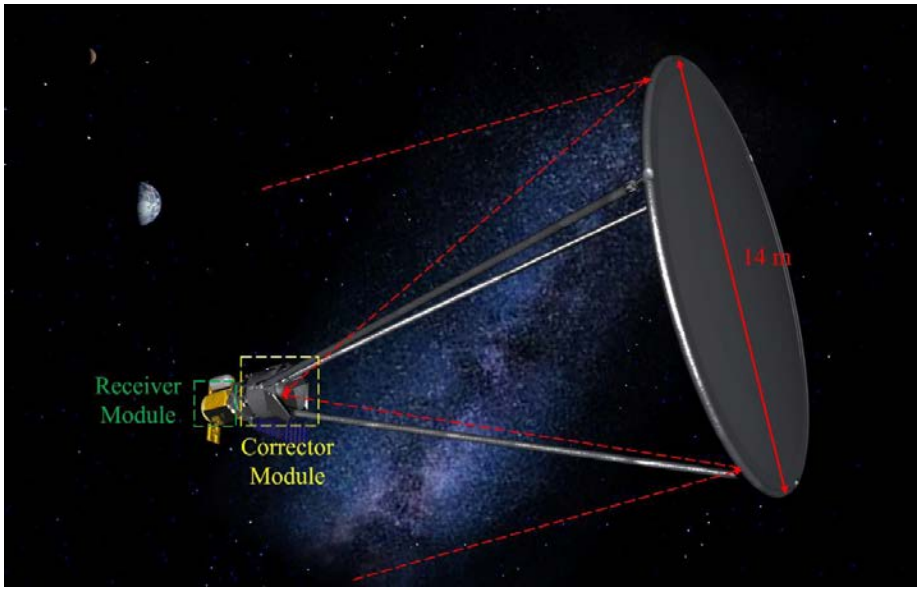
John I Davies reports on recent developments in interstellar studies

IAC 2022

We have a News Feature on this year's International Astronautical Congress, IAC 2022, elsewhere in this issue. We will have a full list of interstellar related items in our August issue, P38.
Here we note a couple of presentations by colleagues and friends of i4is which we can already mention -
Advanced Electric Propulsion Concepts for Fast Missions to the Outer Solar System and Beyond, Angelo Genovese, Initiative for Interstellar Studies
Wednesday 21 September 10:15
iafastro.directory/iac/browse/IAC-22/D4/4/
-and-
The Lunar Module Simulator: An Instructor's Account, Dr Albert Jackson, Triton Systems LLC
Wednesday 21 September 11:03
iafastro.directory/iac/paper/id/68471/summary/
We will be reporting in our November 2022 (P39) and February 2023 (P40) issues. We hope to see many i4is members, Principium subscribers and the workers and enthusiasts for the interstellar vision at this, the big space event of the year. ■

Inflatable infrared telescope to detect water

Engineers and scientists from University of Arizona, L'Garde Inc and Northrop Grumman have proposed an inflatable infrared telescope to detect water. In *Orbiting Astronomical Satellite for Investigating Stellar Systems (OASIS)* this instrument would perform high spectral resolution observations of water at terahertz frequencies [1]. A 14 metre inflatable primary reflector will have an inflatable metallised polymer membrane as the reflecting surface. It is designed to capture a wide range of infrared wavelengths from 63 μm in the mid-infrared (just beyond the range of the James Webb Space Telescope, 0.6 to 28.3 μm) to 660 μm in the very high infrared. 660 μm wavelength is 450 GHz frequency, which is not far beyond the highest radar frequencies [2].
The paper offers a systematic process to optimise the optical design and performance of space telescopes employing inflatable primary reflectors of various sizes. "Life as we know it" (as Mr Spock put it) seems to require water so detection of it is a necessary condition for such life. It is not a sufficient condition on its own but such a substantial instrument would be very attractive in terms of launch costs if inflatable mirror technology can be perfected - and this technical challenge is the main point of the paper. ■



OASIS mission concept showing the corrector and receiver modules (left side of the figure) and the fully deployed 14 m diameter primary reflective antenna A1 (right side of the figure), which is an inflatable membrane optic.
Credit (image and caption): Siddhartha Sirsi et al

[1] *Optical Design of the Orbiting Astronomical Satellite for Investigating Stellar Systems (OASIS)*, Siddhartha Sirsi et al, arxiv.org/abs/2203.05633.
[2] Electromagnetic spectrum en.wikipedia.org/wiki/Electromagnetic_spectrum.

Engineering the Oberth Manoeuvre

Our Centaurian colleague Paul Gilster has a feature on implementing the idea of Herman Oberth (1894-1989) [1], of the Verein für Raumschiffahrt (Society for Spaceflight), back in 1927 in Wege zur Raumschiffahrt (Ways to Spaceflight).

The piece is based on work by Jason Benkoski and colleagues (Johns Hopkins Applied Physics Laboratory) of a combined heat shield and solar propulsion system. They used the test setup for the heat shield of the Parker Solar Probe, which was launched in 2018 and is designed to fly to 8.5 million km from the Sun.

