John I Davies reports on recent developments in interstellar studies

A real, albeit humble, warp bubble (continued)?

In our last issue, P35 November 2021, we reported on *A real, albeit humble, warp bubble?* based on a paper by Harold "Sonny" White et al [1].

In *Did scientists discover a warp bubble? Crunched up space-time, explained*} [2], Sarah Wells explains the ideas in the paper. She mentions parallel work by Erik Lentz (eriklentzphd.com) [3].

She also reports dissent. In *I wrote the book on warp drive. No, we didn't accidentally create a warp bubble* science communicator Ethan Siegel [4] says "the science doesn't check out". He describes the open access *European Physical Journal (EPJ)* (www.epj.org/} as "often dubious". Dr Siegel describes himself as "a scientist familiar with Dr White's grandiose claims surrounding physics-violating engines in the past". Not a fan then?

Warp drive is either a long way off or impractical but, like SETI, continues to attract the attention of scientists and engineers and of science journalists. Let's keep watching this plausible but difficult technology. There are many possible ways to the stars and all the serious ones deserve our attention. ■

Announcement from IRG - See what we heard at Tucson

The presentation videos from the 7th Interstellar Symposium that IRG held in Tucson, Arizona, September 25-27, 2021 are now beginning to be uploaded for viewing. There will be more as the editing is done until everything is online. You can see the videos in the 2021 Presentation Video Archive irg.space/2021-presentation-video-archive/. The 8th Interstellar Symposium will be in Montreal, in 2023; Come to Montreal - i4is will be there with IRG again! ■

Free-floating planets in the Upper Scorpius

In *A rich population of free-floating planets in the Upper Scorpius young stellar association*, published in Nature Astronomy Letters, 22 December 2021 (www.nature.com/articles/s41550-021-01513-x and open publication: arxiv.org/abs/2112.11999[1]), Nuria Miret-Roig, Laboratoire d'Astrophysique de Bordeaux & University of Vienna, Department of Astrophysics and colleagues from CNRS (France), University of Tokyo & National Institutes of Natural Sciences Tokyo, Institut d'Astrophysique de Paris, Depto. de Astrofisica Madrid, Universit Paris-Saclay, Depto. de Inteligencia Artificial UNED Madrid, Universidad de Cadiz, - identify a new population of free-floating planets (FFPs) - planetary-mass objects that are not bound to host stars. FFPs were first discovered in the 1990s but their nature and origin remain uncertain due to a lack of large homogeneous samples that would enable a statistical analysis of their properties. Micro-lensing surveys, using a foreground star to magnify the FFPs have detected them down to a few Earth masses. But the ephemeral nature of micro-lensing events prevents follow-up observations and thus better characterisation. This paper reports the discovery of between 70 and 170 FFPs in the region of Upper Scorpius and Ophiuchus relatively close to the Sun, the largest homogeneous sample of FFPs discovered to date. They suggest that ejections due to dynamical instabilities in giant exoplanet systems must be frequent within the first 10 million years of a system's life and thus account for the origins of significant numbers of FFPs.
Other authorities have suggested that these hard-to-detect bodies are likely to be our nearest interstellar neighbours and that internal heating by nuclear processes might make them capable of sustaining life. ■

[1] *Worldline numerics applied to custom Casimir geometry generates unanticipated intersection with Alcubierre warp metric* , European Physical Journal V81, #677 2021 epjc.epj.org/articles/epjc/abs/2021/07/10052_2021_Article_9484/10052_2021_Article_9484.html
[2] www.inverse.com/innovation/warp-bubble-space-time.
[3] *Breaking the warp barrier: hyper-fast solitons in Einstein–Maxwell-plasma theory*, Erik W Lentz, March 2021 *Classical and Quantum Gravity* V38,#7.
[4] bigthink.com/starts-with-a-bang/no-warp-bubble/ - author: https://bigthink.com/people/ethansiegel/.

