John I Davies reports on recent developments in interstellar studies

Principium will have a News Editor

From our next issue, P45, May 2024 we will have a dedicated News Editor, Parnika Singh. She has been a contributor to recent issues of Principium and has been editing our Members Newsletter for some time and has now accepted this new post. A student at Interlake Senior High School (Bellevue near Seattle), Parnika Singh is Vice President of the Interlake Rocketry Club and is author of *An analysis of interstellar exploration focused on propulsion technologies*, Journal of High School Science (Jan 2023). You will see her byline above from the next issue of Interstellar News.

Sail Trajectories to Proxima b

Photon-Sail Trajectories Towards Exoplanet Proxima b [1] was presented at the 6th International Symposium on Space Sailing, 2023, in June 2023 hosted by the New York City College of Technology, City University of New York. It investigates trajectories in the form of connections between the classical Lagrange points of Alpha-Centauri's binary system (composed of the stars Alpha Centauri A and B, AC-A and AC-B) and the classical Lagrange points of the Alpha Centauri C (AC-C)/Proxima b system assuming graphene-based sails - either two sails with a reflective coating on only one side of the sail or two sails with a reflective coating on both sides. The authors used a genetic algorithm to optimise the linkage conditions between the two three-body systems, focusing on minimising the position, velocity, and time error at linkage. They aim, by this means, to solve the problem of a rendezvous rather than a fly-by at relativistic speeds of 0.1 to 0.2c implied by the base Breakthrough Starshot design and the BIS Project Daedalus fusion rocket design.

Data Return from Proxima Centauri b

Thanks again to our friend Paul Gilster for another brilliant summary of i4is work (www.centauri-dreams.org/2024/01/19/data-return-from-proxima-centauri-b/) based on the paper *Swarming Proxima Centauri: Optical Communication Over Interstellar Distances* (arxiv.org/abs/2309.07061) featured last year in Principium 41 (i4is.org/principium-41/) May 2023, *i4is delivers Communications Study to Breakthrough Starshot: Swarming Proxima Centauri: Optical Communication Over Interstellar Distances*. It also mentions the NASA NIAC grant featured in this issue describing the Space Initiatives and i4is team win of a NASA NIAC grant for a swarming study based on this work, see the News Feature in this issue, *NASA NIAC funds swarming study: Space Initiatives and i4is team to further their study of interstellar swarming mission*.

We're all doomed!

The Solar System, like all star systems, is on a journey. The path ahead for quite a long time is clear but one fine day Private Frazer's gloomy prophesy is likely to be fulfilled [2]. Researchers in Bordeaux and Tucson, Arizona, have examined our long term future path and found that even before the Sun evolves to an inhospitable size there is about a 1% chance that a star will pass within 100 au of the Sun [3]. This is closer than the Voyager 1 and 2 probes and well within the Oort cloud where most long period comets come from so the consequences in terms of perturbation of orbits are potentially catastrophic. The authors did an N-body simulation (Newton discovered the difficulty of predicting the path of three bodies under gravitation and the more general case still does not have an analytic solution). They created a numeric simulation starting in 1998 considering stars with masses relative to the Sun of times 0.05 to times 4, running 12,000 simulations. Curiously enough they expect that Mercury is the most vulnerable - it would be dumped into the Sun. The Sun, Venus and the Moon are our own collision hazards. The outer planets are most likely to be ejected from the Solar System. The work was partly inspired by a science fiction novel in preparation. This sounds rather gloomier that Private Frazer's worst fears.

[1] Tim J Rotmans, Jeannette Heiligers (TU Delft) research.tudelft.nl/files/175113997/2023_Rotmans_Heiligers_Photon-Sail_Trajectories_Towards_Exoplanet_Proxima_b.pdf

[2] Private Frazer is the gloomy undertaker (mortician) in the BBC television sitcom Dad's Army - about the local volunteers in a small seaside town in WW2. He always finds reasons to expect the worse in any situation, hence his catchphrase, "We're all doomed".