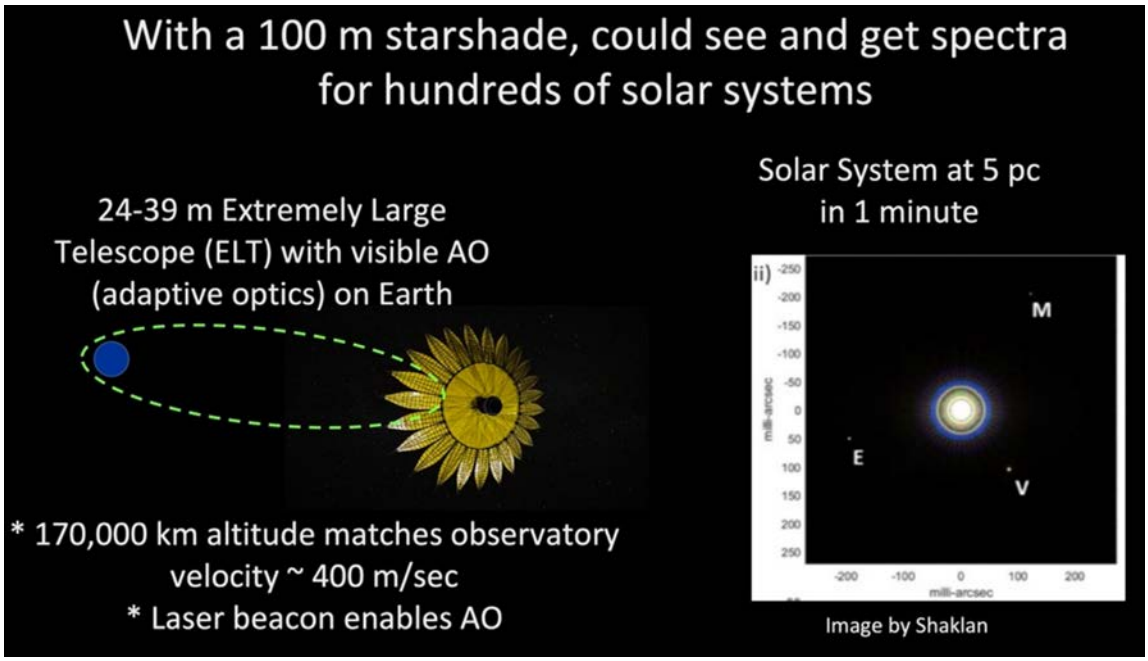
The physics of flying close to the Sun and firing a rocket at closest approach, aphelion, shows that the most acceleration is achieved by delivering the maximum impulse as close to aphelion as possible and with the lowest aphelion achievable. Clearly the closer you are the Sun the hotter you get. But the heavier the heat shield you use the lower the available payload mass. Benkoski and the team "make a virtue of necessity" by letting the Sun provide the heat energy required to drive the rocket propellant while the propellant shields the payload by absorbing that energy.

Engineering is the application of ingenuity as the Latin root, ingenium implies. The JHU team thus exemplify their profession!

As Benkoski writes "The idea is to absorb all this heat with hydrogen, and shoot it out the back of the probe." [2] ■

A Starshade to help earth-based telescopes find exoplanets

In *Hybrid Observatory for Earth-like Exoplanets (HOEE)* John Mather of NASA Goddard Spaceflight Center (GSFC) proposes the first hybrid observatory, combining a 100m diameter starshade in space with a giant telescope on the ground (www.nasa.gov/directorates/spacetech/niac/2022/Hybrid_Observatory_for_Earth_like_Exoplanets/). He tells us "The Hybrid Observatory for Earth-like Exoplanets (HOEE) would convert the largest ground-based telescopes now under construction (Giant Magellan Telescope, Thirty Meter Telescope, and Extremely Large Telescope) into the most powerful planet finders yet designed." These giants can deliver the best available resolution and contrast but are dazzled by the host star of the exoplanet. He notes the example of the sun, which is 10 billion times brighter than the Earth at visible wavelengths. He suggests "A starshade in an astro-stationary orbit would match position and velocity with the moving telescope, and cast a dark shadow of the star, without blocking the light of its planets. Active propulsion would maintain alignment during the observation." ■



Graphic depiction of Hybrid Observatory for Earth-like Exoplanets (HOEE)
Credit: John Mather

[1] *Engineering the Oberth Maneuver*, www.centauri-dreams.org/2022/03/03/engineering-the-oberth-maneuver/ .
[2] *Going interstellar with a sun-skirting probe*. hub.jhu.edu/magazine/2021/spring/apl-interstellar-probe/

i4is in US National Academies Decadal Survey

The Survey has been published as - *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032* (nap.nationalacademies.org/catalog/26522/origins-worlds-and-life-a-decadal-strategy-for-planetary-science)

The most favoured projects are a Uranus orbiter (the least-visited of the planets) and the Mars sample-return but there is a mention for interstellar under the category - *Small Bodies* -

