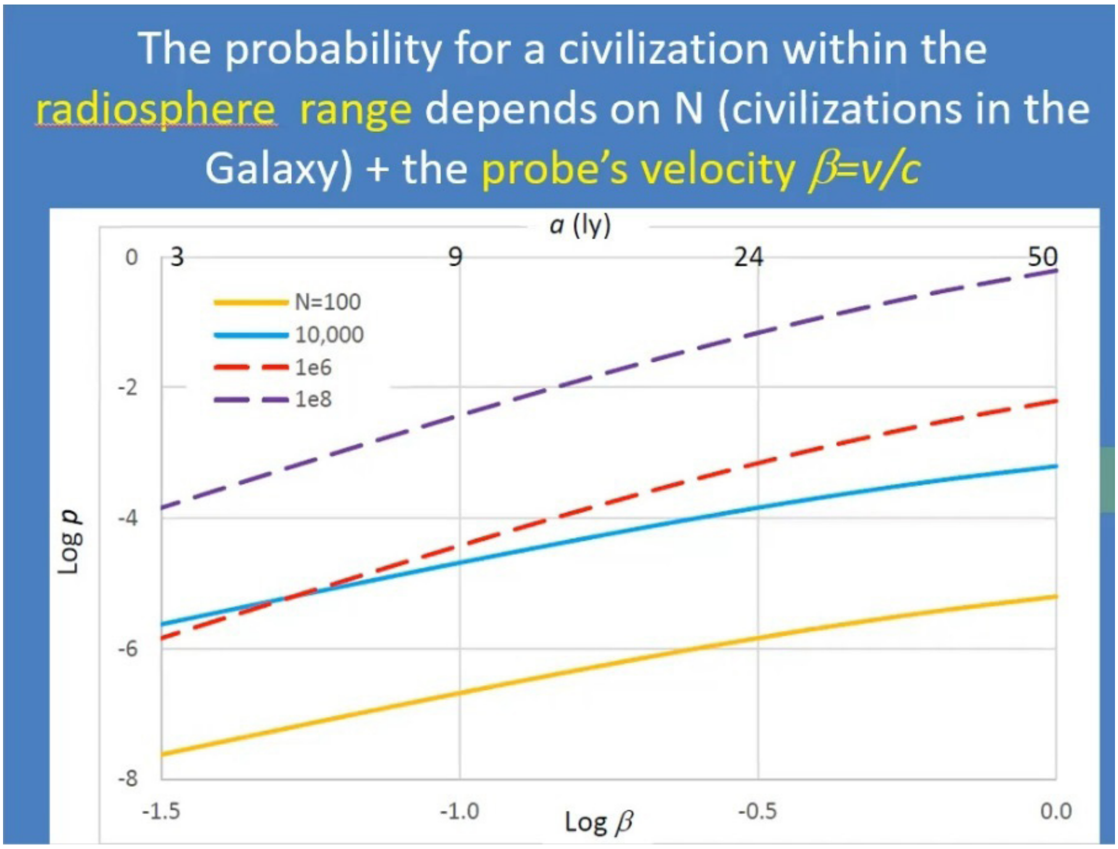
IAF cited presentation video:

dl.iafastro.directory/gallery/file/IAC-21/A4/1/IAC-21,A4,1,17,x63320.lecture.mp4

Open paper: None found

Reported by: John Davies

In another paper at this congress (IAC-21-A1.6.1 Extended Habitable Zone of M-dwarf planets) the presenter suggests that "the Habitable Zone around M-stars is significantly wider than previously thought". Arguing that, with current receiver technology, we can only detect signals deliberately aimed at our solar system. Therefore our "radiosphere" (the radius reached by our unintentional signals) may represent the maximum distance from which we might expect to receive such signals. Wandel also considers probes sent by such ETIs, assumes that they would have two-way communication with their home world and that signals from the home world would be powerful enough for us to detect. He also argues we should look for such signals in the Earth's "transit zone" since we may be detected by analysis of our atmosphere as it intercepts light from the Sun. Overall he concludes that the Fermi Paradox and "The Great Silence" may be attributed just to the sluggish velocity of light!



Plot of (log) probability of civilisations within Wandel's "radiosphere" range against (log) velocity of a probe sent to our Solar System as a fraction of the velocity of light, c.

Suggesting that negative SETI results apply only to that radiosphere.

Credit: Wandel

IAF reference	title of talk/paper	presenter	institution	nation
IAC-21,A4,1,18,x63279	Moon Farside Protection and Astronomy Protection Are Urgent: Asking For A “Farside Science Treaty” Also Called “Switch-Off-Treaty” (“SOT”)	Dr Claudio Maccone	International Academy of Astronautics (IAA) and Istituto Nazionale di Astrofisica (INAF)	Italy

IAF cited paper: dl.iafastro.directory/gallery/file/IAC-21/A4/1/IAC-21,A4,1,18,x63279.pdf

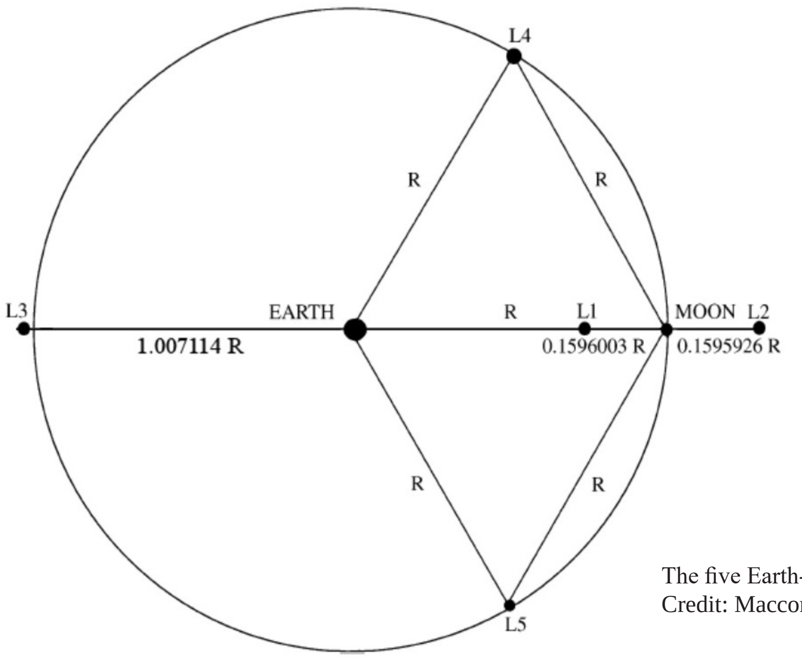
IAF cited presentation video: dl.iafastro.directory/gallery/file/IAC-21/A4/1/IAC-21,A4,1,18,x63279.lecture.mp4