Capture of interstellar objects

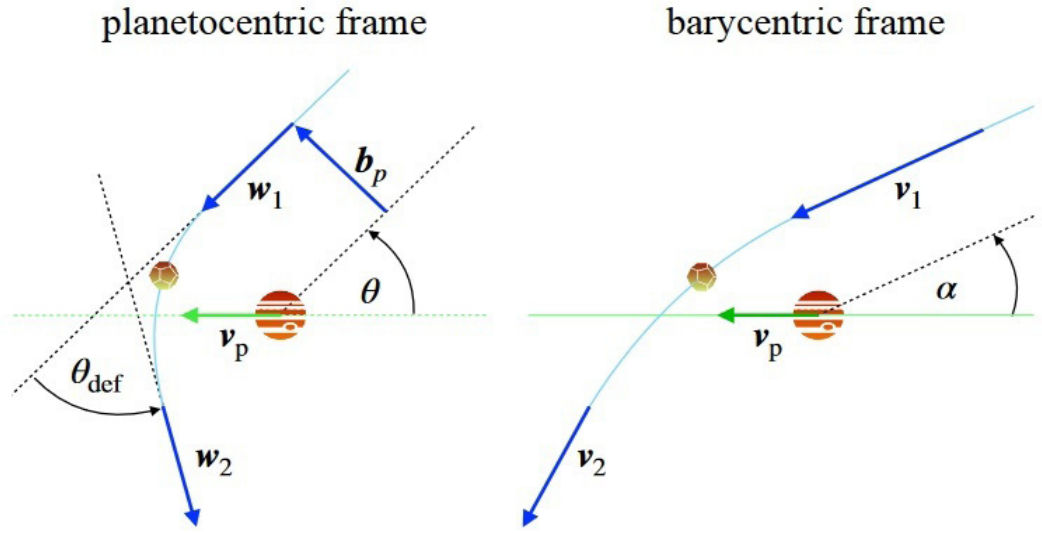
In *Capture of interstellar objects I: the capture cross-section*, researchers from Germany, UK and Switzerland examine how interstellar objects (ISOs) might be captured into orbits within the Solar System [1]. Since the only known ISOs, 1I/'Oumuamua and 2I/Borisov, are heading out on hyperbolic orbits, never to return, finding and identifying captured ISOs is currently the only other source of physical evidence from the rest of the universe.

The paper studies the capture of ISOs by a planet-star binary based on the mass ratio between planet and star, the size of the planet's orbit and its eccentricity. They use a mixture of analytic (roughly speaking "solve the equation") and numeric (roughly speaking "approximate using arithmetic") techniques. Theories of the ejection of ISOs from their birth systems imply interactions with giant planets (as in the slingshot manoeuvres used by the Voyagers and proposed by i4is Project Lyra missions) it might be expected that incoming ISOs can be perturbed into solar orbits by Jupiter or the smaller gas and ice giants in our own system.

They remark that "both the capture rate and the population of captive ISOs depend directly on the number density of these objects in interstellar space, which is not well known". We need to keep looking for both captured and hyperbolic ISOs if we are to learn directly about the rest of the galaxy before our probes can cross the almighty gulf to the nearest stars. ■

Solid core thermal antimatter propulsion

Acta Astronautica has published *Evaluation of solid core thermal antimatter propulsion concepts* [2]. No open access version of this paper seems to be available but the research organisation concerned, ThrustMe (www.thrustme.fr) has been widely published and the abstract is intriguing. Lafleur suggests that energy released during antimatter annihilation can be used to heat a working fluid to directly produce thrust (an "antimatter rocket") or run a thermodynamic cycle to generate power for conventional electric propulsion systems (antimatter power generation). The paper discusses different types of antimatter reactions and solid core reactors, different propellants (hydrogen, water, methane, and carbon dioxide) and electric propulsion technologies (arcjets, Hall thrusters, and gridded ion thrusters). ■



Swing-by of an ISO by a planet. In the frame moving with the planet (planetocentric frame) - the ISO is deflected by angle θ_{def} but retains its speed. If the ISO passes in front of the planet the outgoing barycentric speed (and hence energy) is smaller than the incoming speed enabling capture.

Credit: Dehnen and Hands [1].

The effect is identical to the drop towards the Sun required for a solar Oberth manoeuvre as in the earliest Project Lyra proposals for ISO interception.

[1] *Capture of interstellar objects I: the capture cross-section*, Walter Dehnen and Thomas O Hands, arxiv.org/abs/2112.07468.
[2] *Evaluation of solid core thermal antimatter propulsion concepts*, Trevor Lafleur, Acta Astronautica, Volume 191, February 2022, Pages 417-430

Feasibility of space solar power

The engineering consultancy Frazer-Nash has delivered a report on the feasibility of space solar power to the UK government [1].