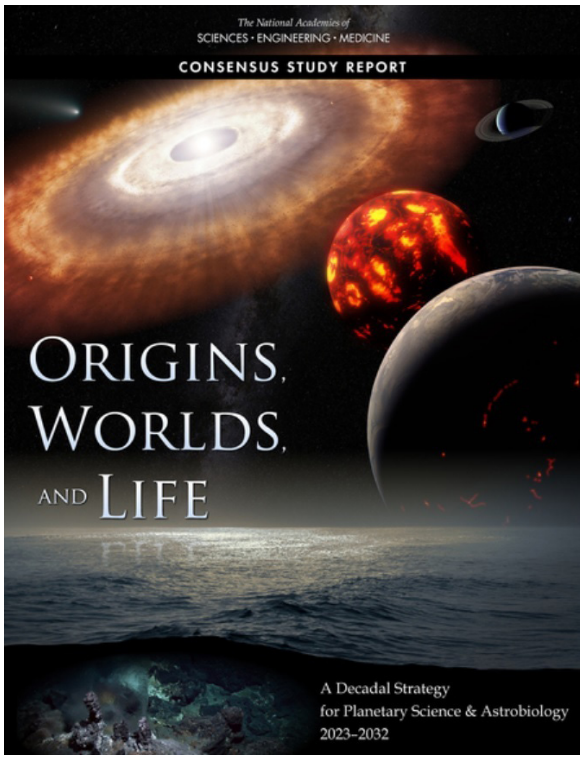
> The surprising discovery of two interstellar objects (ISOs) passing through the inner solar system, 1I/ 'Oumuamua and 2I/Borisov, raises the possibility of direct analysis of materials formed in the disks of other stars. 1I/ 'Oumuamua appeared asteroidal, in that it did not show cometary-like activity (Meech et al 2017), while 2I/Borisov exhibited evidence of a cometary color and tail (Guzik et al. 2020). Constraints on the mineralogy and elemental abundances of ISOs could provide insight into the composition of their parent disks. Improvements to Pan-STARRS1 and launch of the Vera Rubin Observatory will support detection of additional ISOs in coming years, and development of rapid launch capabilities could enable future spacecraft encounters with one of these extrasolar visitors.

- and mention of wider research into the interstellar medium (ISM).

It seems missions to ISOs might be a by-product of planetary defence -

> A critical next step is to develop a flexible implementation approach to quickly characterize threatening objects via reconnaissance missions in order to plan for mitigation if needed. Subsequent to NEO Surveyor, the next priority planetary defense mission is a rapid-response, flyby reconnaissance of an object representative of the most hazardous class of objects (~50 to 100 m diameter; see Planetary Defense chapter). A rapid response capability may also provide a template for responding to newly identified, high-value science targets such as interstellar objects or dynamically new comets.

However the selection panels rejected a "Interstellar Object Rapid Response Mission" (proposed by the Panel on Small Solar System Bodies) noting that the current structure of mission



opportunities within NASA's Planetary Science Division does not lend itself to opportunistic, rapid response missions to newly identified targets of high scientific value - like 1I/'Oumuamua - including rapid launch capabilities to enable future spacecraft encounters.

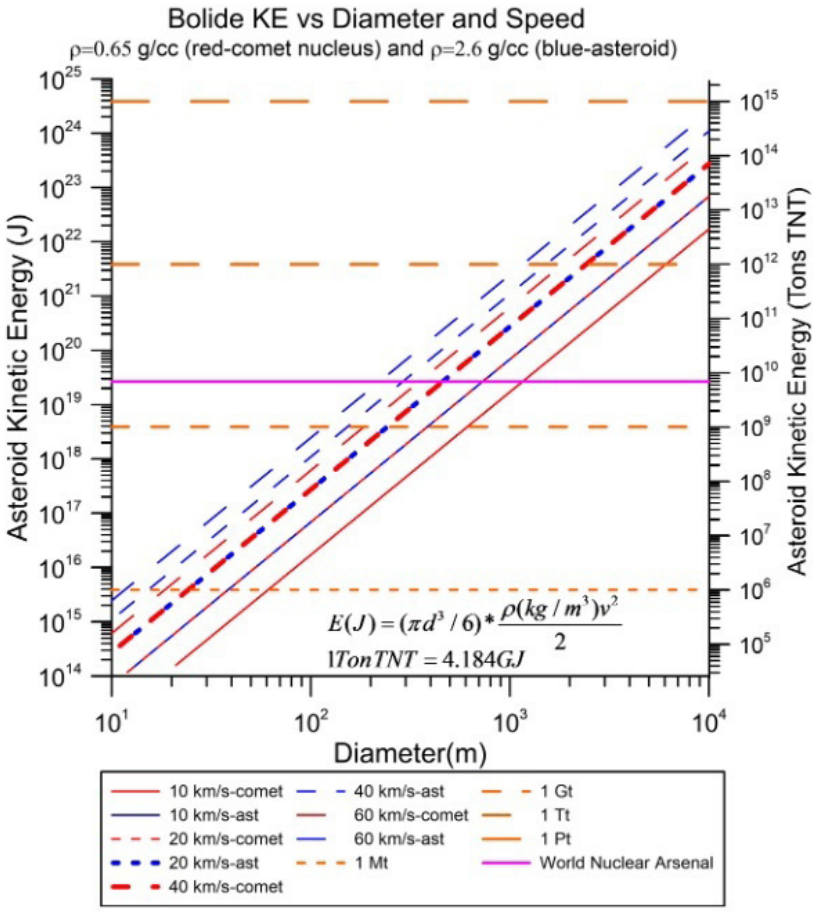
Surprisingly there is no mention of ESA's Comet Interceptor, launching in 2029.

