

# INTERSTELLAR NEWS

John I Davies reports on recent developments in interstellar studies



Tarantula Nebula (NIRCam Image) "The NASA James Webb Space Telescope, developed in partnership with ESA and CSA, is operated by AURA's Space Telescope Science Institute." Credit: Space Telescope Science Institute

## Webb's Tarantula

Occasionally we are distracted by the sheer staggeringness of what observational astronomers can achieve and we temporarily put aside our central objective, getting there, to goggle at the sheer gobsmacking wonder of what is out there. This recent image from the James Webb telescope is a case in point. Just a small clip above.

For the whole thing go to -

[/webbtelescope.org/contents/media/images/2022/041/01GA76MYFNOFMKNRHGCAGGYCVQ](https://webbtelescope.org/contents/media/images/2022/041/01GA76MYFNOFMKNRHGCAGGYCVQ)

- and pick the 124 or 140 MB image. And, for those minded to calculate, here's an ESA video zoom -

[www.youtube.com/watch?v=mnalsMiIjg0](https://www.youtube.com/watch?v=mnalsMiIjg0)

The challenge is to work out how fast their imaginary starship was flying as it zooms to and through the Nebula. A small i4is-logoed prize for the first correct answer to [info@i4is.org](mailto:info@i4is.org)!

- and we liked the new US Postal Service stamp -

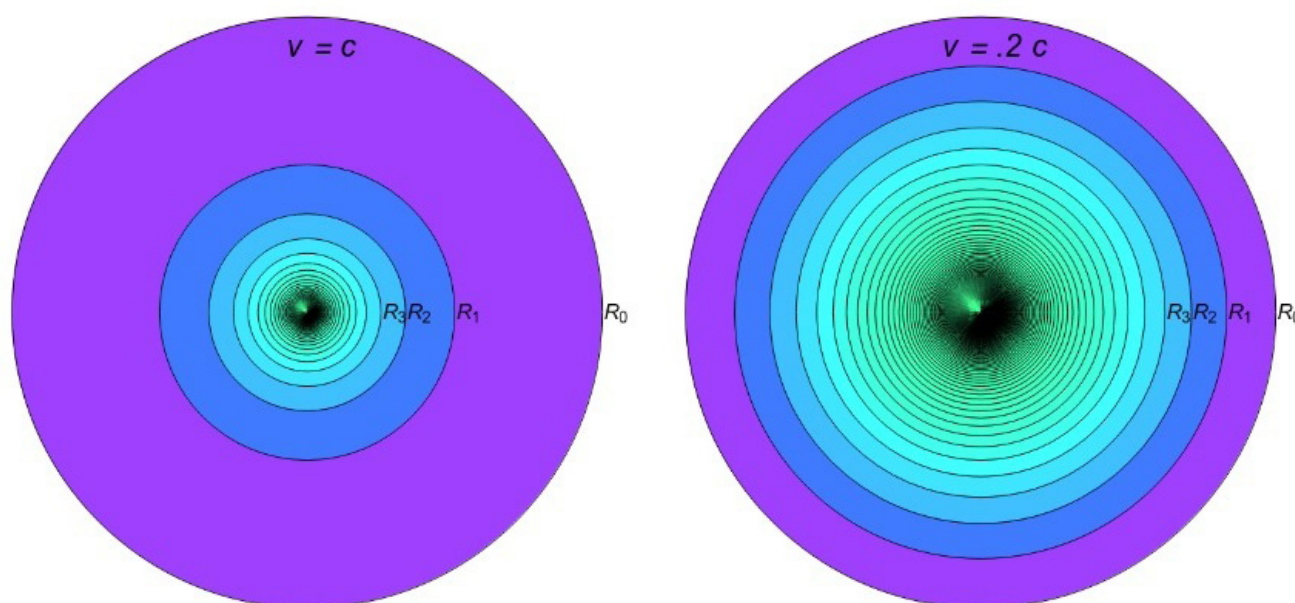


Credit: USPS. <https://about.usps.com/newsroom/national-releases/2022/0726ma-usps-celebrates-james-webb-space-telescope.htm>

## Limit to cosmological communication

In *A causal limit to communication within an expanding cosmological civilization*, S Jay Olson of Boise State University, Idaho ([arxiv.org/abs/2208.07871](https://arxiv.org/abs/2208.07871)) suggests that a civilisation embarking on high-speed intergalactic expansion will have communication between remote galaxies in the civilisation limited by an extreme time delay, due to the distance involved, calling this a "causal horizon". The paper suggests that possible conversation with the home galaxy depends on expansion speed. So space settlements "beyond the horizon" in an expanding cosmic civilisation (ECC) can never be observed by the initiating home galaxy.

Motivated by resource utilisation a wave of colonisation expands at high speed in all directions, saturating every galaxy along the way in an expanding sphere. The paper suggests a general internal property of an ECC – a fundamental limit to communication, imposed by causality. The quantity of interest to us here is the degree of conversation that is possible between a colony and the home galaxy of the ECC. This can be measured by the number of sequential, back-and-forth signals that are possible before the "end of time" thus dividing the ECC into spatial regions, corresponding to different numbers of possible conversations. The net effect is that faster expansion leads to greater isolation. The paper sums this up "For a very high expansion speed, close to  $v = c$  [the speed of light], the large majority of the final ECC volume corresponds to the  $n = 0$  region, where colonies can send no signal at all back to the home galaxy. For lower expansion speeds, the relative size of the  $n = 0$  region is smaller."



The relative size of communication regions for  $v = 1c$  and  $v = 0.2c$ , with the final domain scaled to equal size, for comparison. High expansion velocity means that far more of the final domain exists beyond  $R_1$ , and will never be able to signal the home galaxy.

Credit: Olson

The paper cites the book by Bostrom [1] describing how cosmic expansion could be initiated by a superintelligence suggesting that even if a superintelligence's final goals only concerned what happened within some particular small volume of space, such as the space occupied by its original home planet, it would still have instrumental reasons to harvest the resources of the cosmos beyond but would still limit its final sphere of expansion.

[1] Nick Bostrom, *Superintelligence: Paths, dangers, strategies*, Oxford University Press, 2014. See also *Sending ourselves to the stars?* Principium 12 & 13, February and May 2016.

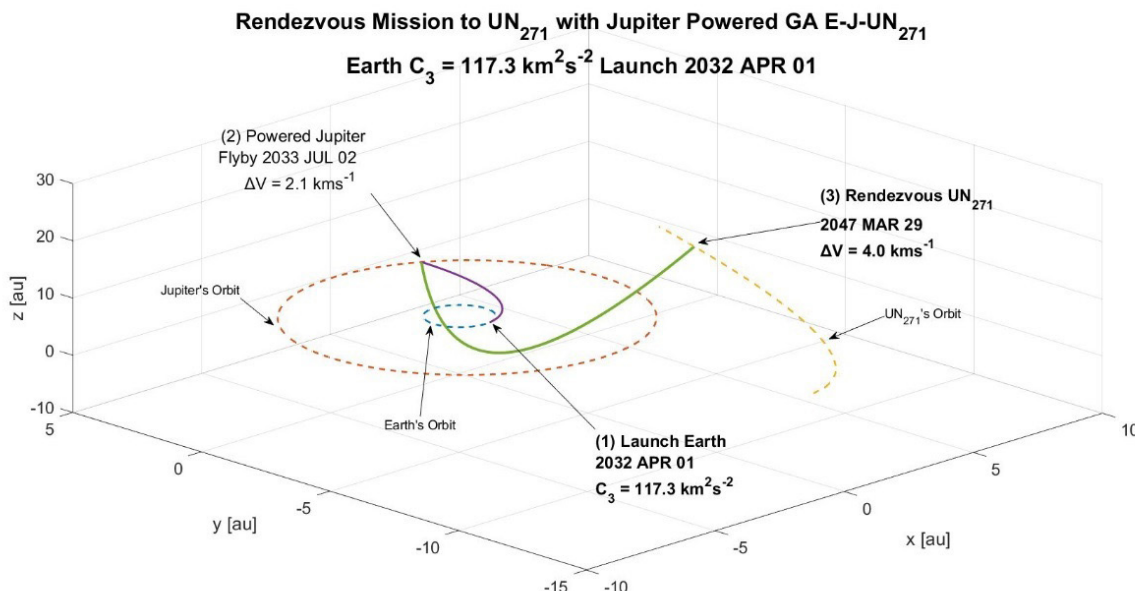


Figure 11. Rendezvous with UN271, Example Mission with Jupiter GA  
Credit (image and caption): Hibberd/Eubanks

## Missions to Comet C/2014 UN271

Comet Bernardinelli/Bernstein, C/2014 UN271, was discovered very early in its journey inwards from the Oort Cloud. UN271 was more than 29 astronomical units (AU) away or about the same distance as the furthest recognised planet, Neptune (with apologies to Pluto for its downgrading to "minor planet") but it's coming in almost perpendicular to the ecliptic plane so it will plunge through, reach perihelion in 2031 at about 10 AU (about as far out as Saturn) and will then head back through the ecliptic roughly where it came from. UN271 is also big; Its comet nucleus is around 140 km across.