Open paper: None found

Reported by: John Davies

Claudio Maccone is one of the greatest and most long-engaged researchers in SETI. Here he argues that, since the Moon Farside is the only place where radio transmissions and noises produced by Humanity on Earth may not reach, the legal protection of the Moon Farside from all kinds of non-scientific future exploitations (real estate, industry and military) has long been a concern. The current "race to Moon" adds to the threat. The farside must be reserved for radar watch (for Earth-impact warning), cosmology and SETI. He proposes the signing of a “Farside Science Treaty” or “Switch-Off-Treaty” by all space-faring Nations under the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS). He gives some history of past farside proposals and notes the recent Chinese relay satellite Queqiao in the Earth-Moon Lagrange 2 (L2) point (beyond the Moon) as the first of what may be many transmitters above the farside. Queqiao would "blind" any future radio telescope on the farside.

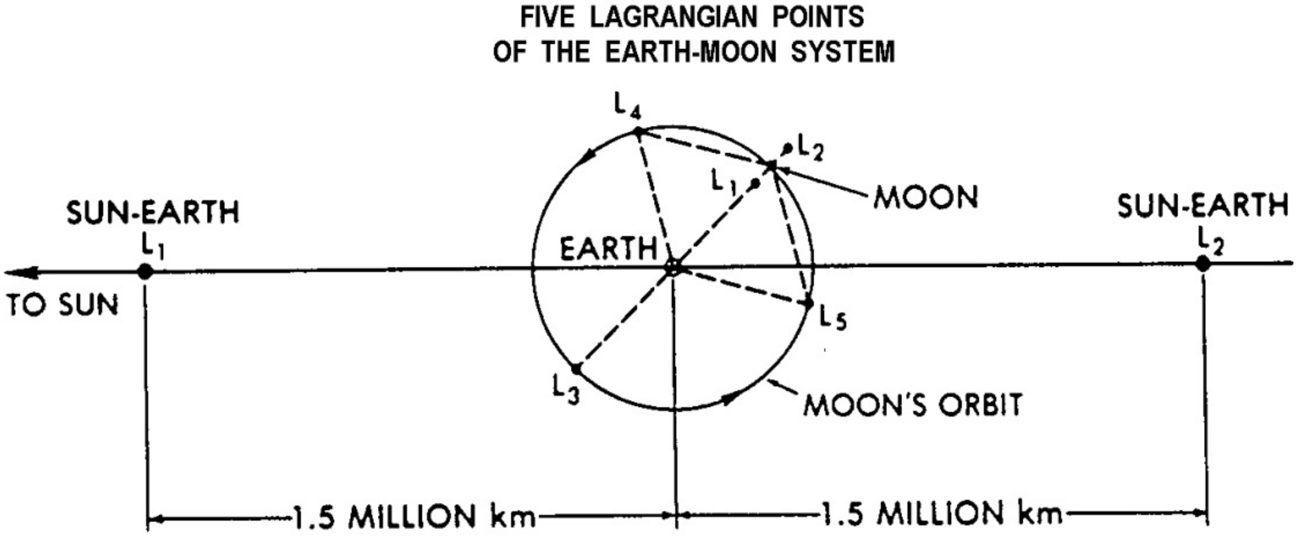
Maccone proposes a Protected Antipode Circle in the centre of the farside protected from radiation coming from L2 and even L4 and L5 (equivalent to the Trojan positions in the Jupiter-Sun system).



The five Earth-Moon Lagrangian Points
Credit: Maccone

There is clearly a "quiet cone" where transmission from Earth and our satellites do not reach [1]. As a flat surface near the centre of the farside area defined by the "quiet cone", Maccone proposes the crater Daedalus for a radio observatory in what may be the quietist place in the near solar system.

[1] Since geostationary satellites are 42,000 km from the centre of the Earth the cone diameter is 84,000 km and the sides are tangents to the Moon's surface



[credit Maccone] "(Courtesy of the late Dr Robert "Bob" Farquar, Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA). In addition to the five Lagrangian Points of the Earth-Moon system (already described in Figure 4) the next two closest Lagrangian Points to the Earth are the Lagrangian Points L1 and L2 of the Sun-Earth system. These are located along the Sun-Earth axis at the distances of about 1.5 million kilometers from the Earth toward the Sun (L1) and outward (L2). Unfortunately, spacecrafts located in the neighborhood of these L1 and L2 Sun-Earth Points do send electromagnetic waves to the Farside of the Moon. Examples are the ISEE-III and Soho spacecrafts, already orbiting around L1, and more spacecrafts will do so in the future around both L1 and L2."

Other places polluting radiation are the Earth-Sun Lagrange points L1 (between Earth and Sun) and L2 (beyond Earth). These are already occupied and are polluting the Moon's "quiet cone" (during new moon and full moon and times around them).

Maccone lists and characterises a number of other pollution source both human and natural and exhorts all with authority and influence to support the proposed Farside Science Treaty.