But notably two of the i4is Project Lyra team papers are cited -

- Eubanks, T, J Schneider, A M Hein, A Hibberd, and R Kennedy. 2020. *Exobodies in Our Back Yard: Science from Missions to Nearby Interstellar Objects*. Available at arxiv.org/abs/2007.12480
- Hein, A, T M Eubanks, A Hibberd, D Fries, J Schneider, M Lingam, R G Kennedy, et al. 2020. *Interstellar Now! Missions to and Sample Returns from Nearby Interstellar Objects*. Available at arxiv.org/abs/2008.07647 and published at Advances in Space Research, Volume 69, Issue 1, 1 January 2022, Pages 402-414 (www.sciencedirect.com/science/article/pii/S027311772100538X)

Don't Forget To Look Up

Professor Philip Lubin is a pioneer of interstellar studies, especially in the field of laser propulsion. With his UCSB colleague, Alexander N Cohen, he has now published a study looking at how existing and very near term technologies might mitigate or eliminate the extinction threat represented by a large comet or asteroid on a collision trajectory with Earth [1]. Such an object of order 10 km diameter hitting the Earth at a closing speed of 40 km/s for the comet and 20 km/s for the asteroid would have an impact energy of roughly 65 Teratons TNT, equivalent to the KT extinction event that made the large dinosaurs extinct about 66 million years ago. The scale of this (and lesser events) is well illustrated by their graph below.



Exo-atmospheric kinetic energy vs diameter and atmospheric entry speed for both typical comet and asteroid densities (0.65 and 2.6 g/cm^3, respectively). Relevant energy scales and total human nuclear arsenal shown for comparison. For diameters greater than 500 m, the bolide energy exceeds the world's nuclear arsenal. Humanity is good at building weapons, but nature is far better at it.

Credit (image and caption): Lubin and Cohen

While impacts equivalent to the KT event are very rare, roughly once per 100 million years, they argue that planetary defence should concentrate immediately on the much larger number of smaller but deadly threats, particularly those from about 20-500m in diameter. They suggest using an array of hypervelocity penetrators, either inert or using conventional explosives for these smaller objects - but being prepared to use the same technique with nuclear explosives for extinction level threats. Depending upon object size, a two-layer defence might be required with initial disintegration sufficient for most fragments to miss the Earth and with threatening fragments dealt with individually. For larger objects - larger than a few km in diameter, their own gravity must also be overcome while smaller objects are held together only by the mechanical strength of their material. They cite their earlier paper discussing this "Pulverize It" (PI) strategy [2] which makes the point that the shock waves from a fragmented object are spread out in both time and location and thus the total destructive effect is mitigated.

Lubin and Cohen consider a wide variety of scenarios and techniques but end with the ominous thought *Don't Forget to Look Down*, which recalls a thought that subterranean and sub-ocean refuges might be a last resort. These were suggested in the novel *Seveneves* by Neil Stephenson. Stephenson, who notably worked with Blue Origin for some time, also suggested a refuge for the eponymous seven Eves, who preserved the human species, based upon the International Space Station (ISS) [3]. Sadly the ISS is now recklessly under threat by the actions of the current Russian government. ■

[1] Don't Forget To Look Up, arxiv.org/abs/2201.10663

[2] PI – Terminal Planetary Defense, Philip Lubin, Jan 2022, arxiv.org/abs/2110.07559

[3] *The Orbits of Seveneves - A book review with a touch of orbital dynamics*, Sander Elvik, Principium 20 February 2018

Philosophy and Science of Space Exploration

Serife Tekin, Carmen Fies and Chris Packham (all University of Texas at San Antonio) propose a new interdisciplinary course, *Philosophy and Science of Space Exploration (PoSE)* [1]. They aim to "help overcome disciplinary silos to advance our understanding of space and critically examine its ethical ramifications, but also will better educate the public on how science works and help overcome the science scepticism that has unfortunately become more prominent in recent years".

They aim to "harvest space science enthusiasm and use it to generate an educated and critical engagement with progress in space science, while at the same time addressing and challenging growing distrust in science". They cite Descartes, Bertrand Russell and Karl Popper in support of the prevalence of a science-based world view. They aim to "take such historical and philosophical conversations a step further by referring to the recent advances in astronomy". Citing "inequities in science education" reported by the (US) National Science Foundation, they believe that their philosophy-based approach will overcome both scepticism and inequities. They will measure success by grasp of the content, development of critical thinking, change in students' interest in the subject matter and "will develop measures of the students' understanding of the tenets of ethics and of astronomy".