The report envisages an orbital demonstrator by 2031 and an operational system by 2040 suggesting delivery of sustainable and clean energy at competitive prices. With input from John Mankins (Mankins Space Technology - using earlier concept, SPS Alpha) and Ian Cash (International Electric Co Ltd - using an earlier concept, CASSIOPei). The report envisages a ground station with a 6.7 km by 13 km elliptical rectifying antenna (converting microwave to DC power) receiving 245 W/m^2 RF power - only 25% of the intensity of the sun at the equator thus inherently safe for life on earth - and delivering 2 GW into the UK power grid.

The power satellite would be a monster 1.7 km across with solar reflectors of similar dimensions. It would be geostationary - thus giving 24 hour service and avoiding damage from proliferating in space debris in lower orbits. The power downlink would be at 2.45 GHz or 5.8 GHz which are industrial, scientific and medical (ISM) designated frequencies.

Power satellites like this could, of course, provide an ideal energy source for space-based beamers delivering laser push to small interstellar probes. The scale economics arising from their application to terrestrial power supply would inevitably alter the relative economics of ground-based versus space-based beamers.

More about the economics of beamers for interstellar missions in *UCSB on the Economics of Interstellar Flight* - elsewhere in this Interstellar News. ■

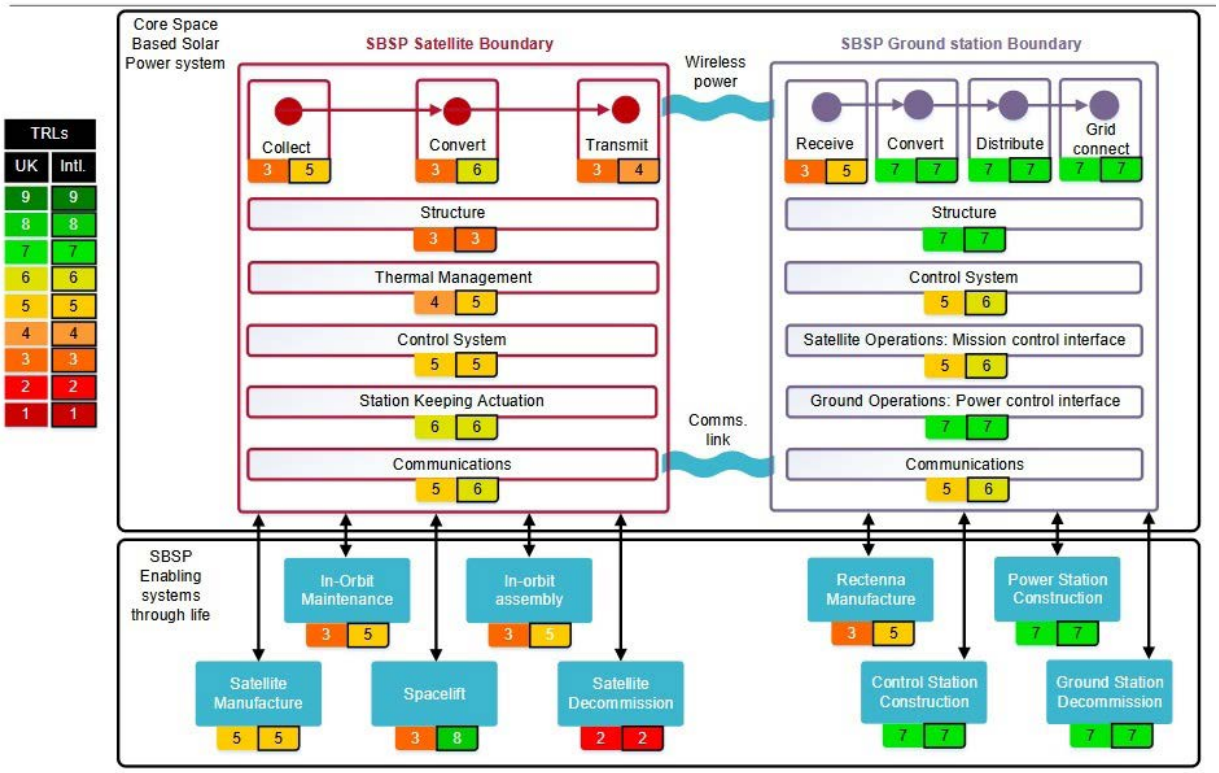


Figure 5: Visual summary of subsystem TRL assessment

Technology Readiness Levels (TRLs) [2]of subsystems from Space Based Solar Power as a Contributor to Net Zero - Phase 1: Engineering Feasibility Report https://www.fnc.co.uk/media/qkleyd5d/fnc-004456-51057r-phase-1-engineering-feasibility-issue-1-0.pdf.