The i4is Project Lyra team proposed a mission to it last year, discussed in *News Feature: Mission to 2014 UN271 using OITS*, Principium 34, August 2021. In a new paper the team advocate *Analysis of Low ΔV Spacecraft Missions to Oort Cloud Comet C/2014 UN271*, Adam Hibberd, T Marshall Eubanks ([arxiv.org/abs/2210.05190](https://arxiv.org/abs/2210.05190)). The team describe various methods for reaching UN271 during the period around its perihelion and ecliptic plane passage, with both flyby and rendezvous options; exploiting direct transfers (see image above), Jupiter powered gravitational assists (GA) or alternatively a series of GAs of the inner planets. They have found viable flyby and rendezvous trajectories, especially using the NASA Space Launch System (SLS) as the launch vehicle.

## Argus Optical Array

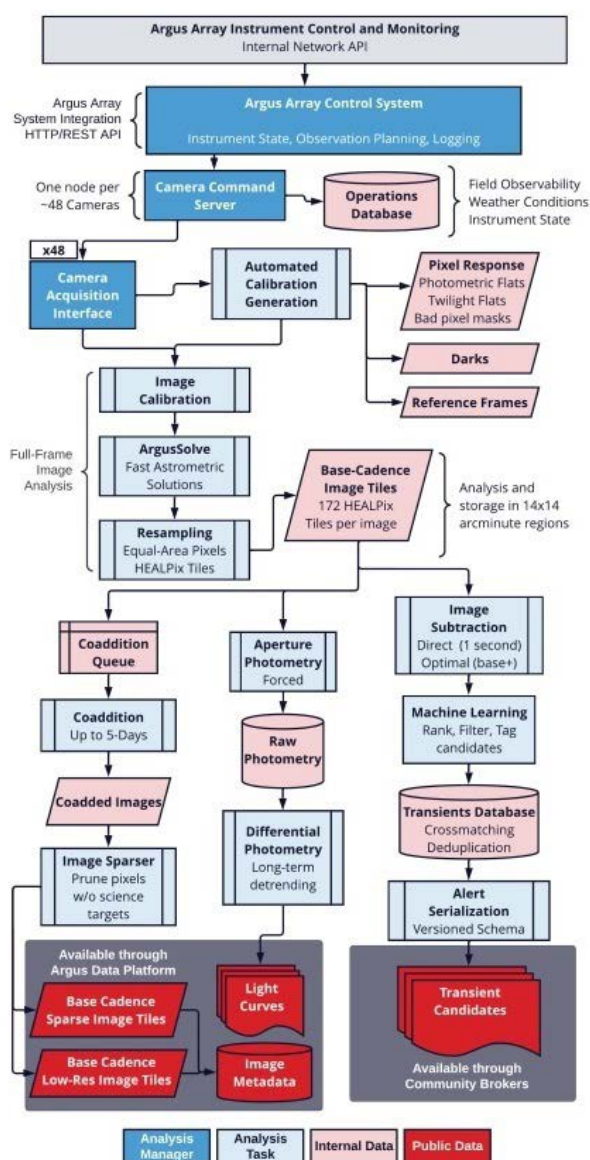
The Argus Optical Array will be an all-sky, arcsecond-resolution, 5 m class telescope which builds a simultaneously high-cadence and deep survey by observing the entire sky all night. The 55 GPix array, currently being prototyped, will consist of 900 telescopes covering 20% of the entire sky, each with a very-low-noise CMOS detector enabling sub-second cadences. Providing depths of 23-24 magnitudes by trading off relatively small apertures for very long co-added exposure times - just as amateur astrophotographers do to deliver the "big telescope" pictures beloved of astronomy magazines. The objective is to enable highly sensitive searches for high-speed transients, fast-radio-burst counterparts, gravitational-wave counterparts, exoplanet microlensing events, occultations by distant solar system bodies, and other phenomena. See *The Argus Optical Array: a 55GPix large telescope surveying 20% of the entire sky every second* ([baas.aas.org/pub/2022n6i409p05/release/1](https://baas.aas.org/pub/2022n6i409p05/release/1)) for more details. To coordinate inputs from 900 telescopes it will use the *Argus Array Hierarchical Data Processing System*, as its instrument control and analysis pipeline [1]. It will use standard commercial X86 computers to distil the raw 11 Tbps data rate into transient alerts, full-resolution image segments around selected targets at 30-second cadence, and

[1] *The sky at one terabit per second: Architecture and implementation of the Argus Array Hierarchical Data Processing System*, Hank Corbett et al, University of North Carolina at Chapel Hill, [arxiv.org/abs/2207.14304](https://arxiv.org/abs/2207.14304)

- ◀ full-resolution co-adds of the entire field of view at 15+-min cadences.

The science goals are detailed in *Low-Cost Access to the Deep, High-Cadence Sky: the Argus Optical Array*, Law et al ([arxiv.org/abs/2107.00664](https://arxiv.org/abs/2107.00664)) and those of specific interstellar interest include -

- Covering the entire sky with a cadence hundreds of times faster than any other deep sky survey
- Spotting interstellar asteroids
- Exoplanet occultation of stars



**Figure 1. Pipeline components, processes, and data products for the Argus Optical Array. Credit (image and caption): Corbett et al**

## Can We Fly to Planet 9?

A new paper by i4is team members and colleagues asks *Can We Fly to Planet 9?*, Adam Hibberd, Manasvi Lingam, Andreas M Hein ([arxiv.org/abs/2208.10207](https://arxiv.org/abs/2208.10207)).

Planet 9 is a hypothetical object in the outer Solar system, which is as yet undiscovered. It has been speculated that it may be a terrestrial planet or gas/ice giant, or perhaps even a primordial black hole (or dark matter condensate). State-of-the-art models indicate that the semimajor axis of Planet 9 is about 400 astronomical units (AU), about 20 times the distance to Uranus. If the location of Planet 9 were to be confirmed and pinpointed in the future, this object constitutes an interesting target for a future space mission to characterize it further. The team describe mission architectures to reach Planet 9 based on a combination of chemical propulsion and flyby manoeuvres, as well as more advanced options (with a ~100 kg spacecraft payload) such as nuclear thermal propulsion (NTP) and laser sails. The ensuing mission duration for solid chemical propellant ranges from 45 years to 75 years, depending on the distance from the Sun for the Solar Oberth manoeuvre. NTP can achieve flight times of about 40 years with only a Jupiter Oberth manoeuvre whereas, in contrast, laser sails might deliver timescales as little as 7 years. We conclude that Planet 9 is close to the transition point where chemical propulsion approaches its performance limits, and alternative advanced propulsion systems (eg NTP and laser sails) apparently become more attractive.

## Could we see extragalactic transmitters?

In *Constraints on extragalactic transmitters via Breakthrough Listen* ([arxiv.org/abs/2209.08147](https://arxiv.org/abs/2209.08147)), Professor Mike Garrett and A P V Siemion [1] observe that SETI surveys traditionally ignore the fact that they are sensitive to many background objects, in addition to the foreground target star. Since the Breakthrough Listen Initiative has embarked on a comprehensive SETI survey of nearby stars in the Milky Way that is vastly superior to previous efforts as measured by a wide range of different metrics we need to better appreciate and exploit the presence of extragalactic objects in the field of view.

[1] respectively - Jodrell Bank, University of Manchester + Leiden Observatory, Leiden University and Berkeley SETI Research Center, UC Berkeley + SETI Institute, Mountain View.

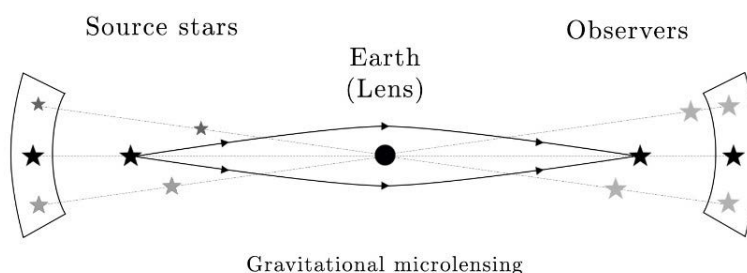
For this paper, the Aladin sky atlas and the NASA/IPAC Extragalactic Database (NED) were employed to make a rudimentary census of extragalactic objects that were serendipitously observed with the 100-m Greenbank telescope observing at 1.1-1.9 GHz. For 469 target fields (assuming a FWHM (full width at half maximum) ([en.wikipedia.org/wiki/Full\\_width\\_at\\_half\\_maximum](https://en.wikipedia.org/wiki/Full_width_at_half_maximum)) radial field-of-view of 4.2 arcminute, NED identified a grand total of 143,024 extragalactic objects, including various astrophysical exotica eg active galactic nuclei (AGN) of various types, radio galaxies, interacting galaxies, and one confirmed gravitational lens system. Several nearby galaxies, galaxy groups and galaxy clusters were identified, permitting the parameter space probed by SETI surveys to be significantly extended. This places constraints on the luminosity function of potential extraterrestrial transmitters assuming it follows a simple power law and that limits on the prevalence of very powerful extraterrestrial transmitters associated with these vast stellar systems are also determined. It is demonstrated that the recent Breakthrough Listen Initiative, and indeed many previous SETI radio surveys, place stronger limits on the prevalence of extraterrestrial intelligence in the distant Universe than is often fully appreciated.