In their introduction the authors report that "growing distrust in science in the United States", exemplified by scepticism about Covid vaccines, contrasts with "growing enthusiasm for and excitement about astronomy and space exploration". In the latter they cite a paper from 2010, *The impact of astronomy*, by Andy Fabian [2]. I can find no such optimism in Professor Fabian's paper. He was President of the Royal Astronomical Society, 2008–2010 and, reporting on his presidency he was articulately pessimistic about the influence of science upon the UK public and government concluding "We have to have a survival strategy, because I really do think we are at an important time in UK astronomy." He reported that "Funding is shrinking" and that "Spreading the money to groups that are subcritical is not a good idea. We need, above all, to maintain intellectual leadership in our research." The premise of this proposal does not appear to be supported by Prof Fabian. My own country (UK) has, I believe, gone backward in its interest in, and respect for, science. Only four years after Prof Fabian's paper a senior government minister seriously suggested that "the British people have had enough of experts" and subsequent events have supported his view [3]. I do not believe that the USA is significantly less sceptical of science than the UK and other European countries. I wish Tekin et al well in their endeavour but I am not confident of their success. ■

Avoiding the Great Filter

In a recent paper *Avoiding the Great Filter: Predicting the Timeline for Humanity to Reach Kardashev Type I Civilization* (arxiv.org/abs/2204.07070), a team from the NASA/Caltech Jet Propulsion Laboratory, Beijing Normal University, Jagiellonian University (Kraków), two high schools in USA & India - and a retired executive from oil company Chevron, have attempted to project our human future to the point where we might avoid the suspected "Great Filter" often suggested as the explanation for the Fermi Paradox "Where are they (ETIs)?". They use Carl Sagan's formulation of the Continuous Kardashev Scale (in *The cosmic connection: An extraterrestrial perspective*, 1973) to estimate that we have achieved 0.728 - only 0.272 short of using all major forms of energy available from our home planet. They reject the simpler exponential growth models of earlier studies and include the United Nations Framework Convention on Climate Change (UNFCCC) alongside the five major types of energy sources (Coal, Natural gas, Crude, Nuclear and Renewable). They worry that achieving Kardashev Type I may not be sustainable long term. They quote Edward Osborne Wilson (RIP) from a 2009 debate at the Harvard Museum of Natural History - "The real problem of humanity is the following: We have Palaeolithic emotions, medieval institutions, and godlike technology".

The paper is quite detailed with respect to energy analysis but does not appear to justify its implicit assumption that achieving Kardashev Type I will deliver us from any Great Filter. ■

[1] *Teaching Philosophy and Science of Space Exploration (PoSE)*, Feb 2022, https://arxiv.org/abs/2202.11130
[2] *The impact of astronomy*, Andy Fabian, in Astronomy & Geophysics, V51 #3, June 2010, https://academic.oup.com/astrogeo/article/51/3/3.25/224270
[3] *The EU must learn from the anti-expert narrative that drove Brexit*, editorial in Nature 16 December 2020

Researching 'Oumuamua as an Alien Craft

In *Research Programs Arising from 'Oumuamua Considered as an Alien Craft* (arxiv.org/abs/2111.07895), Martin Elvis (Center for Astrophysics, Harvard & Smithsonian) analyses the controversial hypothesis that 1I/'Oumuamua is an alien craft using a lightsail for propulsion - or the wreckage of one. He considers both a craft under control and one which is now an uncontrolled wandering interstellar hulk. He further subdivides the uncontrolled case into "anonymous METI" (messaging to extraterrestrial intelligence) and "inadvertent METI". He takes no position on the alien craft hypothesis but considers options to further explore that hypothesis.

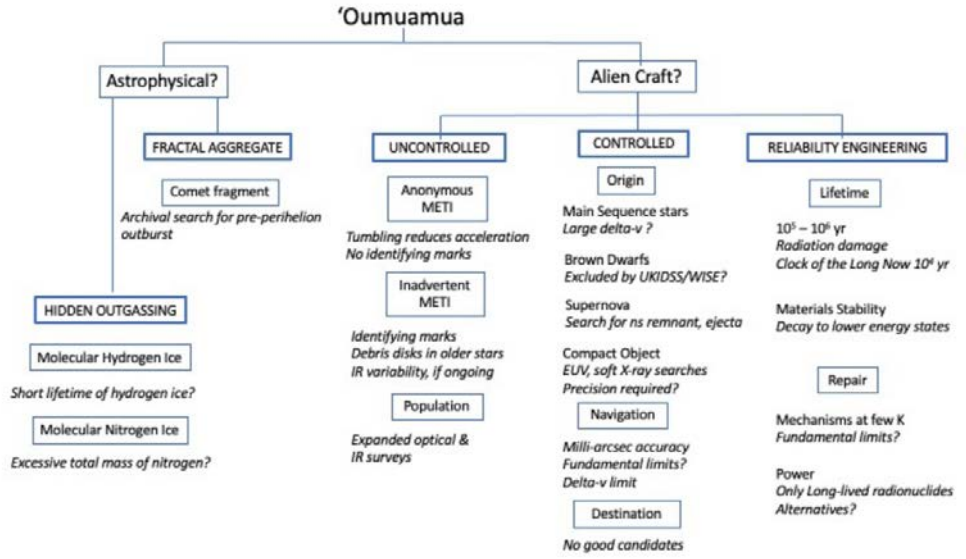
The anonymous METI case implies a sort of "message in a bottle". Since its velocity is very close to that of the Local Standard of Rest (LSR) - the velocity of the galactic crowd in our neighbourhood - this might imply an intention to disguise its point of origin. It might also imply a large population of such objects so that at least one "message in a bottle" will be found by another intelligence.