Credit: Frazer-Nash

[1] Press release: *Frazer-Nash report for UK government shows feasibility of space solar power* 27/09/2021: www.fnc.co.uk/discover-frazer-nash/news/frazer-nash-report-for-uk-government-shows-feasibility-of-space-solar-power/, *Space Based Solar Power: De-risking the pathway to Net Zero - Executive Summary* www.fnc.co.uk/media/e15ing0q/frazer-nash-sbsp-executive-summary-final.pdf

[2] ISO 16290:2013 Space systems — Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment www.iso.org/standard/56064.html

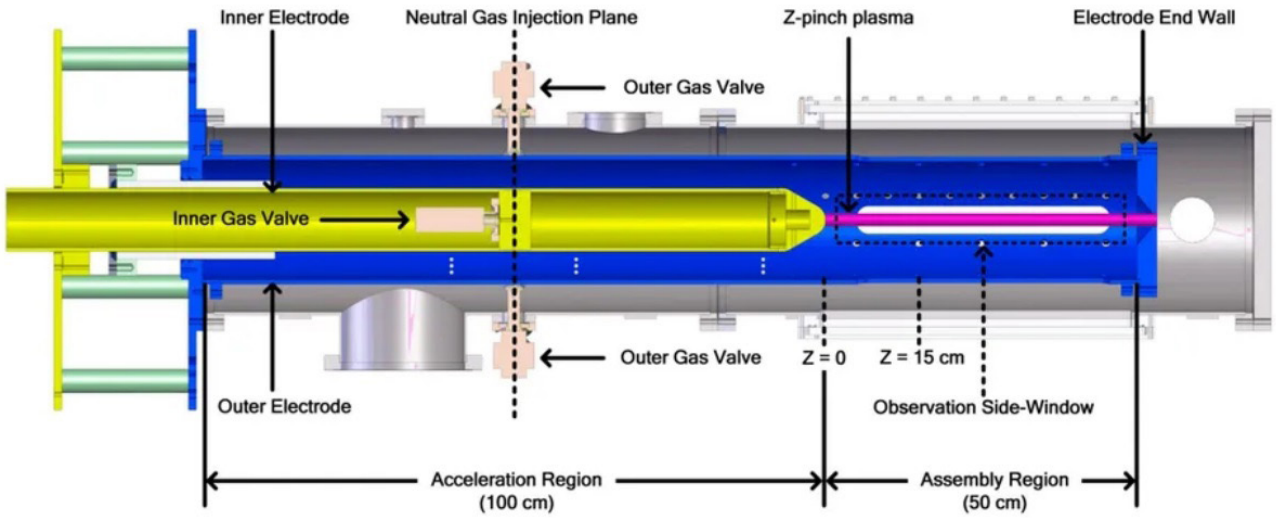
Hyper-Fast Positive Energy Warp Drives

Erik W Lentz of Pacific Northwest National Laboratory, USA (www.pnnl.gov/), has published a paper *Hyper-Fast Positive Energy Warp Drives* (arxiv.org/abs/2201.00652). He points out that travel at speeds beyond that of light has been associated with requirements for staggeringly large amounts of energy and "negative energy" too! In this article he summarises a new approach that identifies "soliton" solutions capable of superluminal travel while being sourced by purely positive energy densities based on his own paper, *Breaking the warp barrier: hyper-fast solitons in einstein-maxwell-plasma theory* [1].

Ever since Miguel Alcubierre's 1994 paper *The warp drive: hyper-fast travel within general relativity,* physicists and engineers have been attacking the mighty problems involved in turning his idea into reality. It seems we are still a long way from achieving this and there may still be things that make it infeasible but the possible effects of achieving superluminal travel can only barely be imagined. ■

IEEE reports - A Pinch of Fusion

The University of Washington work on Z-pinch fusion was mentioned in Rob Swinney's article *Extreme Deep Space Exploration* in Principium 25 May 2019. A recent IEEE Spectrum magazine reports on the spinoff company Zap Energy, aiming to move this work towards a commercial phase. They explain how sheared-flow stabilisation can overcome instability in the plasma stream [2].
Z-pinch fusion is the method explored in the Icarus Firefly study of Robert Freeland and Michel Lamontagne as explained by Patrick Mahon in Principium 22 August 2018, *Reaching The Stars in a Century Using Fusion Propulsion – A Review Paper based on the 'Firefly Icarus' Design* (i4is.org/reaching-the-stars-in-a-century-using-fusion-propulsion/).
Commercialisation of fusion for terrestrial use must inevitably assist its development for space propulsion and thus the possibility of heavyweight interstellar probes. ■



From IEEE article: As deuterium gas is injected into Zap Energy's FuZE-Q reactor, electrodes introduce synchronous pulses, which strip electrons from the deuterium atoms to create a plasma, or ionized gas. The plasma accelerates toward the assembly region, where the current creates a radial shear, or pinch, in the plasma flow. This magnetic field maintains stability as it simultaneously confines, compresses, and heats the plasma to fusion conditions.