## "To see ourselves as others see us!"

In *To a Louse*, Robert Burns mediated on our inability to "To see ourselves as others see us". In *Earth through the looking glass: how frequently are we detected by other civilisations through photometric microlensing?*, Suphapolthaworn et al [1], a team from Hokkaido University (Thailand), Jodrell Bank, University of Manchester and University Bourgogne Franche Comté attempt that feat in the context of SETI.

They observe that microlensing is proving to be one of the best techniques to detect distant, low-mass planets around the most common stars in the Galaxy and, in principle, Earth's microlensing signal could offer the chance for other technological civilisations to find the Earth across Galactic distances. They consider the photometric microlensing signal of Earth to other potential technological civilisations and call the regions of our Galaxy from which Earth's photometric microlensing signal is most readily observable as the "Earth Microlensing Zone" (EMZ). The EMZ can be thought of as the microlensing analogue of the Earth Transit Zone (ETZ) from where observers see Earth transit the Sun. Just as for the ETZ, the EMZ could represent a game-theoretic Schelling point [2] for targeted searches for extra-terrestrial intelligence (SETI) [3]. They use the Gaia DR2 catalogue with apparent magnitude less than 20 (recall that celestial magnitudes are inverted, the Sun has an apparent magnitude of ~-27 and Proxima Centauri is about 11) to generate Earth microlensing probability and detection rate maps to other observers. Our Solar system is a multi-planet system but they suggest that Earth's photometric microlensing signature is almost always well approximated by a binary lens assumption. Nevertheless they find that the Earth is in fact well-hidden to observers with technology comparable to our own. Even if observers are located around every Gaia DR2 star with apparent magnitude <20, they expect photometric microlensing signatures from the Earth to be observable on average only tens per year by any of them. So to others we are a hard-to-find exoplanet and it's hard to see how we can better achieve Burns' objective. See also "Search for an Alien Message to a Nearby Star" later in this section.

Figure 3. An illustration of a gravitational microlensing event and observer-source pairings for this study. Credit (image and caption): Suphapolthaworn et al



[1] S Suphapolthaworn, S Awiphan, T Chatchadanoraset, E Kerins, D Specht, N Nakharutai, S Komonjinda and A C Robin, Monthly Notices of the Royal Astronomical Society, V515 #4, October 2022 [arxiv.org/abs/2206.09820](https://arxiv.org/abs/2206.09820)

[2] A default choice in the psychology of games [en.wikipedia.org/wiki/Focal\\_point\\_\(game\\_theory\)](https://en.wikipedia.org/wiki/Focal_point_(game_theory))

[3] Note the parallel between this and a treffpunkt, watering-hole or poste-restante, in *AMiTe Treffpunkt - A proposal for communication between Kardashev Type IIb civilisations*, David F Gahan in Principium 32 February 2021

## Perhaps galaxy migrants are choosy?

In *Galactic settlement of low-mass stars as a resolution to the Fermi paradox*, Jacob Haqq-Misra and Thomas J Fauchez [1] ([arxiv.org/abs/2210.10656](https://arxiv.org/abs/2210.10656)) suggest that, though an expanding civilisation could rapidly spread through the galaxy, we should not necessarily expect extraterrestrial presence in the solar system. Not all stellar types may be equally useful for a long-lived civilisation. Perhaps low-mass stars, and K-dwarf [2] stars in particular, would be ideal migration locations for civilisations that originate in a G-dwarf [3] system. The authors use a modified form of the Drake Equation to show that expansion across all low-mass stars could be accomplished in 2 Gyr, including waiting time between expansion waves to allow for a close approach of a suitable destination star and only requiring travel distances about 0.3 light years (ly) to settle all M-dwarfs [4] and about 2 ly to settle all K-dwarfs. They suggest that interstellar expansion will prefer to migrate from a short-lived to a long-lived star and will thus primarily target low-mass systems in order to maximise the longevity of galactic settlement.

## SETI: risk of perceived technology advantage

In *Geopolitical Implications of a Successful SETI Program*, ([arxiv.org/abs/2209.15125](https://arxiv.org/abs/2209.15125)), Jason T Wright (Penn State), Chelsea Haramia (Spring Hill College, Mobile, Alabama) and Gabriel Swiney (NASA and Harvard Law School) analyse recent work thinking through the potential geopolitical results of even minimal successful SETI by Kenneth Wisian (University of Texas at Austin, ex-USAF Major General) and John Traphagan (also University of Texas at Austin), [5] who concluded that there is a measurable risk of conflict over the perceived benefit of monopoly access to ETI communication channels. Given the likelihood that any civilisation we hear from is likely to have anywhere from hundreds to billions of years of technology development lead time on humanity,

even the most seemingly trivial of resulting scientific knowledge, if wielded solely by one nation, might confer an enormous strategic advantage and that even the suspicion that this may be so would be highly destabilising. W&T reject the view that -

"passive SETI is widely regarded as presenting little or no risk to humanity, apart from upsetting some people with incompatible world views".

Wright et al believe that Wisian and Traphagan (W&T) overestimate the necessity for a "realpolitik" approach believing that their approach is based on an overly narrow contact scenario. They conclude that the W&T recommendations are unlikely to work and may even precipitate the ills that they foresee. In response they recommend transparency and data sharing, further development of post-detection protocols, and better education of policymakers to prepare them for a contact scenario.

Without access to the full W&T paper this writer provisionally suspects that W&T may be right. It was certainly a view taken by cosmologist Sir Fred Hoyle, as dramatised in his 1957 novel *The Black Cloud* and his 1961 TV drama *A for Andromeda*.



Fred Hoyle (second left) as an undergraduate in Cambridge in the early 30s. Credit: St John's College, Cambridge

[1] respectively Blue Marble Space Institute of Science, Seattle and American University, Washington DC

[2] [en.wikipedia.org/wiki/Stellar\\_classification#Class\\_K](https://en.wikipedia.org/wiki/Stellar_classification#Class_K)

[3] [en.wikipedia.org/wiki/Stellar\\_classification#Class\\_G](https://en.wikipedia.org/wiki/Stellar_classification#Class_G)

[4] [en.wikipedia.org/wiki/Stellar\\_classification#Class\\_M](https://en.wikipedia.org/wiki/Stellar_classification#Class_M) [5] Kenneth W Wisian and John W Traphagan., *The Search for Extraterrestrial Intelligence: A Realpolitik Consideration*. Space Policy, May 2020, summary: [www.sciencedirect.com/science/article/abs/pii/S0265964620300199](https://www.sciencedirect.com/science/article/abs/pii/S0265964620300199), no open paper.

## i4is Technical Director wins LSI award

Limitless Space Institute (LSI) has announced the 2nd biennial LSI Grants awards. Dr Andreas Hein's team at the University of Luxembourg won with - *Extremely Light-Weight Solar Sails for Fast Deep Space Missions* (SEEDLING): Investigate viability of fabricating  $\mu\text{m}$  thick aerographite sheets; determine load capability; integrate into feasible sail-craft, University of Luxembourg.

The full set of award winners are at - [www.prnewswire.com/news-releases/limitless-space-institute-announces-2nd-biennial-lsi-grants-awards-301617203.html](http://www.prnewswire.com/news-releases/limitless-space-institute-announces-2nd-biennial-lsi-grants-awards-301617203.html).

Notably -

*Direct Fusion Drive Based on Centrifugal Mirror Confinement*, University of Maryland  
*Real Acceleration and Impulse Limits of Light-Sails*, Delft University of Technology  
*The Path Forward: Directed Energy Phased Array (DEPA) Technology*, UC Santa Barbara  
*Traversable Wormholes and Warp Drive: A Road To Interstellar Exploration*, University of Bergamo [1]  
*The Casimir Torque Thruster*, University of California, Davis  
*Navigating the atmosphere: Transferring terrestrial beamed energy to light-sail spacecraft*, Australian National University.

The awards have additional support from Breakthrough Initiatives.

## Identifying ISO Impact Craters

Samuel H C Cabot and Gregory Laughlin have considered how we might identify impact craters made by interstellar objects (ISOs) [2]. Gregory Laughlin has been interested in ISOs for many years, having co-authored numerous papers starting in 2017 (Google Scholar search; Laughlin interstellar). In this paper he and his colleague Samuel Cabot turn their attention to evidence for past ISOs concentrating on lunar impact craters as a long-preserved record. ISOs exhibit relatively high encounter velocities compared to asteroids and comets. They suggest that the melt volume within

craters of a given diameter may be a potential means of identifying ISO craters, as faster impacts produce more melt but this is a challenging task since melt volume and high-pressure petrology, possible diagnostic features, would need in situ analysis of large volumes of material though this may be possible using images from the Lunar Reconnaissance Orbiter camera (LROC) ahead of in situ examination by robotic or human explorers.