IAF reference	title of talk/paper	presenter	institution	nation
IAC-21,A4,2,12,x61987	Radio Bridges of the Future between Solar System and the Nearest 50 Stars	Claudio Maccone & Nicolò Antonietti	International Academy of Astronautics & Istituto Nazionale di Astrofisica	Italy

IAF cited paper: dl.iafastro.directory/gallery/file/IAC-21/A4/2/IAC-21,A4,2,12,x61987.pdf

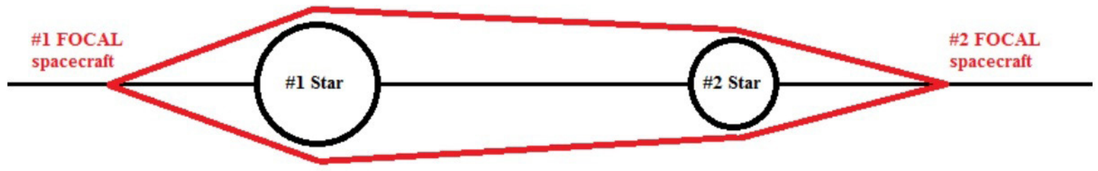
IAF cited presentation video:

dl.iafastro.directory/gallery/file/IAC-21/A4/2/IAC-21,A4,2,12,x61987.lecture.mp4

Open paper: None found

Reported by: John Davies

Dr Maccone (see report IAC-21,A4,1,18,x63279 above) discusses the 50 potential radio bridges between the Sun and each of our nearest 50 stars using the Solar Gravitational Lens (SGL) positions which exist for all massive bodies such as stars. In the coming centuries he envisages a communications network using these radio bridges as energy-efficient relay points. He gives a quick introduction to the SGL concept and goes on to suggest scenarios with and without the SGL. He suggests a gain of about 70 db for the SGL (meaning $10^{7.0}$ = 10 million). This advantage makes his proposed network feasible at greatly reduced transmitter powers. He suggests that "a Civilization much more advanced than Humans in the Galaxy might already have created such a network of cheap interstellar radio links: a true Galactic Internet". If we want to join it we must build relays at SGL points oriented towards our neigbours.



Maccone's illustration of the transmit and receive gain at the end of a SGL relay.

Using his 70 db gain per SGL this would be 70+70=140 or $10^{14.0}$ = 100,000,000,000,000 or 100,000 billion.

Image credit: Maccone

He gives numerical examples of bridges between the Sun and Barnard's star (about six light years), the Sun and Sirius-A, between the Sun and another sun-like star located at the galactic bulge and finally between the Sun and another sun-like star located inside the Andromeda galaxy (M 31). He tabulates the relevant parameters of 50 stars [1] and estimates to potential channel capacities for relays between each of them and the Sun.

This is a very long term vision but Dr Maccone believes that the present paper will still be useful in a few centuries to set up his Roadmap of the Human Expansion into the Galaxy.

IAF reference	title of talk/paper	presenter	institution	nation
IAC-21,A4,2,18,x62033	The Need for a Worldwide and International SETI Journal	Dr Claudio Maccone	International Academy of Astronautics (IAA) and Istituto Nazionale di Astrofisica (INAF)	Italy

IAF cited paper: dl.iafastro.directory/gallery/file/IAC-21/A4/2/IAC-21,A4,2,18,x62033.pdf

IAF cited presentation video:

dl.iafastro.directory/gallery/file/IAC-21/A4/2/IAC-21,A4,2,18,x62033.lecture.mp4

Open paper: None found

Reported by: John Davies

Dr Maccone observes that Acta Astronautica (ActaA) is the official journal of the International Academy of Astronautics (IAA). The publisher Elsevier believes there is insufficient audience for a specialised SETI journal but Maccone has found that SETI papers are often rejected by ActaA and a SETI journal would need a wider cultural scope than ActaA. He suggests that SETI needs to become more "political", helping the world to become ready for a possible “SETI Crisis” in case of first contact with ETI. Maccone gives some history of SETI and identifies 12 current SETI programmes. The limitations of ActaA are, to an extent, made up by the IAF Digital Library set up last year.

Dr Maccone concludes by asking "is the time ripe for the creation of a New International Journal devoted to SETI Only ?"

[1] Proxima Centauri, Barnards star, Wolf 359, Lalande 21185, Sirius A, BL Ceti, Ross 154, Ross 248, Epsilon Eridani, Lacaille 9352, Ross 128, EZ Aquarii A, Procyon A, 61 Cygni A, Gliese 725 A, GXAndromedae, Epsilon Indi A, DX Cancri, Tau Ceti, Gliese 1061, YZ Ceti, Luyten star, Teegarden star, Kapteyn star, Lacaille 8760, Kruger 60 A, Ross 614 A, Gliese 628, Gliese 35, Gliese 1061, Wolf 424 A, TZ Arietis, Gliese 867, LHS 292, Gliese 674, Gliese 1245 A, Gliese 440, Gliese 1002, Ross 780, Gliese 412 A, Groombridge1618, Gliese 388, LHS 288, Gliese 832, LP 944-020, DENIS/DEN02554700, Gliese 682, 40 Eridani A, EV Lacertae, 70 Ophiuchi A

Losing Access to Space

Are we building a fence around our planet?

A personal view - John I Davies

A recent article in Space Daily [1] flagged by a BIS news group [2] raised again the concern that we may be fencing ourselves in to our planet with orbiting debris. The interstellar ambitions of i4is and our companions in this long-term endeavour may thus be rendered unachievable even in the long term.

Debris around Earth.
Credit: ESA

A look around Google Scholar finds much legal & regulatory, a fair bit on proposals for remediation and some about equipping satellites to de-orbit themselves.

There seems to be little on long term scenarios including statistical analysis of debris and collisions. Here is a comment in a 2021 paper from the 1st ESA NEO and Debris Detection Conference (2019)-

conference.sdo.esoc.esa.int/proceedings/sdc8/paper/206/SDC8-paper206.pdf

> It is important to emphasize that this framework is not intended to make forecasts of the debris environment, while future iterations may provide useful forecasts, research is still needed to better understand the appropriate model structures and specifications for forecasting [3].

Who is working to yield that research?

My amateur judgement, for what it's worth, is pessimistic. I see no plausible scenarios which do not make access to space hazardous to the point where debris collision is the most significant inhibiting factor limiting our exploitation and exploration of space - possibly to the point where crewed missions are too risky for all but the foolhardy and we simply have to do without space as a resource.