Credit: (caption and image): ZAP Energy

[1] *Breaking the warp barrier: hyper-fast solitons in einstein–maxwell-plasma theory,* Eric W Lentz - in *Classical and Quantum Gravity* 38, p. 075015 (Mar 2021). arxiv.org/abs/2006.07125.
Solitons are single self-propagating waves - first observed in a canal by a Scottish engineer, John Scott Russell in 1834, www.mansfield.ox.ac.uk/solitary-waves-colin-please-maths. Russell went on to design the steamship *Great Eastern*, in collaboration with Isambard Kingdom Brunel.
[2] *Magnetic-Confinement Fusion Without the Magnets*, published in the January 2022 print issue of IEEE Spectrum as "A Pinch of Fusion." spectrum.ieee.org/zap-energy-fusion-reactor.

100 GW beamer by coherent combination of 100 M lasers

The Breakthrough Starshot ground-based laser array - order 100 GW of continuous wave optical power - requires coherent combination of many lasers into one beam to achieve a high optical power output. Bandutunga et al [1] propose a photonic solution for optical phase sensing and control to enable the coherent combination of order 10^8 individual lasers - to sense and compensate for atmospheric distortions.
Key points include -

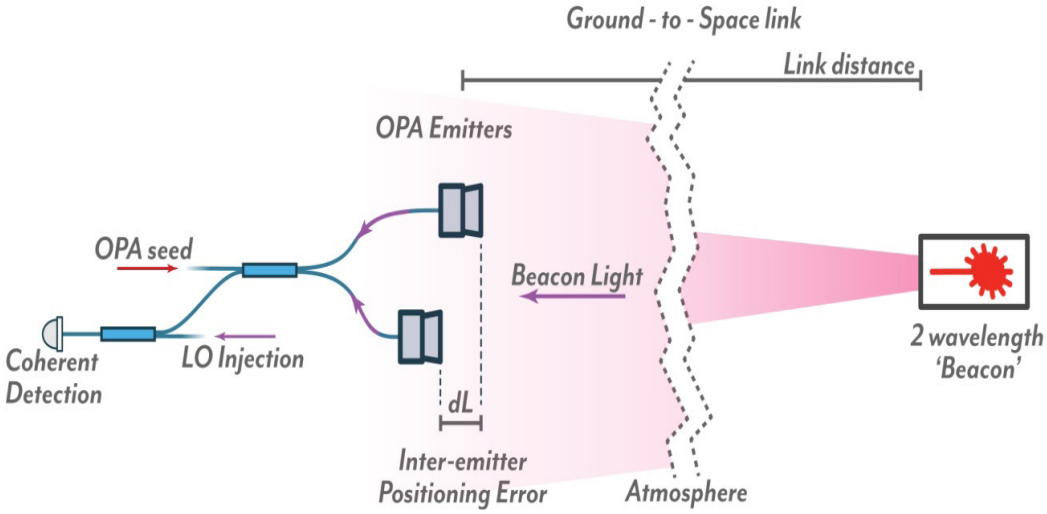
• The system employs digitally enhanced heterodyne interferometry (DEHeI), using pseudo-random binary codes to uniquely identify and demodulate the interference signal from multiple lasers. This capability to uniquely identify optical paths (in effect a unique fingerprint) permits the measurement of the optical phase acquired along the non-common light paths to each emitter [2].

Bandutunga and Ward (B&W) propose a hybrid method that combines DEHeI multiplexed phase sensing with wavelength division multiplexing (WDM) to enable a multilayer hierarchical control scheme capable of individual phase control of an arbitrary number of optical emitters.

• They point out that any method that relies on back-reflected light from the sailcraft will have to deal with long delays due to light travel time at interplanetary distances.

• They propose to obtain the external phase measurements required for atmospheric pre-correction with a satellite-based laser "guide-star". The sensing beam covers the entire beamer array, perhaps a square kilometre with 100 million emitters.