## ISO Accessibility and Mission Design

The subject of interception of interstellar objects (ISOs), pioneered by the i4is Project Lyra team, continues to attract interest. A team with lead author Benjamin P S Donitz from CalTech, of NASA Jet Propulsion Laboratory and the University of Hawaii at Manoa present *Interstellar Object Accessibility and Mission Design* ([arxiv.org/abs/2210.14980](https://arxiv.org/abs/2210.14980)) which discusses the accessibility of and mission design to ISOs with varying characteristics. This includes a discussion of state covariance estimation over the course of a cruise [3] handoffs from traditional navigation approaches to novel autonomous navigation for fast flyby regimes and overall recommendations about preparing for the future in situ exploration of these targets.

The team observe that lessons learned here also apply to the fast flyby of other small bodies including long-period comets and potentially hazardous asteroids, which also require a tactical response with similar characteristics. They also observe that though telescopic observations from Earth-based observatories and telescopes can provide valuable science, a dedicated spacecraft can acquire unique information through higher-resolution optical remote sensing and physical interrogation of the target which could resolve the shape, rotation properties, surface morphology, and composition of an asteroid-like ISO and mass spectroscopy can report the gas composition of a comet-like ISO. In addition, using an impactor at an asteroid-like ISO could also reveal fresh surface material to remove any effects of space weathering due to long exposure to interstellar space.

[1] Congratulations to Dr Remo Garratini, a long established friend and colleague of i4is. This has been his research area for many years. See, for example, Principium articles - *Traversable Wormholes and the Casimir Energy in Modified Gravity*, in our report *Wormholes Come to London*, "Interstellar Wormholes: Physics and Practical Realisation" Part 2, in Principium 10, August 2015 and *Wormhole-Stargates: Tunnelling Through The Cosmic Neighbourhood*, in the same issue and also his own article *Wormholes, Energy Conditions and Time Machines*, in Principium Issue 22, August 2018. There is also a report of *Casimir traversable Wormholes*, part of a report on the last *Foundations of Interstellar Studies Workshop* 2019, in Principium 26, August 2019.

[2] *Identifying Interstellar Object Impact Craters*, The Planetary Science Journal (American Astronomical Society), Volume 3, Number 7 [iopscience.iop.org/article/10.3847/PSJ/ac77e9/pdf](https://iopscience.iop.org/article/10.3847/PSJ/ac77e9/pdf).

[3] JPL's Mission Analysis, Operations, and Navigation Toolkit Environment was used to perform covariance analysis for spacecraft and ISO trajectory pairs.

Like the Project Lyra team they believe that key questions about the ISOs found so far remain open, and can only be addressed with a dedicated spacecraft flying out and obtaining close-up and in-situ measurements of the ISO's shape, properties, and composition.

Navigating to an ISO requires state determination of the object and trajectory correction to ensure a high-accuracy flyby (the team reject rendezvous as too challenging given the present "state of the art"). They review current state of practice in autonomous navigation moving from "ground in the loop" (GITL) in mission cruise phase. An approach phase would last from ten to dozens of days before encounter until 24 hours from encounter, entering the terminal phase when knowledge of the encounter point is reduced to below about 100 km. They suggest optical navigation using onboard cameras.

The mission profile is summarised in a diagram.

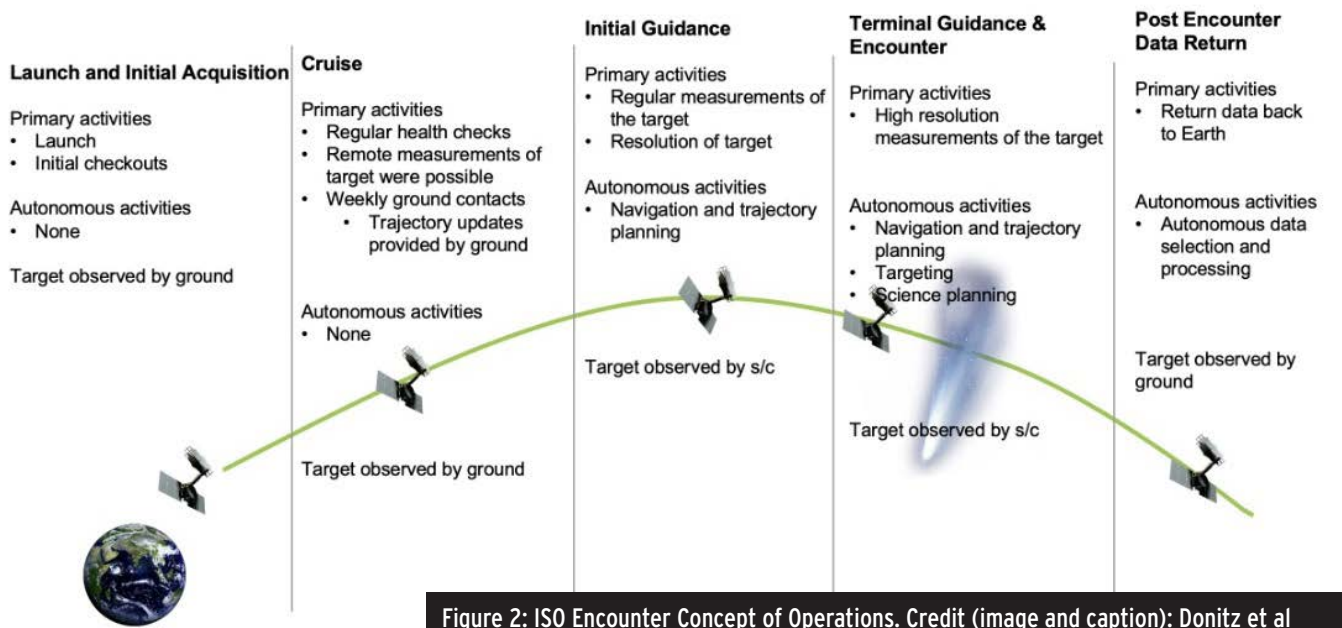


Figure 2: ISO Encounter Concept of Operations. Credit (image and caption): Donitz et al

The authors at Caltech and JPL collaborated to investigate Neural-Rendezvous "a novel deep learning-based Guidance & Control framework for encountering fast-moving targets, including ISOs, robustly, accurately, and autonomously in real-time even with the limited computational capacity of current spacecraft" and testing it for the mission using the JPL SmallSat Dynamics Testbed (SSDT), "a high-fidelity dynamics simulation that models realistic uncertainties and design variables involved in flying a spacecraft". They report performance 20-30 times better than existing autonomous navigation techniques. They suggest that both the initial mission profile and terminal guidance need significant additional refinement as the most significant next steps.

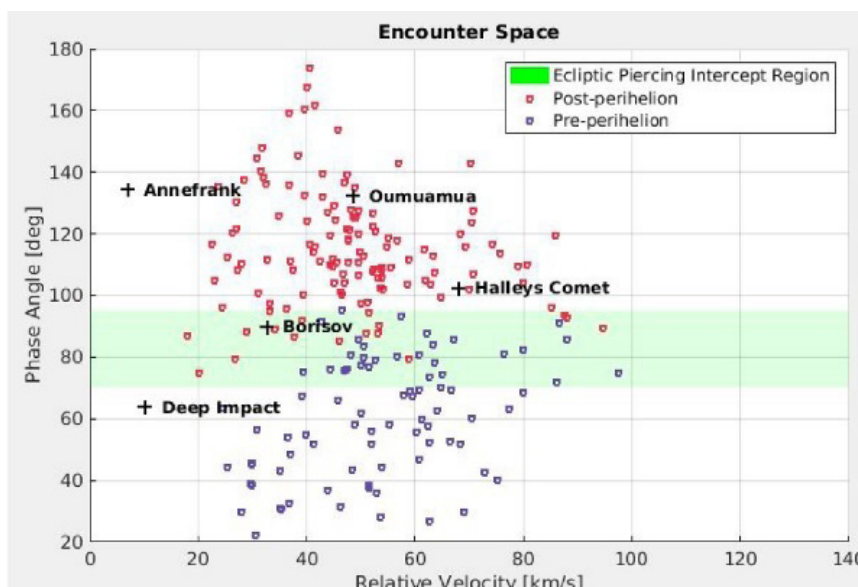


Figure 1: Most trajectories have relative velocities at  $>60$  km/s and phase angles of  $>120^\circ$ . Credit (image & caption): Donitz et al

◀ A personal view by your editor: The JPL/Caltech/U of Hawaii team make no distinction between 1I/'Oumuamua and 2I/Borisov despite the fact that 2I differs little from Solar System comets while 1I is unique in both form and behaviour (see numerous Project Lyra papers, other peer-reviewed research and Principium articles going back to the first Project Lyra paper within weeks of the discovery of 1I). This error is compounded by Figure 1 in the paper (see previous page), which the paper states "...shows the distribution of all ISO flyby cases with their relative velocity and phase angle" but shows Halley's comet and, presumably, other non-interstellar objects since there are several hundred objects shown in the diagram.