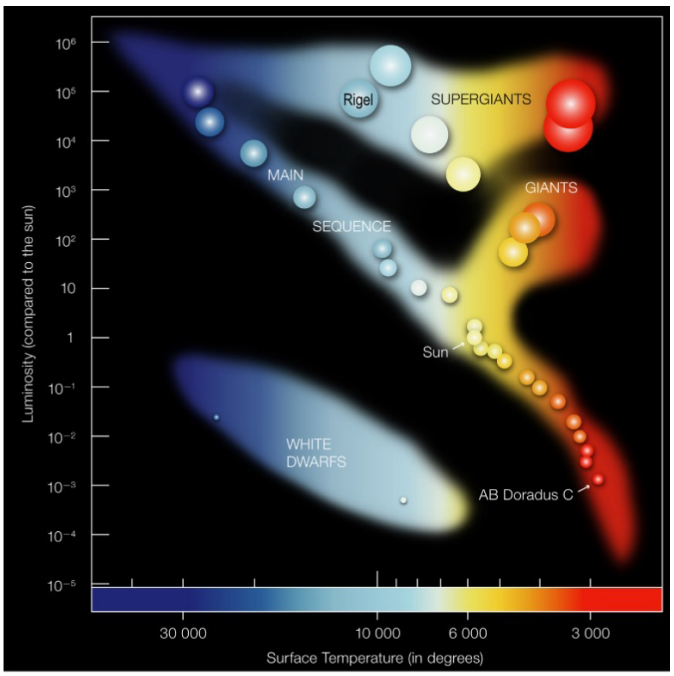
[3] *Future trajectories of the Solar System: dynamical simulations of stellar encounters within 100 au*, Sean N Raymond et al, 2023 arxiv.org/abs/2311.12171

On the first probe between two interstellar civilisations

The indispensable Paul Gilster (www.centauri-dreams.org) draws our attention to an intriguing paper. In *On the first probe to transit between two interstellar civilizations* [1] Graeme H Smith (University of California, Santa Cruz) offers a new angle on the perennial Wait Equation (faster probes are developed over time and overtake earlier probes [2]), the perceived effect at the destination system of arriving probes "If a space-faring civilization embarks on a program to send probes to interstellar destinations, the first probe to arrive at such a destination is not likely to be one of the earliest probes, but one of much more advanced capability." Professor Smith [3] considers two scenarios for probe velocities over time, they increase either linearly or exponentially. At the destination he concludes that more advanced probes will overtake and arrive first. And this effect will be most pronounced for the most distant sending civilisations. If this is so then "Unidentified Aerial Phenomena" (UAP), if they are the product of ETI, should include very advanced technology.
The discussion following Paul Gilster's article [4] is also interesting.

Photovoltaic Onboard Power for Interstellar

In *Interstellar Photovoltaics for Exploring Alien Solar Systems* (arxiv.org/abs/2401.06124) Professor George F Smoot (Donostia International Physics Center, Spain dipc.ehu.eus/es) considers using local star power from photovoltaics at the destination system. These would be tailored for the particular target star to deliver maximum power and low mass. This power constrains both the downlink power transmission (and thus the bandwidth available) and the local computing capability (and thus data compression, information selectivity and probe flexibility). Smoot observes that organic photovoltaics (OPVs) have photoactive layers which are nanometre-thin films that can be deposited on thin plastic substrates and on curved surfaces. OPVs exhibit mechanical flexibility and there is even evidence for self-healing from radiation damage. He uses a handy Hertzsprung-Russell Diagram from Wikipedia showing the brightness and temperature colour versus effective surface temperature of stars and explains the relevant characteristics of the planet Alpha Centauri b.



The Hertzsprung-Russell Diagram. Credit:Wikipedia commons and European Southern Observatory, en.wikipedia.org/wiki/File:Hertzsprung-Russell_Diagram_-_ESO.png

[1] International Journal of Astrobiology, December 2022, www.cambridge.org/core/journals/international-journal-of-astrobiology/article/abs/on-the-first-probe-to-transit-between-two-interstellar-civilizations/00AEDC0E153C45A576DE78EFA5E2F85A
[2] en.wikipedia.org/wiki/Interstellar_travel#Challenges
[3] www.astro.ucsc.edu/faculty/index.php?uid=ghsmith
[4] www.centauri-dreams.org/2023/10/30/the-order-of-interstellar-arrival/