Of course none of this system complexity would be necessary for a space based beamer - but it might take a bit longer to build! ■



From B&W Fig 4. Conceptual overview of the "Beacon" sensing approach. A two wavelength optical source within the isoplanatic patch of the optical phased array (OPA) is used to illuminate all emitter telescopes. Light from the Beacon is coupled into the OPA arms, combined, and then interfered with a local oscillator field (LO injection). Using the multiplexing technique digitally enhanced heterodyne interferometry, the Beacon wavefront, as seen by individual emitters, can be separately measured. Using a combination of emitter measurements at the two Beacon wavelengths, we reconstruct the phase correction required for the OPA wavelength enabling dynamic correction of atmospheric wavefront distortions as well as static phase offsets between emitters due to inter-emitter positioning errors.

[1] Photonic solution to phase sensing and control for light-based interstellar propulsion, Chathura P Bandutunga, Paul G Sibley, Michael J Ireland, and Robert L Ward - all Australian National University, Journal of the Optical Society of America B Vol. 38, Issue 5, pp. 1477-1486, www.osapublishing.org/josab/fulltext.cfm?uri=josab-38-5-1477&id=450064

[2] Modulating each beam with a unique pseudorandom code enables errors caused by spurious interference to be reduced by a factor inversely proportional to the PRN code length - see Shaddock, JPL, 2007 Optical Society of America, *Digitally enhanced heterodyne interferometry*, opg.optica.org/ol/abstract.cfm?uri=ol-32-22-3355

JWST - so far so good

The launch of the Ariane 5 carrying the James Webb Space Telescope was a nail-biting Christmas present - with the unwrapping in the following two weeks. Enough has been written already but perhaps the most memorable moment following the main event was the fond goodbye between the Ariane upper stage and the JWST as it headed for Sun-Earth Lagrange point 2. Many fingers were crossed as the mirror segments were adjusted enroute and for the final insertion into its Lissajous orbit around L2 on 24 January. All remarkably smoothly done.

We have months to wait to see first results but let's offer congratulations to NASA, ESA, CSA, Arianespace and the JPL and other engineers - particularly for the mirror origami which seems to have worked flawlessly. ■

Separation of the JWST about 28 minutes after launch - from camera in Ariane upper stage. Credit: NASA and Arianespace

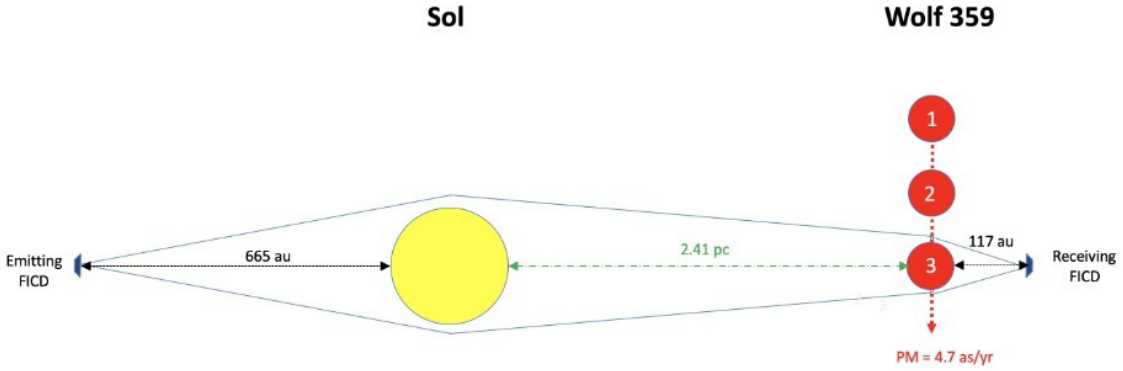
Interstellar communication from hypothetical alien probes

Michaël Gillon (Université de Liege), Artem Burdanov (MIT) and Jason T Wright (Pennsylvania State University) hypothesise that our Galaxy has been fully explored by self-reproducing probes forming an efficient communication network at the galactic scale by direct links between neighbouring systems, using the systems' host stars as Gravitational Lenses (GL). They describe their search for these focal interstellar communication devices (FICDs) in a paper *Search for an alien communication from the Solar System to a neighbor star* [1].

They suggest Wolf 359, the third nearest stellar system, as the best target for a search for interstellar communication from these hypothetical alien probes. Since Earth is a transiting planet as seen from Wolf 359, it would pass in a communication beam of the probe once per year.