The Inadvertent METI case might imply something like the upper stage of the launcher for New Horizons, the probe to Pluto and beyond. Or perhaps just waste from a space-based factory of some sort.

If it was under control then can we discover its origin (or destination for that matter)? Here Elvis perhaps goes a little far since it is easy to disguise the intended long-term trajectory of a controlled object so speculation about this seems pointless? The longevity of such an interstellar explorer is clearly a major design issue and Elvis cites a human example of a mechanism with an intended lifetime of 10,000 years, the "Clock of the Long Now".

A prototype of the Clock of the Long Now, on display at the Science Museum
Credit (image and caption): Science Museum, London

This is a detailed analysis (about 8,000 words) raising many interesting issues and, I believe, justifying its advocacy of a broad and well-defined research programme built around the hypothesis that 1I/'Oumuamua is an alien craft. It includes a useful taxonomy of possibilities. ■



Taxonomy of possibilities for the nature of 1I/'Oumuamua and later ISOs.
Credit: Martin Elvis

More from Centauri Dreams on Laser Sails and Ramping Up the Technosignature Search

Thanks again to the indefatigable Paul Gilster for drawing attention to two more papers stimulated by Breakthrough Starshot, *Delving into the Interstellar Sail* [1] - they are Campbell et al, *Relativistic Light Sails Need to Billow* [2]; - and - Brewer et al, *Multiscale Photonic Emissivity Engineering for Relativistic Lightsail Thermal Regulation* [3].

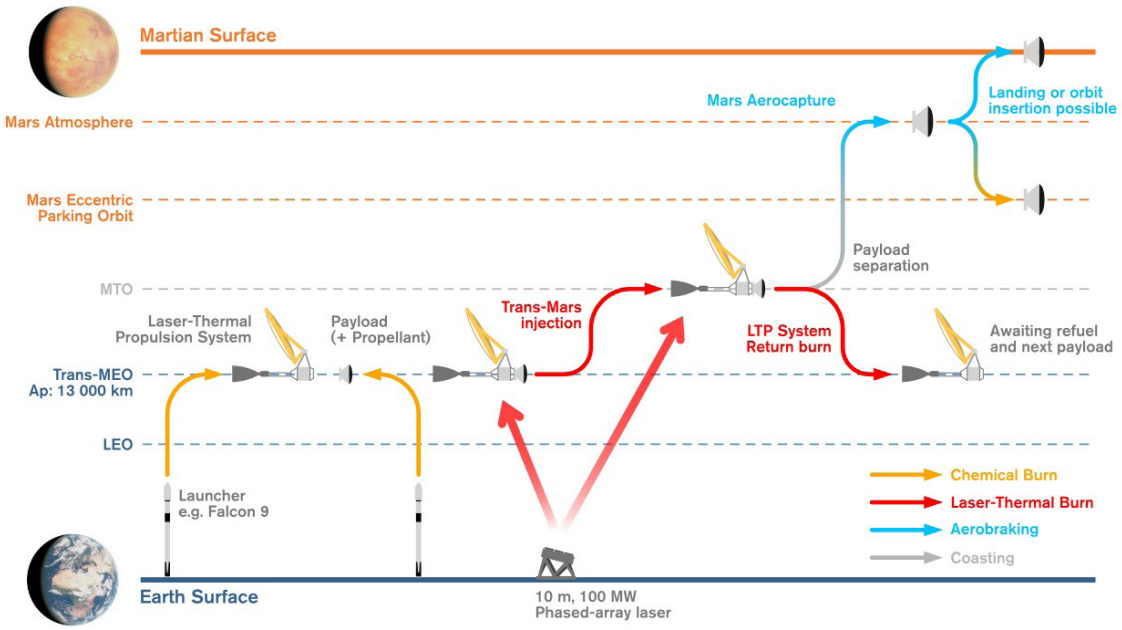
Paul also draws our attention to work to ramp up the search for technosignatures (www.centauri-dreams.org/2022/04/06/ramping-up-the-technosignature-search/). He celebrates the system upgrades to the Very Large Array (VLA) radio telescope, COSMIC (Commensal Open-Source Multimode Interferometer Cluster Search for Extraterrestrial Intelligence). COSMIC will have access to the complete datastream from the entire VLA, in effect an independent copy of everything the VLA observes. The VLA is an array of 27 dishes each 25 metre diameter in New Mexico, operating in a continuous frequency range from 1 to 50 GHz. We are truly in a golden age of SETI! ■

Riding a laser to Mars in 45 days

Phys.org draws attention to work at McGill University, *Riding a laser to Mars - in 45 days* [4] The paper is in Acta Astronautica, Volume 192, March 2022 and open publication [5].