Just as an interplanetary civilisation is a prerequisite for human access to the stars, our access to space is a prerequisite for an interplanetary civilisation. No space means no interstellar.

At Principium I will be keeping an eye on this issue and we would welcome comments from readers - especially those with a professional interest in our long-term access to space.

[1] *A world without access to space*, Oct 25, 2021 www.spacedaily.com/reports/A_world_without_access_to_space_999.html

[2] groups.google.com/g/astronautical-news

[3] *An Integrated Debris Environment Assessment Model*, Akhil Rao and Francesca Letizia, 8th European Conference on Space Debris

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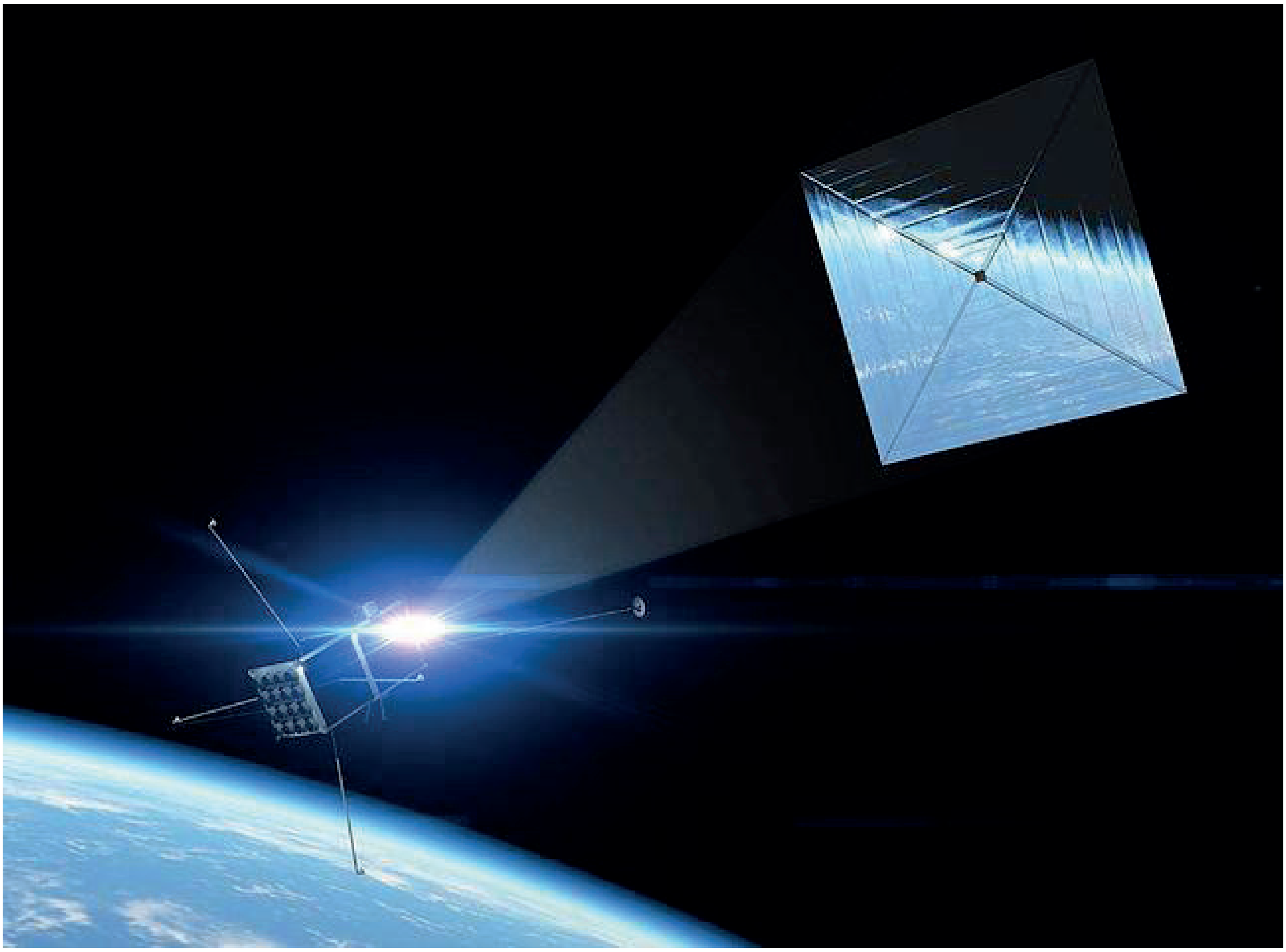

The Initiative for Interstellar Studies (i4is) has launched a membership scheme intended to build an active community of space enthusiasts whose sights are set firmly on the stars. We are an interstellar advocacy organisation which:

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The downlink from swarming micro-probes

John I Davies

Of the two probably feasible means of reaching interstellar distances, tiny laser propelled sailcraft and multi-thousand ton fusion rocket propelled vehicles, the former look the most promising in the next few decades. The downlink transmission of information from either is challenging, given the distances involved but tiny sailcraft present the larger challenge. Earlier pieces in Principium have examined the problem; here we look more closely at the class of solutions which exploit the fact that these sailcraft, can be very numerous since they are individually relatively inexpensive and thus may operate in swarms.

This article is prompted by work in progress by an i4is team. Principium will summarise this work in a later issue. Peter Milne commented most usefully on a draft version. Any errors remain with the author.