They have made a first attempt to detect optical messages emitted from the Solar System to this star, using observations gathered by the TRAPPIST-South and SPECULOOS-South robotic telescopes. These would be sensitive enough to detect constant emission with emitting power as small as 1 W but the search was not successful despite searching for less optimally positioned transmitters within the ecliptic plane.

They are now extending their search beyond the ecliptic plane and for both transmitters and for reflections from a hypothetical solar sail which might be used to maintain the position of such a probe. ■



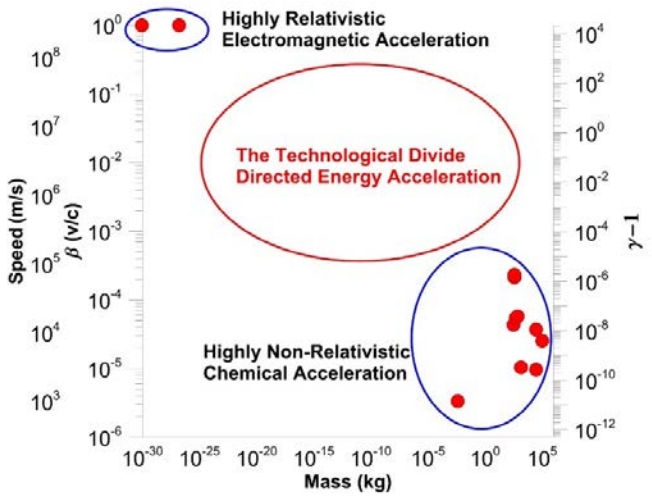
Geometry of the hypothesized communication link from the solar system to the Wolf 359 system (distances and stellar sizes are not to scale). The Wolf 359 system is shown at 3 different positions. Position 1 corresponds to the time of the emission of the photons that we receive from it now. Position 2 corresponds to its current position. Position 3 corresponds to the time it will receive the photons emitted now by the FICD. (caption based on Gillon et al Fig 2) Image Credit: Gillon et al

[1] Search for an alien communication from the Solar System to a neighbor star arxiv.org/abs/2111.05334

UCSB on Economics of Interstellar Flight

Thanks to our interstellar colleague, Paul Gilster, for drawing our attention to more excellent work by Professor Philip Lubin's team at the University of California - Santa Barbara. A paper *The Economics of Interstellar Flight [1]* will be formally published in a special issue of Acta Astronautica in early 2022. As part of the economic calculus for large scale directed energy (the beamers envisaged by Breakthrough Starshot and earlier studies by Professor Lubin and by members of the i4is team) he expands beyond interstellar missions to rapid interplanetary transit, long-range beamed power (for ion, ablation, and thermal engines), long-range recharging of distant spacecraft, long-range and ultra high bandwidth laser communications, remote composition analysis, manipulation of asteroids, and planetary defence. He sees this as an exponentially expanding growth area driven by diverse economic interests and requiring a fundamental change in system designs to deliver the cost reductions required. The paper outlines the physics that must drive the economics and derives an analytic cost model to support forward planning.

Challenges include exponential growth in some of the technologies but not in others resulting in complex dynamics of system costs and suggesting the need for an "interstellar roadmap" including photonics and electronics and a detailed understanding of other, non-exponential, factors.



Credit: (image and caption) Lubin and Cohen

Figure 1: Speed and fractional speed of light achieved by human accelerated objects vs mass of object from sub-atomic to large macroscopic objects. Right side y-axis shows $\gamma - 1$ where γ is the relativistic "gamma factor." $\gamma - 1$ times the rest mass energy is the kinetic energy of the object.

The paper contains a detailed analysis of many cost factors but energy cost dominates in most cases.

This suggests that directed energy propulsion technology will be largely a spinoff of other applications, like early space capability assisted by military application from Von Braun onwards. Lubin and Cohen point out the larger infrastructure costs of a space-based beamer but, despite the dominance of the cost of energy in this work, does not appear to consider the implications of space-based power sources, notably energy satellites, for example the solar power stations envisaged in UK government-sponsored research (see *Feasibility of space solar power* - earlier in this Interstellar News). A similar "spin-off" effect looks likely to decrease the cost of space-based power. Since earth rotation effects are eliminated, the continuous power required would be greatly reduced since thrust could be applied for hours and even days. ■

Beyond Solar System - beware dark matter

A recent paper by Edward Belbruno (Yeshiva University, NYC) and James Green (Princeton University) *When Leaving the Solar System: Dark Matter Makes a Difference* (arxiv.org/abs/2201.06575) suggests that, since the mass of our galaxy is predominantly dark matter, trajectories for spacecraft sufficiently far from the Sun will be affected. In fact has it already affected our existing trans-Neptunian probes? Can we devise a spacecraft to explicitly detect this force? And it would certainly affect interstellar probes if and when we launch them.