The proposal is for a ground-based 10m wide 100 MW laser array to heat a core of hydrogen plasma. This would enable a 45-day transit time to Mars. They suggest a 1-ton payload and 706 kg of propellant delivering 8 g acceleration (1 ton looks a bit small for a human mission and 8 g is also a bit of a challenge for humans).

The claim is that this would yield unprecedented efficiency, specific impulse of 3,000 seconds and a mass to power ratio of 0.01 kg/kW or less. Longer transit times, probably for cargo rather than human missions, would allow greater masses. The paper cites a NASA solicitation seeking revolutionary propulsion for rapid, deep-space transit that identified a number of candidate missions of interest: traversing the distance between Earth orbit and Mars orbit in no more than 45 days, traversing a distance of 5 AU in no more than one year, traversing a distance of 40 AU in no more than five years, and traversing a distance of 125 AU in no more than ten years. ■

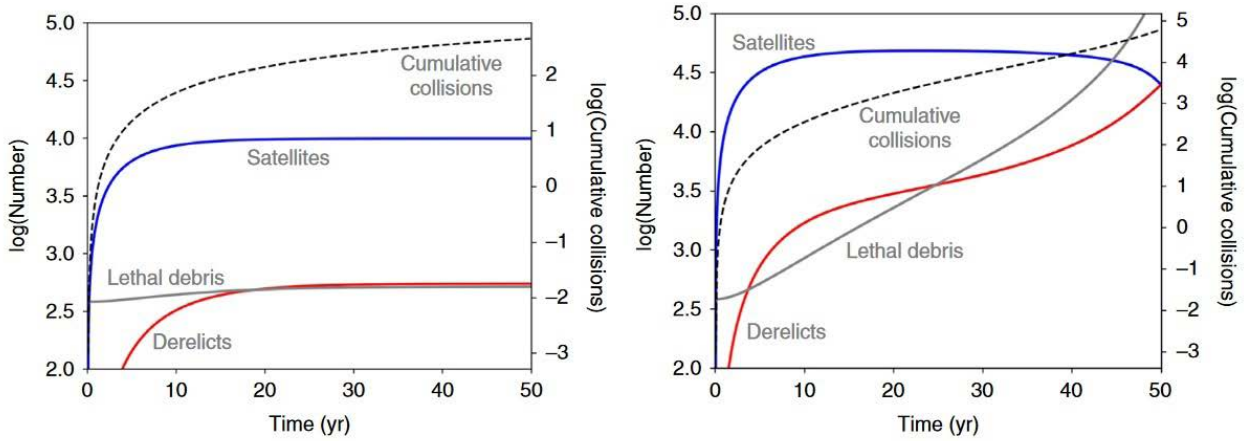


Concept of Operation diagram for a reusable Laser-Thermal Propulsion Systems.
Credit (image and caption): Duplay et al

[1] Centauri Dreams: www.centauri-dreams.org/2022/02/24/delving-into-the-interstellar-sail/
[2] Nano Letters 22, 1 (2022), 90-96 pubs.acs.org/doi/10.1021/acs.nanolett.1c03272
[3] Nano Letters 22, 2 (2022), 594-601 pubs.acs.org/doi/10.1021/acs.nanolett.1c03273 and arxiv.org/abs/2106.03558
[4] *Riding a laser to Mars - in 45 days* phys.org/news/2022-02-laser-mars.html
[5] *Design of a rapid transit to Mars mission using laser-thermal propulsion*, Emmanuel Duplay, Zhuo FanBao, Sebastian Rodriguez, Rosero Arnab Sinha, Andrew Higgins - all at Department of Mechanical Engineering, McGill University Acta Astronautica, Volume 192, March 2022 (www.sciencedirect.com/science/article/abs/pii/S0094576521006305?via%3Dihub)/ - there is an open publication version at arxiv.org/abs/2201.00244.