Introduction

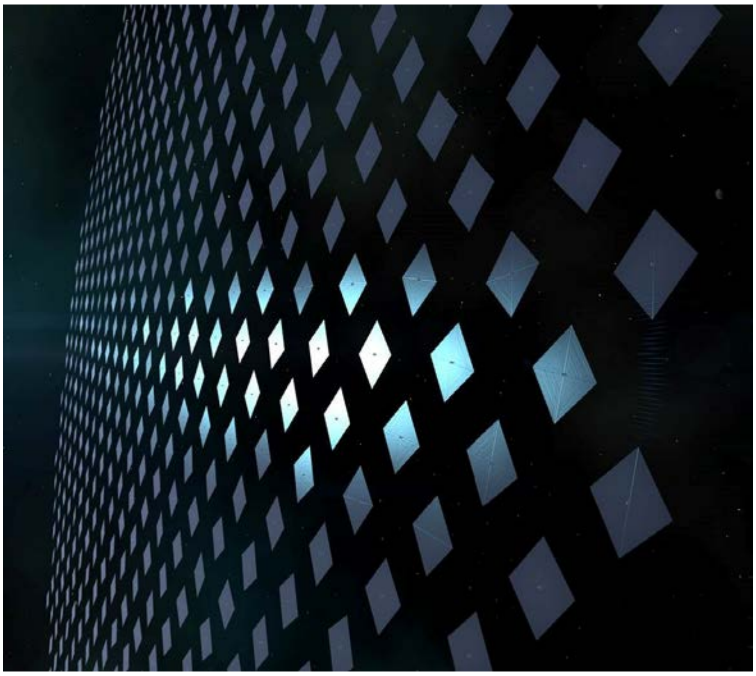
The scale economies made possible by the relatively low cost of tiny sailcraft relative to the very large cost of the multi-Gigawatt laser beamer used to propel them naturally lead to the idea of co-operation between large numbers of probes heading for a single target system. There are at least two ways of exploiting this - a relaying chain of probes reducing the transmit power required by each probe and a swarm of more or less simultaneously arriving probes forming a co-operating array of transmitters. This article will survey both of these, with the emphasis on the swarm approach.

Launching the swarm

The base scenario envisaged by Breakthrough Starshot is a single very large laser array propelling a succession of probes. The economics of this can be (over!) simplified in a linear equation of the form y=ax+b. Specifically -

Total cost = (cost per probe+energy cost per launch)*(number of probes)+(build cost of the laser array) abbreviated to Ct=Cp*Np+Bc.

Since the fixed build cost of the laser array is very large and the expected cost per probe is relatively tiny the number of probes to be launched by a single array is expected to be very large. Like most engineering economics there are complications, the most prominent of which is the energy cost per launch. For the baseline scenario of acceleration to 0.2c and thus about 20 years to Alpha Centauri the re-usable ground-based components are estimated at 8 billion USD and the energy cost per shot is 6 million USD [1].



Sailcraft swarm as envisaged by Adrian Mann (bisbos.com/)

We can assume that, with thousands of tiny sailcraft, costs per sailcraft are likely to be tiny by comparison. If we keep this down to, say, the cost of a current top range smartphone this would be 1,000 USD plus 6 million USD energy cost. If we assume a "fleet" of 10,000 of these then, again very crudely, Ct=Cp*Np+Bc becomes Ct=(1,000+6,000,000)*10,000+8,000,000=60 billion + 8 billion. Even allowing for a factor of 10 underestimate of probe cost it therefore seems likely that hard engineering experience - that things wear out eventually - would mean that replacement or repair of the heavily-used ground-based components will become an important factor.

In short, swarms are cheap - and if you can reduce the energy cost per shot then it may become trivial!

[1] *The Breakthrough Starshot system model*, Kevin L G Parkin, Acta Astronautica V152, Nov 2018 open access parkinresearch.com/wp-content/uploads/2018/07/starshotmodel.pdf

The Bucket Brigade - relaying probes

A paper published last year (2020), *Relaying Swarms of Low-Mass Interstellar Probes* [1] examined the idea of relaying the results from very small probes via a chain of similar probes to overcome the challenge of the inverse square law operating over light years. This was suggested in a proposal by i4is to NASA NIAC [2]. More about this in an earlier issue of Principium, P31[3], reporting from a Starshot workshop with major contributions from the i4is team [4].

The Light Brigade - Swarming at AlphaC

Principium readers are likely to be familiar with co-operation between astronomical telescopes to achieve results which surpass what can be achieved by any single instrument. This is now possible with both optical and radio telescopes and examples range from the UK MERLIN system (www.e-merlin.ac.uk) and worldwide co-operations to single site systems of "antenna farms" such as the Atacama Large Millimeter/submillimeter Array (ALMA) currently in operation [5] or the Square Kilometre Array (SKA) being built at two sites - in Australia and South Africa (www.skatelescope.org).

These are receivers but can this work for transmitters? One obvious example is the use of phased arrays for radar. This is a mature technology developed for military use since the 1950s.

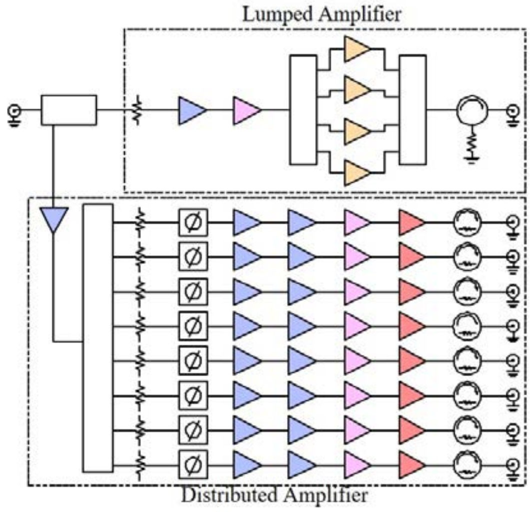


Figure 6. SSPA RF Section

An early example a multiple antenna downlink

Solid State Power Amplifiers (SSPAs) driving multiple transmit antennas in the MESSENGER spacecraft to Mercury [8]

Credit: Robert E Wallis, Sheng Cheng,

The scale economies of laser propulsion, massive expensive laser arrays but tiny and comparatively cheap probes, mean that a large fleet of probes can be propelled by a single laser array. Each probe has very limited capabilities and it is therefore interesting to consider how they might co-operate.

Given the challenges of the downlink this leads to two possible approaches –

• Relaying between probes – each receiving a signal from an earlier probe and transmitting it to a later probe in a “bucket brigade” fashion to overcome the effects of the inverse square law, see *The Douglas Adams Problem squared!* in P31 [6].