There is no need to invoke "Little Green Men" (LGMs) to suggest that 1I represents a science problem wholly unprecedented in its challenge and that therefore a chase mission grows in urgency as the months and years pass without any appearance of a similar object. If our ignorance remains in 10 years time then we will look increasingly myopic having allowed a unique and mysterious object to have passed beyond our reach.

## Is Oumuamua perihelion date significant?

Some preliminary thinking about the trajectory of our first discovered ISO, 1I/'Oumuamua, in a recent piece by Adam Hibberd *Exploring 'Oumuamua's Perihelion Date* ([i4is.org/exploring-oumuamuas-perihelion-date/](https://i4is.org/exploring-oumuamuas-perihelion-date/)). Adam reports he has "been mucking around with 'Oumuamua's orbit on my computer lately". Looking at the orbit parameters he asks "what happens if we keep all of 'Oumuamua's parameters fixed and just change the perihelion date and time?". Varying this parameter over a year around the observed perihelion date and graphing it against perigee distance (ie closest approach to Earth) he finds that the minimum perigee occurs very close to the observed perigee. Adam also tells me that this is an annual cycle so 1I would have been within a few days of closest perigee around that date each year. He's still thinking about this, and he has his own reservations already, but take a look at this blog entry and mull it over yourself.

## Keith Cooper on the 'Oumuamua puzzle

In *Interstellar object Oumuamua still puzzling scientists 5 years after discovery* ([www.space.com/oumuamua-discovery-solar-system-implications](https://www.space.com/oumuamua-discovery-solar-system-implications))

Keith Cooper, our former editor, mulls the continuing mystery. Keith, for some years editor of *Astronomy Now* ([astronomynow.com](https://astronomynow.com)), has interviewed Greg Laughlin, an astronomer at Yale University [1] about the deepening 1I/'Oumuamua mystery. The principal topic is the hypothesis of the solar system "throw line". Laughlin and Caltech astronomer Konstantin Batygin coined the term to define where a giant planet is able to slingshot a small body with enough acceleration to achieve escape velocity from the gravitational pull from its star. The farther out the planet is, the easier this becomes because the star's gravity decreases with radial distance. In our solar system, according to Laughlin, the throw line is at about 372 million miles (about 600 million kilometres) from the Sun. Jupiter, Saturn, Uranus and Neptune are beyond our solar system throw line, and all could have ejected bodies into interstellar space but "hot Jupiters", commonly discovered exoplanets, are too close to their stars to do this. Laughlin still likes the idea that 'Oumuamua is a chunk of solid hydrogen ice since he suggests that it would explain all of 'Oumuamua's strange properties [2]. Cooper concludes by observing that further ISOs have failed to turn up as had been predicted by several astronomers. Laughlin said -

"If objects like 'Oumuamua are discovered in short order by Rubin-LSST, then that's pointing to a large population of Neptune-like planets. But if it finds no such objects, then the degree to which 'Oumuamua was unusual will become more and more pronounced."

All this uncertainty underlines the importance of preparations to examine 'Oumuamua closely by the only possible means, a mission to it. I4is Project Lyra pioneered such planning within weeks of the discovery of this first ISO and continues to refine and extend the options for such missions.

[1] Author of several papers on the interstellar object (ISO), 1I/'Oumuamua and related topics, see *In Situ Exploration of 'Oumuamua-like objects* Principium 21, May 2018, and *On the Anomalous Acceleration of 1I/2017 U1 'Oumuamua* Principium 25, May 2019.

[2] See *Was 'Oumuamua made of molecular hydrogen ice?*, Principium 30, August 2020, *An Interstellar Visitor: sorting the fact from the speculation* by Professor Alan Aylward, Principium 32, February 2021 and *Book Review: Extraterrestrial: The First Sign of Intelligent Life Beyond Earth*, Avi Loeb, reviewed by Patrick Mahon, Principium 33, May 2021

[3] The Vera C. Rubin Observatory in Chile will begin observing by the middle of this decade, with its 8.4-metre, wide-field survey telescope. If predictions hold true, it is expected to discover at least one interstellar interloper every year. ▶

## ◀ Laser Inertial Confinement Fusion

In *Interstellar Propulsion Using Laser-Driven Inertial Confinement Fusion Physics*, our co-founder, Kelvin F Long, continues his active contribution to interstellar thinking. This latest paper [1] is part of a wider Special Issue of Universe, *Exploration of Interstellar Space: Concepts, Space Science and Missions*, edited by Prof Dr Roman Ya Kezerashvili (New York City College of Technology, The City University of New York).

Kelvin's paper examines the basics of inertial confinement fusion propulsion and options for its use. Inertial confinement fusion is the basis for the terrestrial experiment at the National Ignition Facility ([wci.llnl.gov/facilities/nif](http://wci.llnl.gov/facilities/nif)) and the 1978 BIS design study, Daedalus [2]. He looks at the system design of such propulsion, examining mechanisms and inefficiencies. He suggests a model spacecraft system, as illustrated below.

See also News item *NIF 2021 record yield shot* later. Kelvin also surveys some early fusion propulsion thinking including Orion, 1957-1965, Helios, 1964-1965, Enzmann, 1966, Sirius, 1970, Hyde, Wood and Nuckolls, 1971-1972 and Daedalus, 1973-1978 (and a parallel Soviet Icarus, 1976), And later work including Hyde, 1983, Vista, 1987-2003, Longshot, 1988, Schulze (NASA), 1991, Halyard, 1997 and Icarus (specifically the Resolution design), 2009. This is a wide survey, though the writer has a reservation

"It was not the intention here to give a fully comprehensive review of ICF propulsion, but merely to illustrate the various physics processes at work which go into calculating the performance of a space vehicle propelled by this mechanism and to describe some of the vehicle concepts that have been developed."

However this is a substantial piece of work, 39 pages with 86 references. The technical aspects are sometimes challenging to the non-specialist but I think it will be valuable to all interested in interstellar propulsion.

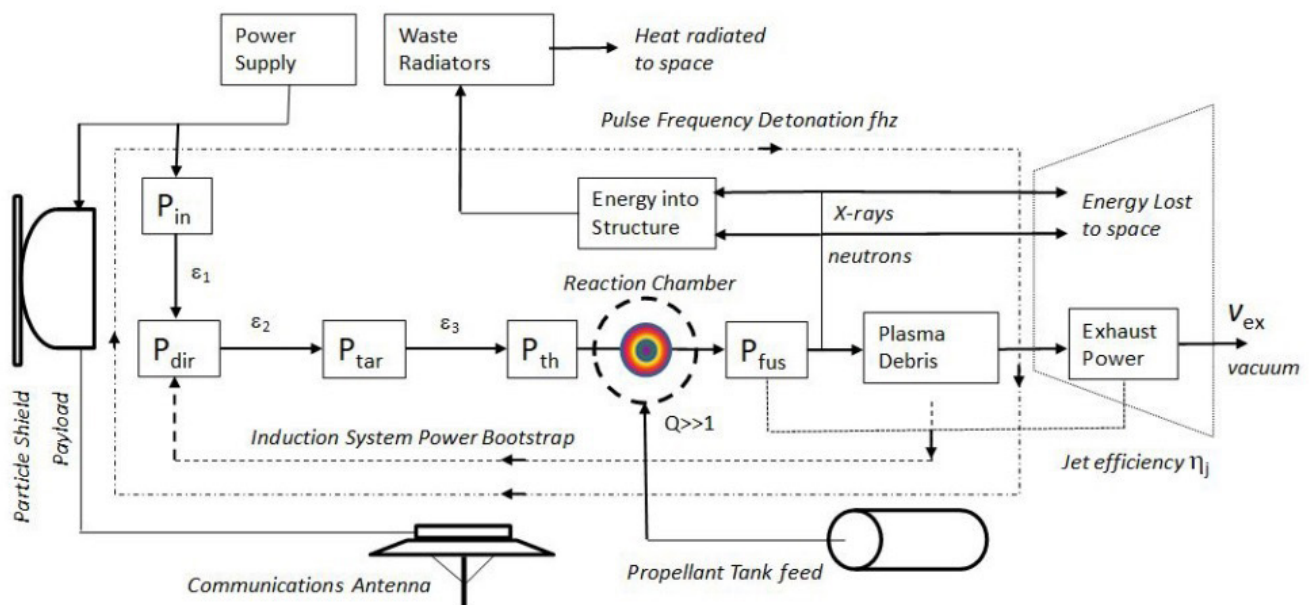


Figure 5. Illustration of an ICF spacecraft and its engine power cycle. Credit (image and caption): K F Long

[1] *Interstellar Propulsion Using Laser-Driven Inertial Confinement Fusion Physics*, Universe 2022, 8, [www.mdpi.com/2218-1997/8/8/421](http://www.mdpi.com/2218-1997/8/8/421)

[2] See Project Daedalus – A Beginners' Guide in Principium 24, [i4is.org/principium-24/](http://i4is.org/principium-24/).