We only know (or think we know?) about the existence of dark matter because the galaxy seems to be rotating too fast for gravity from known objects (baryonic matter) to hold it together and that light is bent around external galaxies too much to be accounted for by what we see in them.

Dark matter is so weird that physicists have even suggested modified versions of existing gravity theories as an alternative explanation for what astronomers observe.

This paper calculates the force per unit mass, or equivalently, acceleration, on a particle due to the dark and baryonic matter of the galaxy using two different models.

[1] *The Economics of Interstellar Flight*, Philip Lubin, Alexander N Cohen, preprint at arxiv.org/abs/2112.13911

◀ The two models used are developments of analytic approximations to real galaxies-

- the Hernquist model
- the Navarro-Frenk-White (NFW) model.

The trajectories of Pioneer 10 and New Horizons may give some insight into this likely effect. The lifetime of the RTG power source on Pioneer 10 may be a critical issue. The proposed Interstellar Probe of JHU-APL may have an even better opportunity to measure this effect.

Whatever the mass of our eventual probes to other star systems they will be affected. And since both laser-push and fusion rocket propulsion designs imply a boost phase and a long coasting phase it will be difficult to apply course corrections in mid journey. We therefore need to understand and measure this effect in the planning of these missions. ■

Conceptual illustration of the Wind Rider plasma magnet drive: Credit: Brent Freeze

Trappist 1 - Gravitational Lens in 8 Years

A paper at the December 2021 meeting of the American Geophysical Union, *Wind Rider Pathfinder Mission to Trappist 1 - Solar Gravitational Lens Focal Region in 8 Years* [1] proposes a pathfinder mission to 542 AU, within the Solar Gravitational Lens (SGL) focal region. This would provide -

- calibration data for instruments on a flagship interstellar probe
- initial optical measurements of a scientifically interesting target such as Trappist-1 (given selection of a suitable angle relative to the sun and plane of the ecliptic)

Practical Interplanetary Propulsion Study Group (PIPG) constructed a radial profile for the solar wind ranging from 1 AU through the foreshock at 83 AU, to a notional heliopause at 123 AU, and the near interstellar medium out to 1,800 AU. The resulting matrix of plasma parameters was applied to a trajectory model "seed code," to test flight paths for future probes leading to a proposed cubesat equipped with a Wind Rider propulsion system. Wind Rider is a suggested drag device primarily intended for fast trip times across the solar system. More in *Wind Rider: A High Performance Magsail*, (www.centauri-dreams.org/2021/11/19/wind-rider-a-high-performance-magsail/). They suggest a 1 year science campaign at the end of a total pathfinder mission time after launch of less than 8 years. They also suggest an option to gradually decelerate to a near stop at the end of the mission, using the Wind Rider to drag against the interstellar plasma. ■

Tailpiece: Wacky Scientists hire wacky vicars - or not?

The people at *Interesting Engineering* can't resist a quip - or in this case a missing one! They spotted a piece which originated in *The* (London) *Times - Heavens above: NASA enlists priest to prepare for an alien discovery* which announced that "The Rev Dr Andrew Davison, a priest and theologian at the University of Cambridge with a doctorate in biochemistry from Oxford, is among 24 theologians to have taken part in a NASA-sponsored programme at the Center for Theological Inquiry (CTI) in Princeton in the US to assess how the world's major religions would react to news that life exists on worlds beyond our own." Principium addressed what is a serious issue in a *Book Review: Religions and Extraterrestrial Life, David A Weintraub*, page 51 in Principium 29, May 2020 (i4is.org/wp-content/uploads/2020/05/Principium29-print-2005271554opt.pdf).

The Interesting Engineering piece was subtitled *A rabbi, an imam, and a priest walk into the NASA...* but the punchline was missing. A prize for the best joke with this first line! ■

KEEP AN EYE ON OUR FACEBOOK PAGE

Our Facebook page at **www.facebook.com/InterstellarInstitute** is a lively forum much used by our own Facebookers and others active in our subject area.

[1] *Wind Rider Pathfinder Mission to Trappist-1 Solar Gravitational Lens Focal Region in 8 Years* agu.confex.com/agu/fm21/meetingapp.cgi/Paper/796237