• Organise probes as a swarm of widely-separated small spacecraft to behave as a single distributed entity to increase the total transmitted power and narrow the beam transmitted so that more of the signal may be received, see *A Starshot Communication Downlink* in P31 [7].

The recent i4is work addresses the second of these.

[1] *Relaying Swarms of Low-Mass Interstellar Probes*, David Messerschmitt (UC Berkeley), Philip Lubin (UC Santa Barbara) and Ian Morrison (Curtin University, Australia), July 2020, arxiv.org/abs/2007.11554

[2] Reported in the section *Robert Kennedy's observations on Group 8 - Accommodating and exploiting multiple probes* in the Principium article *News Feature: Breakthrough Starshot Communications Workshop* - May 2020 Principium 31 November 2020 page 70

[3] *News Feature: Breakthrough Starshot Communications Workshop - May 2020 Summary and i4is contributions*, Principium 31 November 2020 page 70 - see i4is.org/wp-content/uploads/2021/08/News-Feature-Breakthrough-Starshot-comms-workshop-Principium31-print-2011291231-opt.pdf.

[4] *Starshot Communications Workshop report from Interconnect focus group*, Jacobs, Hein, Swinney, Kennedy (private communication)

[5] *ALMA uses interferometry to combine signals* www.almaobservatory.org/en/about-alma/how-alma-works/.

[6] *The Interstellar Downlink - Principles and Current Work, 2.1 The Douglas Adams Problem squared!* Principium 31 page 28 and i4is.org/wp-content/uploads/2021/08/The-Interstellar-Downlink-Principium31-print-2011291231-opt.pdf.

[7] *The Interstellar Downlink - Principles and Current Work, 4.2 A Starshot Communication Downlink* citing a paper of that title by Kevin L G Parkin, May 2020, see link in previous reference

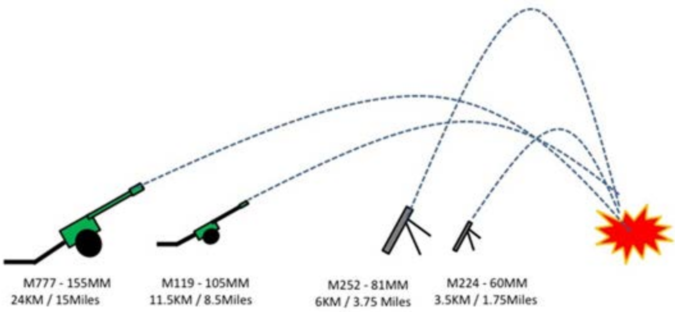
[8] *Phased-Array Antenna System for the MESSENGER Deep Space Mission*, R E Wallis and Sheng Cheng, "Phased-array antenna system for the MESSENGER deep space mission," 2001 IEEE Aerospace Conference Proceedings 2001, pp. 1/41-1/49 vol.1, Open access messenger.jhuapl.edu/Resources/Publications/Wallis_Cheng.2001.pdf

Where multiple transmitters are sending the same information then receivers, whether single or multiple, need to be able to add the signals together to have the best chance of reconstructing the information which has been transmitted. The most prevalent modern example is in distributed mobile networks such as in the 3G, 4G and 5G standards which serve the billions of mobile phones worldwide. These most recent standards provide for multiple base stations to serve any one mobile. Clearly the received signals will not be in step since they have travelled over different distances (and in typical terrestrial settings there will also be reflected signals, sometimes even stronger than the direct signal) [1]. The classic example of this, as seen by a user, is "ghosting" in early television services.

The limitations of very small probes propelled by a very large laser bank suggest that co-operation between them is an idea worth exploring. There are two major challenges in achieving this - bringing a large number of probes together to co-operate at the target star and organising the co-operation between them so that their transmission add together at the receiver.

Assembling the swarm

In order to assemble a swarm at the target star the members of the swarm need to be launched in quick succession or their speeds must vary so they arrive together. The time between launches is referred to as the launch cadence. There is a clear military analogy here, "time on target" to concentrate artillery fire from separate sources on a single target at an agreed time [2].



Time on target - showing simultaneous arrival of multiple projectiles at same aiming point..

Credit: adapted from MS302, ROTC Department of Military Science, St John's University - sjumilitaryscience.weebly.com/

Recall that the Starshot benchmark speed is 0.2c or about 60,000 km/second so with a single laser array and an acceleration time of 9 minutes (see Parkin, *The Breakthrough Starshot system model*, cited above) the inter-probe distance would be 9*60*60,000=32.4 million kilometres. That's more than 84 times the distance to the Moon, 384 thousand km. There are three main ways to achieve simultaneous arrival -

• Change the transmitted beam power so that earlier probes receive slightly less acceleration and thus later probes catch up and all arrive together.

• Increase sail size or reflectivity for later probes so that these probes receive slightly more acceleration.

• Decelerate probes as the target stars are reached - slowing earlier probes more than later probes. Deceleration also allows more time for observation.

More about this in a news item *Slow Down!* in P32, February 2021 page 21 and one way of doing this in an earlier issue*"Slow down!": How to park an interstellar rocket* by Tishtrya Mehta in P21, May 2018 page 3.

To get the signal back from all of the swarm their transmissions need to add together - this is called phase coherence.