## Is anyone out there? Two SETI papers

Three papers reported in this issue take different views of the likelihood of successful SETI, neutral, pessimistic and optimistic, but their approaches and objectives differ considerably. In *Perhaps galaxy migrants are choosy?*, above, the author is optimistic. In the two papers reported here a less positive view is taken.

In *Avoiding the "Great Filter": Extraterrestrial Life and Humanity's Future in the Universe*, Jonathan H Jiang (JPL) et al (arxiv.org/abs/2210.10582) take a pessimistic view, proposing several possible doomsday scenarios for ourselves, including anthropogenic and natural hazards, suggesting reforms we require in individual, institutional and intrinsic behaviours to avoid the Great Filter here on Earth. They take a gloomy view of "humanity's technological cleverness outpacing our better judgment". Some of the possible filters discussed are -

- Unchecked population growth
- Nuclear War
- Pathogens & Pandemics
- Artificial Intelligence (but there is no mention of Bostrom's *Superintelligence*, cited in this *Interstellar News - Limit to cosmological communication*)
- Asteroid & Comet Impacts and
- Climate Change

However they cite the Democratic Peace Theory [1] - which holds that democracies are hesitant to go to war with each other, saying it has historically been borne out.

The paper contains a minor mistake, referring to "William Gibson's *Necromancer*" - which looks like a classic spell-checker assisted error.

In *Exploration of M31 via Black-Hole Slingshots and the "Intergalactic Imperative"*, Andrew Gould (Max-Planck-Institute for Astronomy, Königstuhl), shows that a gravitational slingshot using a stellar-mass black hole (BH) orbiting SgrA\* [2] could launch robotic spacecraft toward M31 at 0.1c - with timescales of several million years for settlement. However he remarks that the achievable speed is ultimately limited by the BH mass but also by the tensile strength of steel, (the latter sounds absurd since we are likely to improve well beyond steel before we can get anywhere near the required BH mass of 5 solar masses or build a craft to go to M31). He states that the BH encounter must be accurate to ~1 km. Deceleration into M31 would rely on a similar BH. Some quotes indicating the scope of this idea -

"The shepherd spacecraft [guiding the longer distance craft to the BH encounter] would travel a few hundred AU in front. It would make a map of all the small BHs and choose the best one."

"After carrying out this mission, the shepherd spacecraft could plunge deep into the potential well of SgrA\*, which would enable it to head back toward Earth. On its return, it could receive a report from the primary spacecraft summarizing the success (or otherwise) of its launch. Then it could convey this message to Earth when it reached the solar neighborhood, a few Myr later."

The author suggests using a network of white-dwarf-binary "hubs" as the backbone of a 0.002c [3] transport system, which would enable complete exploration of the Milky Way (hence full measurement of all non-zero terms in the Drake equation) on 10 Myr timescales.

This paper thus takes a very long-term view as in some earlier articles in *Principium* 17 and 18 by Dmitry Novoseltsev, *Engineering New Worlds: Creating the Future* - and in *Principium* 32 by David Gahan, *AMiTe Treffpunkt - A proposal for communication between Kardashev Type IIb civilisations*.

The topic will no doubt challenge some of our best minds for some time to come. Even if a positive is achieved there will be remaining questions and issues to address.

[2] Sagittarius A, the supermassive black hole at our galactic centre

[1] They cite Bueno de Mesquita et al, *An Institutional Explanation of the Democratic Peace*, *The American Political Science Review*, V93, 1999

[3] c=300,000 km/sec so 0.002c is 600 km/sec. Contrast the speed of the Voyagers on their very long interstellar journey, 15-17 km/sec

## ◀ Why We Don't See ETI Super-Als

In *A Solution to the Fermi Paradox Based on Adaptations and Diminishing Returns: On What Super-Als Are Like and Why We Don't See Them* ([osf.io/bq438/](https://osf.io/bq438/)), Daniel Vallstrom suggests that evolving Als will be subject to the same cooperative evolutionary pressure as biological entities. He also suggests that diminishing returns from increased access to material resources may mean that there will be no incentive to colonise entire galaxies, thus providing a possible explanation of the Fermi paradox. He invokes Planck's principle in the sociology of scientific knowledge, parallel to and predating Kuhn's "paradigm shift" ideas, and simply saying that progress occurs when the proponents of defunct theories simply die [1]. He also references ideas in economics such as Nash's game theory and morality including the ethics of vegetarianism (for biological beings of course!). He suggests that there is little to be gained from expansion beyond a certain point where diminishing returns accrue from further expansion so Kardashev progression does not occur [2]. He also sees no "payoff" for communication with lesser intelligences (presumably including our own).

## No laser signals from Alpha Cent A or B

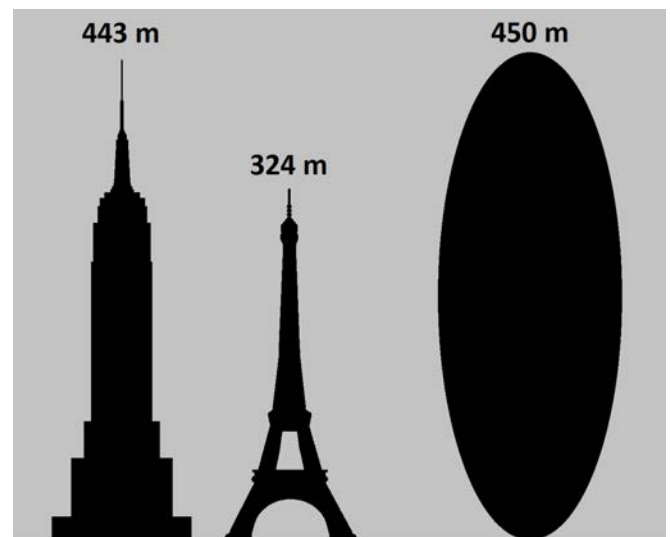
G W Marcy of the Center for Space Laser Awareness, Santa Rosa, California suggests that "Speculative models of the Milky Way Galaxy include communication networks composed of transmitters, receivers, and nodes stationed near and between stars" and cites references from Bracewell 1973 to Hippke 2021 [3]. Marcy has conducted a search for laser light from the directions of Alpha Centauri A and B using spectra gathered between 2004 and 2018 but found no laser emission lines in *A Search for Optical Laser Emission from Alpha Centauri AB* (Monthly Notices of the Royal Astronomical Society, October 2022 ([academic.oup.com/mnras/article/516/2/2938/6668809](https://academic.oup.com/mnras/article/516/2/2938/6668809))).

Credit: Phoenix CZE/Wikipedia

The data included 15 056 spectra of Alpha Cen B and 306 spectra of Alpha Cen A, from the HARPS spectrometer between 2004 and 2018, available on the European Southern Observatory (ESO) public data archive ([archive.eso.org](https://archive.eso.org)). He says that his criteria would have revealed optical laser light from the directions of Alpha Cen B if the laser had a power of at least 1.4-5.4 MW and of three times that for Alpha Cen A. The conclusion is that "... a growing desert is emerging in the search for extraterrestrial technology."

## Laser sailcraft for PHO and ISO missions

A recent paper *Sailing to Apophis LPSC-2016* [4] by a team, mainly of i4is researchers, demonstrates that using laser-driven light-sail probes to implement quick-reaction missions to intercept potentially hazardous objects (PHOs) approaching Earth would be a cost-effective alternative to keeping a fuelled rocket with a conventional probe on standby. The team suggest an initial test of this capability using the upcoming close approach of Asteroid 99942 Apophis. Apophis is a near-Earth asteroid 450 metres in size that will harmlessly pass close to Earth on April 13, 2029 [5]. Apophis will pass approximately 30,000 km from Earth, traveling approximately 7,400 m/s at closest approach, taking about 12 hours to cross the Moon's orbit. So it will be within geostationary altitude. Not to "freeze the blood" but this is a big object!



[1] Contrast Popper's concept of conjecture and refutation and consider the possible counter example to Planck, that of Continuous Creation cosmology which died out years before its principal proponent, Fred Hoyle.