The case for space environmentalism

An international team with lead author at the University of Edinburgh has published *The case for space environmentalism* (Lawrence et al, www.nature.com/articles/s41550-022-01655-6.pdf) in *Nature Astronomy*. They summarise the case for considering the orbital space around the Earth as an additional ecosystem, subject to the same care and concerns, and the same broad regulations as the oceans and the atmosphere. They suggest that damage to the orbital space environment has problematic features in common with other types of environmental issue. First, the observed and predicted damage is incremental and complex, with many contributors. Second, whether or not space is formally and legally seen as a global commons, the growing commercial exploitation of what may seem to be a 'free' resource is, in fact, externalising the true costs. They identify three categories of the space environment - the radio interference environment, the optical sky as an environment, orbital space as an environment and also cumulative effects and emergent behaviour. Their general term for everything we put up there is anthropogenic space objects (ASOs). They roughly classify collisions into minor, disabling, and disrupting or lethal. Noting that anything 1mm in size or larger can cause minor damage, such as perforating a solar array. The two scenarios they suggest -



The evolution of the satellite population, debris population and cumulative collisions for scenarios at a height of 600 km with frequent de-orbiting.
a. 2,000 launches per year aimed at a stable population of 10,000 satellites.
b. 10,000 launches per year aimed at a population of 40,000 satellites.
Calculations made using the JASON Report model [1]
See also fig 20 and equation 5-22 of the Jason Report, cited above.
Credit (image): Lawrence et al
Credit (caption above): adapted from Lawrence et al

- note the catastrophic trend of lethal debris in scenario b.
Principium is observing, reporting and commenting on Space Debris. For example in a News Feature, *Special on space debris at IAC21*, in this issue. Our principal concern is access to space but we will also keep an eye on the wider issues addressed in this paper. ■

[1] *Jason Report on the Impacts of Large Satellite Constellations*, www.nsf.gov/news/special_reports/jasonreportconstellations/ and www.nsf.gov/news/special_reports/jasonreportconstellations/JSR-20-2H_The_Impacts_of_Large_Constellations_of_Satellites_508.pdf

Studying an ISO using the Webb telescope

The JWST will gradually become operational over the next few months. A recent announcement from NASA, *Studying the Next Interstellar Interloper with Webb* (www.nasa.gov/feature/goddard/2022/studying-the-next-interstellar-interloper-with-webb) says that many, many more ISOs are thought to exist and -

> "The supreme sensitivity and power of Webb now present us with an unprecedented opportunity to investigate the chemical composition of these interstellar objects and find out so much more about their nature: where they come from, how they were made, and what they can tell us about the conditions present in their home systems".

If its trajectory intersects with Webb's viewing field then using the Near-Infrared Spectrograph (NIRSpec), observers will analyse the "chemical fingerprints" of gases released by the object as any ices present are vaporised by our Sun's heat and, with the Mid-Infrared Instrument (MIRI), they will observe any dust that the object is producing, from microscopic particles to pebbles. NIRSpec can detect emission from individual gas molecules including water, methanol, formaldehyde, carbon dioxide, carbon monoxide, and methane. MIRI will look for the heat spectrum produced by solid particles, dust grains or the ISO's nucleus.
The i4is Lyra programme will continue to explore the possibilities for intercepting ISOs near or far but a new ISO, especially one as mysterious as 1I/'Oumuamua, would be a real find. How lucky do we need to be to find another in the next few years while 1I is still a reachable target? ■

SETI in 2021

This second annual survey of SETI research from Pennsylvania State University researchers [3] lists 93 papers and books published or made public in 2021. Topic areas include search methods, technosignatures, theories of ETI and social aspects of SETI. The authors have aimed to be "usefully subjective" rather than comprehensive, excluding, for example, papers in which SETI is peripheral. ■

Non-terrestrial artefacts in the Solar System

Avi Loeb at Harvard is already driving a project to actively look for non-terrestrial artefacts in the Solar System [1], however a team led from KTH Royal Institute of Technology, Sweden, suggests that we may already have usable evidence in old astronomical data, including the photographic plates which were the main medium for capturing astronomical images up to a few years ago [2]. Pre 1957 plates are of special interest since Sputnik 1 was the first artificial intruder into astronomical observation. ■

Probability of Communicating ETIs

Wenjie Song and He Gao of Department of Astronomy, Beijing Normal University, discuss *The Number of Possible CETIs within Our Galaxy and the Communication Probability* [4]. Using Monte Carlo simulations they estimate the number of possible CETIs within our Galaxy and the communication probability among them. They suggest two poorly known parameters have a great impact on the results - the probability of life appearing on terrestrial planets (f_c) and eventually evolving into a CETI (F). Inevitably they start with that famous handy checklist, the Drake Equation. Despite the uncertainties they identify, they believe their results may quantitatively explain why we have not detected any alien signals so far (the even more famous Fermi paradox). In support they suggest that developments in the discovery of so many exoplanets and the data on star formation rate (SFR), it is now possible to conduct a quantitative study of this problem. Their simulation results result in a range of possibilities of humans achieving communication with an ETI based on plausible upper and lower values of f_c and F. ■

[1] *Galileo Project for the Systematic Scientific Search for Evidence of Extraterrestrial Technological Artifacts,* iq.harvard.edu/galileo
[2] *A glint in the eye: photographic plate archive searches for non-terrestrial artefacts*, Villarroel et al, 2022 arxiv.org/abs/2110.15217
[3] *SETI in 2021*, Macy J Huston, Jason T Wright arxiv.org/abs/2203.11172
[4] The Astrophysical Journal, 2022 April https://iopscience.iop.org/article/10.3847/1538-4357/ac561d/pdf