For the Earth-based beamer proposed in the benchmark Starshot model there are additional constraints -

• Target probe visibility to the beamer on a rotating Earth

• Availability of power for the beamer in the required amounts at the required times including the effects of pricing in a regional or possibly even global energy grid

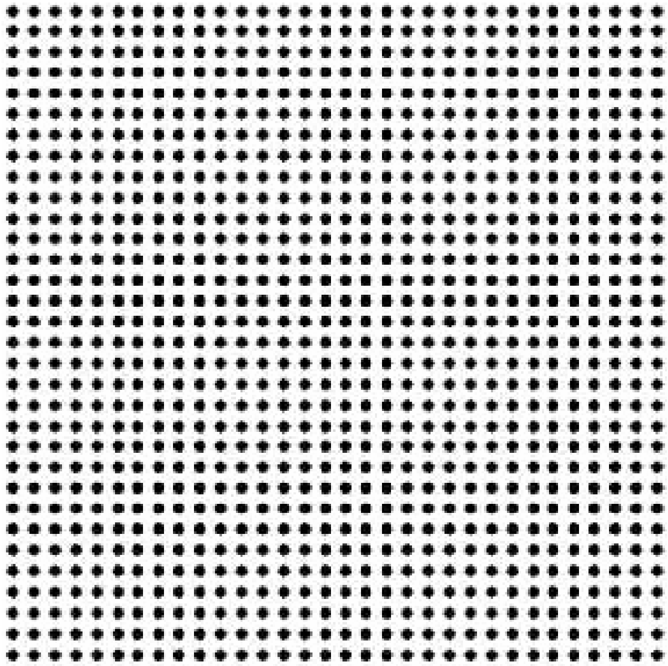
The former problem disappears for a space based beamer and the latter may be reduced substantially since solar radiation is an "always on" power source. Here there is a possible conflict with the possibility of space-based power generation for terrestrial use. This would produce scale economies and drive innovation but might then make power for our beamer compete with more obviously economically attractive commercial use of the same or similar technology.

[1] Capacity Bounds and Power Allocation for Wireless Relay Channels, Høst-Madsen & Zhang, 2004, IEEE Transactions on Information Theory. Volume: 51, Issue: 6, June 2005, open access: citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.68.6975&rep=rep1&type=pdf

[2] Early uses of this artillery technique relied on a BBC time signal en.wikipedia.org/wiki/Time_On_Target

Co-operating transmissions

To achieve phase coherence transmitting probes need to synchronise their transmissions. To quote our interstellar colleague, T Marshall Eubanks, "There are few things in this world as useful as a good clock..." [1]. To enable a swarm of widely-separated very small spacecraft to behave as a single distributed entity seems to require advances in optical clocks, quantum metrology, mode-locked optical lasers, and network protocols. If we can get 1000 such micro-probes to transmit "in sync" as a single distributed entity possibly based on a master clock signal from an earth or space-based transmitter then we may have a very effective downlink strategy without requiring the massive fusion driven spacecraft of the "Heavy Brigade".



A 1024 square array, 32*32.

Credit: Wang & Pinheiro, Structural and Spectral Properties of Deterministic Aperiodic Optical Structures - Crystals, December 2016 www.researchgate.net/publication/311550549_Structural_and_Spectral_Properties_of_Deterministic_Aperiodic_Optical_Structures

A sufficiently large swarm might also support an uplink able to carry more than a synchronising signal. Control is clearly infeasible with a feedback loop over a roundtrip delay of at least 8 years but software changes are a useful possibility.

More exotic means of communication such as quantum entanglement may even abolish some or all of the problems of interstellar communication but it also offers some more immediately feasible benefits in improving clock synchronisation[2].

For both swarm and "bucket brigade" inter-probe communications links will be required. For the swarm each probe needs to be capable of communicating with at least two other probes and maintaining pointing to them for the duration of downlink communications, in addition to transmitting towards Earth.

Conclusion

There is a Yorkshire saying "Many a mickle makes a muckle" also said in Scotland and attributed to US President George Washington, Laser propelled interstellar spacecraft have a distinct disadvantage over their heavyweight fusion rocket powered cousins but human ingenuity always looks at what may be achievable with the means most immediately at hand and this is such an instance. Fusion propulsion may allow us to build probes which can provide very substantial research results in a single vehicle and may even propel worldships but they are many decades and perhaps centuries away. Thousands of tiny sailcraft can achieve much in the nearer term - and have advantages of resilience and scalability. We look forward to hearing from them and the public impact of that first close-up picture of an exoplanet can only be imagined.

The major difficulty is the energy cost per launch. If the beamer is competing with current electricity costs on Earth then it may be a "show stopper". If space-based power is available then the situation may be reversed since power generated in space is most easily used there.

[1] Harrison's chronometer made determination of latitude feasible back in 1730 en.wikipedia.org/wiki/John_Harrison.

[2]A Quantum Network of Clocks, P Kómár et al, Nature Physics, 15 June 2014, DOI: 10.1038/NPHYS300 jila.colorado.edu/sites/default/files/2019-07/ClockQuantumNetwork_NatPhys2014.pdf.

NEXT ISSUE

Second report - Interstellar at the *72nd International Astronautical Congress, Dubai, October*

The Heavy Brigade: Downlinks from Icarus Firefly and BIS Daedalus

Report on Limitless Space Institute: Human Exploration of the Far Solar System and on to the Stars

i4is Contributing Editor Samar AbdelFattah, DM TECH (www.disruptivemobility.com) - i4is onsite reporter at IAC 2021, Dubai.

Cover Images

Our cover images this time relate to two very different current space missions. Both have implications for interstellar studies.

Front Cover

Our front cover photo is a NASA image of work on the James Webb Space Telescope. Amongst all the other hopes riding on this near-infra-red monster are clues to the atmospheres of the nearer exoplanets. If any life signs are detected then the case for interstellar probes will be immensely strengthened and we are sure that public attention will turn to exoplanets and exobiology.

Our thoughts will be with the Webb when it launches from the ESA launch site on one of the very last Ariane 5 vehicles. Ariane 5 is probably the most reliable heavyweight launcher currently in service but rocketry remains a tricky business.

And again a few days later when that big folding mirror unfolds and the even bigger sunshade also deploys. Nail-biting times for all in i4is and the interstellar studies community.

Back Cover

Our rear cover image shows a representation of the trajectory of the asteroid-visiting probe, Lucy, courtesy of Southwest Research Institute (SWRI - lucy.swri.edu/mission/Tour.html).

Top- The trajectory of the spacecraft. The spacecraft is in red, the Earth and its orbits are in blue, and Jupiter and its orbit are in green.

Bottom- The trajectory can also be looked at in a frame rotating with Jupiter. The spacecraft is in red, the Earth is in blue, and Jupiter is in green. In this view, the planets' orbits are represented by bands that indicate the minimum and maximum distances between the planet and the Sun (also known as the perihelia and aphelia).