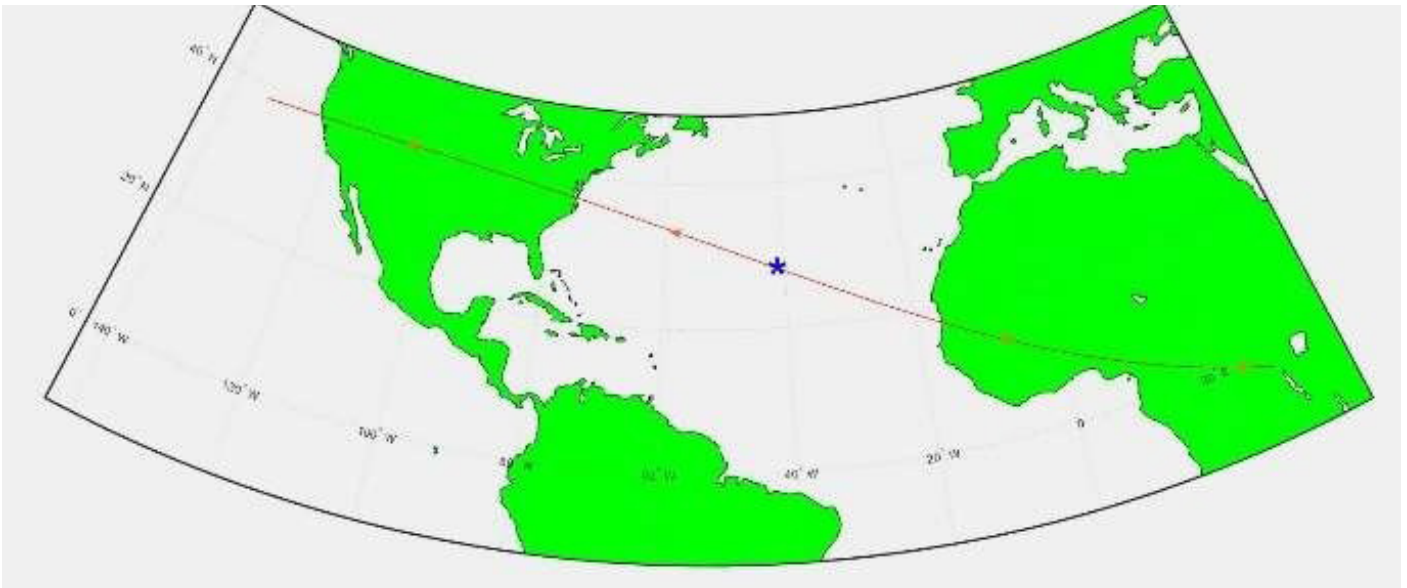
[2] For thoughts in this see the series *Engineering New Worlds: Creating the Future* by Dmitry Novoseltsev in Principium issues in Principium 17, May 2017 and Principium 18, August 2017

[3] Bracewell *The Opening Message from an Extraterrestrial Probe*, *Astronautics & Aeronautics*. 11: 1973 and Hippke *Interstellar communication network. III. Locating deep space nodes*, [arxiv.org/abs/2104.09564](https://arxiv.org/abs/2104.09564)

[4] *Sailing to Apophis LPSC-2016*, William Paul Blase (DCS Corporation), Marshall Eubanks (Space Initiatives Inc and i4is), Adam Hibberd (i4is), Robert G Kennedy III (Tetra Tech and i4is), A M Hein (i4is), May 2022, [www.researchgate.net/publication/361730796](https://www.researchgate.net/publication/361730796)

[5] NASA information at [solarsystem.nasa.gov/asteroids-comets-and-meteors/asteroids/apophis/in-depth/](https://solarsystem.nasa.gov/asteroids-comets-and-meteors/asteroids/apophis/in-depth/)

## Apophis Groundtrack Earth Encounter 2029 April 13th (\* = Perigee of Apop1his at 31653km, 21 h 45m 21s UTC)



Apophis trajectory during encounter. Ground track is from right to left and will proceed over possible launch sites in Virginia 42 minutes after perigee, and sites in Colorado and the Western US during the next 40 minutes

Credit (image and caption): Blase et al

Two sailcraft would be launched on a Black Brant sounding rocket; one to be released at 75 km altitude – the minimum altitude at which the laser could still overcome atmospheric drag, the other at the rocket's maximum altitude of 1,500 km. The laser would then thrust each probe in succession to 30,000 km apogee, timed to bracket the asteroid's pass so that one probe encounters it while falling back to Earth, the other while ascending. Both probes would acquire images and data from Apophis during their pass. One probe would be timed to impact Apophis so that the second probe could acquire data on the resulting debris plume. The impacting probe could also carry a hardened and cushioned transponder to enable future tracking of the asteroid. Both launches could be from US launch sites. The ground track lies across the continental USA and Africa.

They propose a solid-sail approach in which the sail is a solid body, albeit made from ultra-light materials, with the entire rear surface being the reflective sail element and the electronics mounted

on the forward layer. These are sounding rocket launches and in the subsequent trajectory the data-acquiring probe would be light enough to decelerate to relatively slow speeds in Earth's thermosphere and then fall slowly to the Earth's surface for retrieval. Initial calculations show the probe as described can be driven to the required apogee at 30,000 km using a drive laser at a wavelength of 1,064 nm (which readily penetrates the atmosphere and is currently available with industrial fibre lasers) and a total drive beam intensity of 17 MW (industrial electric furnaces routinely consume at more than ten times this rate).

Also worth a look is *To The Kuiper Belt! Solar System Precursor Missions with Solar and Laser-Driven Sailcraft* [1], by the same authors. Sailcraft are our (immediate) future for these ambitious missions; Hard to reach with reaction propulsion but feasible relatively short term using early and not-too-demanding laser propulsion.

[1] *To The Kuiper Belt! Solar System Precursor Missions with Solar and Laser-Driven Sailcraft* (presented at the Breakthrough Initiatives, "Sundiver" workshop, University of Luxembourg, where Andreas Hein is Associate Professor of Space Systems Engineering) [www.researchgate.net/publication/360937695 To The Kuiper Belt Solar System Precursor Missions with Solar and Laser-Driven Sailcraft](https://www.researchgate.net/publication/360937695_To_The_Kuiper_Belt_Solar_System_Precursor_Missions_with_Solar_and_Laser-Driven_Sailcraft)

## NIF 2021 record yield shot

Three peer-reviewed papers highlight the scientific results of a National Ignition Facility (NIF) record yield shot on 8th August 2021 ([www.llnl.gov/news/three-peer-reviewed-papers-highlight-scientific-results-national-ignition-facility-record](http://www.llnl.gov/news/three-peer-reviewed-papers-highlight-scientific-results-national-ignition-facility-record)) .

Given the ultimate energies promised for this technology the chief scientist for the Lawrence Livermore National Laboratory inertial confinement fusion program seems appropriately named - Omar Hurricane. He said "The record shot was a major scientific advance in fusion research, which establishes that fusion ignition in the lab is possible at NIF."

This is inertial confinement fusion as in BIS Project Daedalus and some of its successors. Perhaps we are just a little closer to propulsion to take big payloads to the stars (and much faster transit around our solar system)?

The papers cited are -

*Lawson Criterion for Ignition Exceeded in an Inertial Fusion Experiment*, H Abu-Shawareb et al. (Indirect Drive ICF Collaboration) Phys. Rev. Lett. 129, 075001 - Published 8 August 2022  
[journals.aps.org/prl/abstract/10.1103/PhysRevLett.129.075001](https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.129.075001)  
Open publication at - [researchgate.net](https://researchgate.net) [1]

*Experimental achievement and signatures of ignition at the National Ignition Facility*, A B Zylstra et al. Phys. Rev. E 106, 025202 - Published 8 August 2022, [journals.aps.org/pre/abstract/10.1103/PhysRevE.106.025202](https://journals.aps.org/pre/abstract/10.1103/PhysRevE.106.025202)  
No open publication found

*Design of an inertial fusion experiment exceeding the Lawson criterion for ignition*, A L Kritcher et al. Phys. Rev. E 106, 025201 - Published 8 August 2022  
[journals.aps.org/pre/abstract/10.1103/PhysRevE.106.025201](https://journals.aps.org/pre/abstract/10.1103/PhysRevE.106.025201)  
Open publication: [journals.aps.org/pre/abstract/10.1103/PhysRevE.106.025201](https://journals.aps.org/pre/abstract/10.1103/PhysRevE.106.025201)

## Overview of The Galileo Project

Professor Avi Loeb is a distinguished astrophysicist, former head of astronomy at Harvard and chair of the Advisory Council of Breakthrough Starshot. His ideas about alien object in the solar system are radical and he has published a book, *Extraterrestrial: The First Sign of Intelligent Life Beyond Earth* - which suggested an artificial origin for the first observed interstellar object (ISO) 1/'Oumuamua, We reviewed this in P33, last year. In our last issue we reviewed the comprehensive survey, *Life in the Cosmos: From Biosignatures to Technosignatures*, by Manasvi Lingam and Avi Loeb. In P35 last year we had a News Feature, *Loeb on an Artificial Origin for 'Oumuamua*. This latest paper, *Overview of The Galileo Project*, [arxiv.org/abs/2209.02479](https://arxiv.org/abs/2209.02479), by Prof Loeb is an overview of his Galileo Project, a scientific research programme to search for extraterrestrial equipment near Earth. He suggests that "Taking the path not taken, it is likely to pick some low-hanging fruit."