Lucy, named after the early hominid of that name, launched from Cape Canaveral on 16 October 2021, on a mission to both sets of Trojan asteroids. These lie on the orbit of Jupiter, 120 degrees ahead and behind the giant planet, in the Jupiter-Sun Lagrange 4 and 5 positions. These places of stability, Lagrange 1 to 5, are both interesting and useful for many purposes and the 4 & 5 positions are dynamically stable so things tend to accumulate there.

Lucy will first fly by the Earth for two gravity assists. On its way out to the Trojans, Lucy will travel through the main asteroid belt and will fly by (52246) Donaldjohanson, an asteroid that the Lucy team named after one of the co-discoverers of the Lucy fossil.

It will continue outwards into the leading swarm of Trojan asteroids, the L4 Trojan swarm. This is also known as the “Greek camp” of Trojan asteroids - most of the asteroids in this swarm are named after Greek heroes around the time of the Trojan war. Lucy will fly by four of these “Greek” Trojans: (3548) Eurybates and its satellite Queta in August 2027, (15094) Polymele in September 2027, (11351) Leucus in April 2028, and (21900) Orus in November 2028.

The spacecraft’s orbit will then take Lucy back towards the orbit of Earth. When its orbit takes the spacecraft outwards again, Jupiter and the Trojan swarms will have rotated so that the spacecraft will pass through the trailing L5 swarm of Trojan Asteroids, otherwise known as the “Trojan camp.” Here, on March of 2033, Lucy will fly past the Greek “Trojan camp”. The flyby of this binary asteroid pair will be the grand finale of the mission. However, Lucy will be on a stable orbit and can continue flying through the Trojan swarms for many years to come. [text adapted from swri website]

Mission

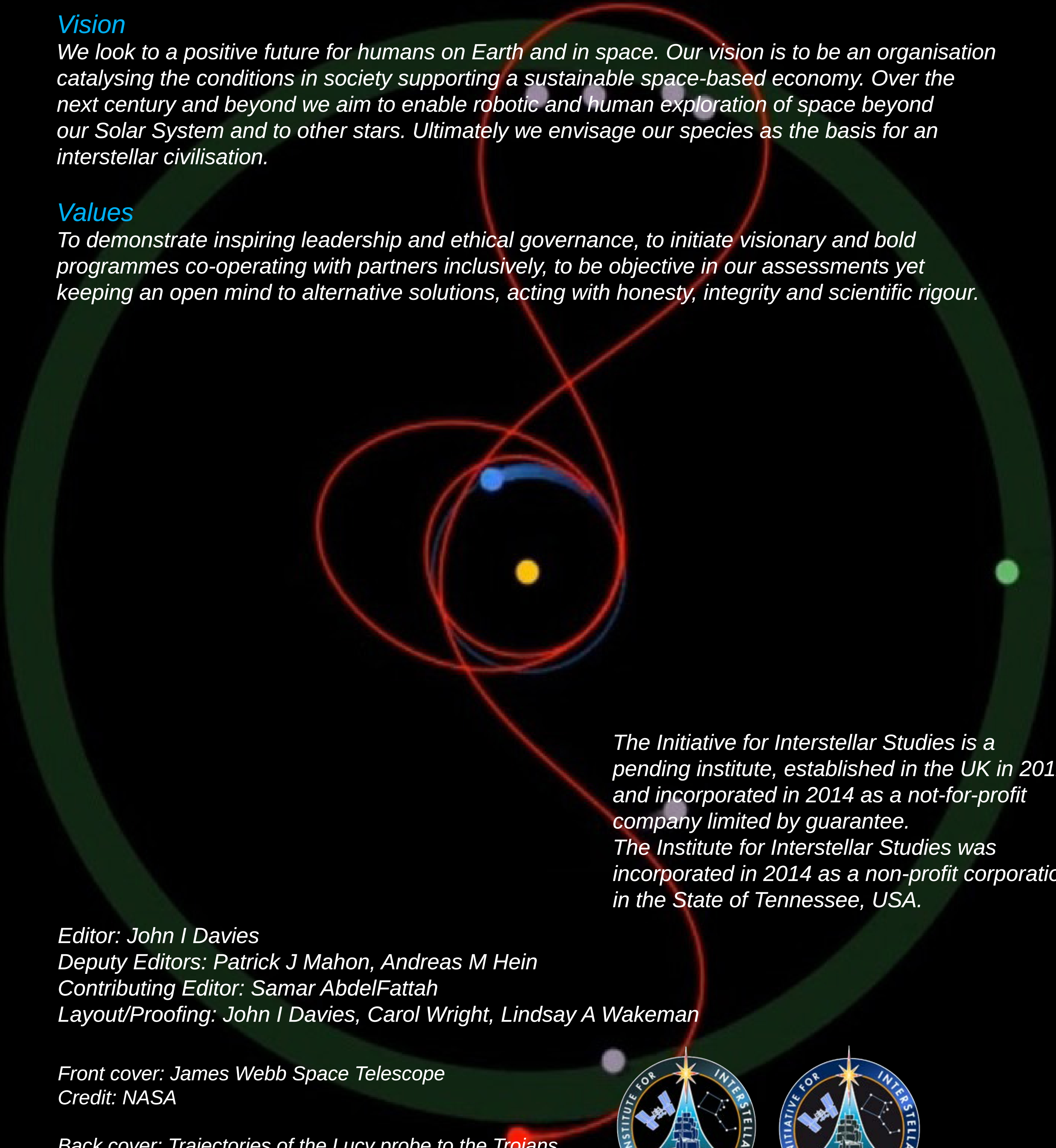
The mission of the Initiative & Institute for Interstellar Studies is to foster and promote education, knowledge and technical capabilities which lead to designs, technologies or enterprise that will enable the construction and launch of interstellar spacecraft.

Vision

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

Values

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



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Front cover: James Webb Space Telescope
Credit: NASA

Back cover: Trajectories of the Lucy probe to the Trojans
Credit: Southwest Research Institute

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Scientia ad sidera
Knowledge to the stars