He describes it as "a fishing expedition" whose results would be primarily natural and human-made objects. He hopes and expects to find objects that appear to be of non-human but artificial origin. He aims to use novel instruments to monitor the sky in the optical, infrared and radio bands, as well as in audio, magnetic field and energetic particles signals to be analysed and catalogued by artificial intelligence. He quotes Sherlock Holmes "When you have eliminated all which is impossible, then whatever remains, however improbable, must be the truth." (from *The Sign of Four*). In the short term he plans an expedition to retrieve the fragments of a meteor, believed to have been an ISO [2] from the ocean floor in an attempt to determine its composition and structure. He proposes planning for a mission to rendezvous with "the next 'Oumuamua" (though he appears to take no note of ideas from i4is Project Lyra and others to intercept 1/'Oumuamua itself). He believes that the instruments developed by the Galileo Project will "represent a brand-new observatory design with unprecedented capabilities".

[1] [www.researchgate.net/profile/Aaron-Fisher-2/publication/364331337\\_Lawson\\_Criterion\\_for\\_Ignition\\_Exceeded\\_in\\_an\\_Inertial\\_Fusion\\_Experiment/links/6349a8a62752e45ef6b7c93f/Lawson-Criterion-for-Ignition-Exceeded-in-an-Inertial-Fusion-Experiment.pdf](https://www.researchgate.net/profile/Aaron-Fisher-2/publication/364331337_Lawson_Criterion_for_Ignition_Exceeded_in_an_Inertial_Fusion_Experiment/links/6349a8a62752e45ef6b7c93f/Lawson-Criterion-for-Ignition-Exceeded-in-an-Inertial-Fusion-Experiment.pdf)  
[2] CNEOS\_2014-01-08 ([en.wikipedia.org/wiki/CNEOS\\_2014-01-08](https://en.wikipedia.org/wiki/CNEOS_2014-01-08))

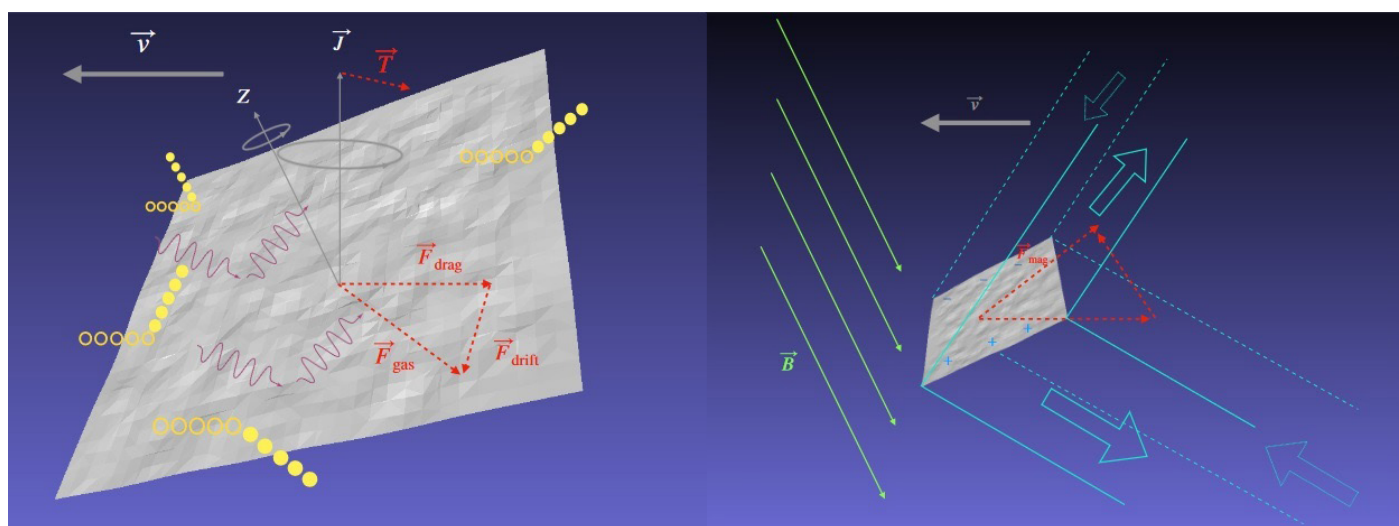
## Testing the light-sail scenario for an ISO

In a new paper *Observable tests for the light-sail scenario of interstellar objects*, [arxiv.org/abs/2208.13818](https://arxiv.org/abs/2208.13818), Wen-Han Zhou, Université Côte d'Azur, and colleagues from China and the USA, examine the idea that the first observed interstellar object (ISO), 1I/ʻOumuamua, is a light sail. They also aim to characterise future ISOs using similar techniques. They suggest that the drift of a freely rotating light sail in the interstellar medium would be about 100 AU even if the travel distance is only 1 parsec (one parsec is about 200,000 AU or 3.26 light-years). They also suggest that a tumbling light-sail would be most unlikely to be visible in all 55 observations spread over two months after discovery and that radiation pressure could cause a larger displacement that is normal to the orbital plane for a lightsail. All these factors are at odds with actual observations of 1I/ʻOumuamua. In short, they conclude that ʻOumuamua is a very odd object but it is not odd enough to be a lightsail.

## Search for an Alien Message to a Nearby Star

In this paper [1] Michaël Gillon (University of Liège), Artem Burdanov (Massachusetts Institute of Technology) and Jason T Wright (The Pennsylvania State University) suggest that if alien probes have colonised the whole galaxy, they could have formed an efficient galactic-scale communication network by establishing direct gravitationally lensed links between neighbouring systems. If so it could make it possible to eavesdrop on the emission of local probes to one of these stars from positions opposite the nearest ecliptic stars and thus this is a promising artifact-seeking SETI strategy. The authors hypothesise alien Focal Interstellar Communication Devices (FICDs) discoverable in our solar system.

The paper cites related work from Rob Swinney and Pat Galea in 2011, *Project Icarus: Mechanisms for Enhancing the Stability of Gravitationally Lensed Interstellar Communications*, P Galea & R Swinney JBIS v64, p. 24-28), and Rob will be commenting in more detail on this work in our next issue.



**Fig 1. Schematic illustration of the hydrodynamic (left panel) and magnetic (right panel) drag on a moving light sail in a turbulent ISM with a magnetic field,  $B$  (green). The tumbling sail is represented by a thin gray sheet with a bumpy surface and a spin axis in the  $Z$  direction that precesses around its angular momentum,  $J$ , axis.**

Credit (image and caption): Zhou et al

[1] Search for an Alien Message to a Nearby Star The Astronomical Journal, Volume 164, Number 5, 27 October 2022, [iopscience.iop.org/article/10.3847/1538-3881/ac9610/pdf](https://iopscience.iop.org/article/10.3847/1538-3881/ac9610/pdf)

## Frank Drake 1930-2022

We were sad to hear of the passing of Frank Drake - May 28, 1930–September 2, 2022. However, 92 years is a "good innings" as we in the cricket-playing nations put it. He was one of the very few true pioneers of SETI. His famous equation gives us all a very useful "rule of thumb" for the likelihood of meeting any interstellar neighbours -

**"The number of detectable civilisations in the Milky Way galaxy = the rate at which stars are born \* the fraction of stars that host planets \* the number of habitable planets per planetary system \* the fraction of those planets on which life evolves \* the fraction of life that evolves intelligence \* the fraction of intelligent life that develops communicative technologies \* the average length of time civilisations are detectable."**

Drake just missed the Second World War but was briefly an engineer officer in the US Navy as part of his engineering physics degree at Cornell University. A PhD in astronomy at Harvard followed. He was at Green Bank observatory for most of his career. Later he was at the University of California at Santa Cruz and was a founder of the SETI Institute.

Drake, the man and the astronomer, is captured fondly by his daughter, Nadia, a science journalist, in *My dad launched the quest to find alien intelligence. It changed astronomy.* ([www.nationalgeographic.com/science/article/father-launched-quest-find-alien-intelligence-changed-astronomy](http://www.nationalgeographic.com/science/article/father-launched-quest-find-alien-intelligence-changed-astronomy)).



Frank and Nadia Drake at the Green Bank Observatory in 2016. Behind them is the 85-foot Tatel Telescope, which Frank used to conduct Project Ozma—the first modern scientific search for communicating extraterrestrials—in 1960.

Credit (image): Nadia Drake.

Credit (caption): nationalgeographic.com

Our team had only fleeting encounters with Drake.

**Marshall Eubanks** recalls meeting him several times towards the end of his life, and he was always kind, gracious, and quick to include the young researchers in NASA's NIAC, and other meetings, in his discussions. He had a good sense of humour and was a good comrade in after-meeting conversations in the bar.

**Andreas Hein** recalls the impression he gave at a Breakthrough Discuss in 2019 at UC Berkeley - relaxed and definitely not aloof. If our species is to reach the stars then an encounter with ETI would perhaps be the greatest milestone - whether it occurs before or after. *Nature* remembered him "He showed Earth that SETI was possible and practical, and embraced the idea that the most fascinating science might not yield results in one person's lifetime [www.nature.com/articles/d41586-022-02962-8](http://www.nature.com/articles/d41586-022-02962-8)."