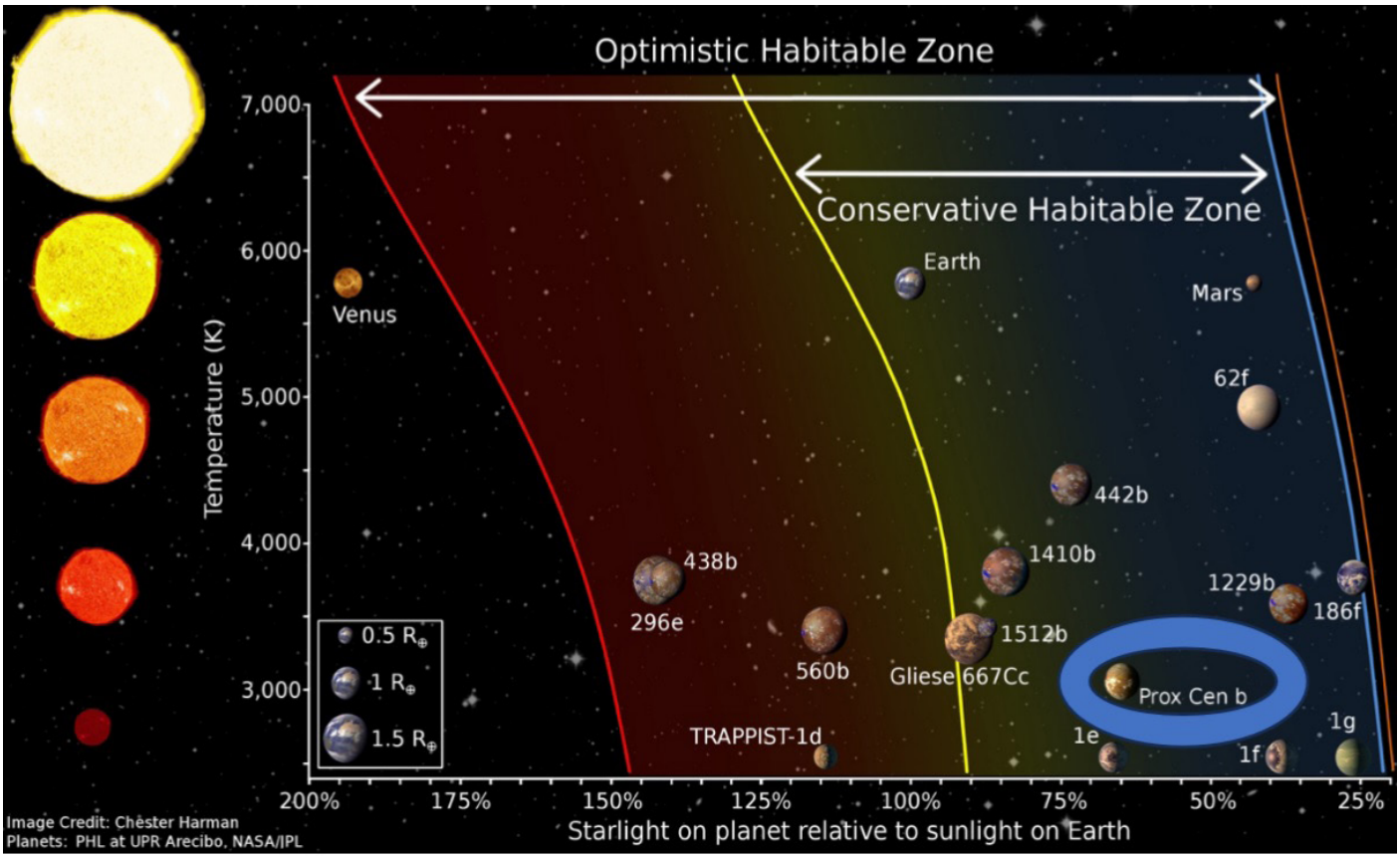


Figure showing sample known planets and potential habitable zones and their relative light power flux from their stars.
Credit: ESA and Wikipedia en.wikipedia.org/wiki/Habitable_zone

His analysis finds habitable zones, for our form of life, and illustrates his results.
He explains matching the photocell material with the peak of the stellar spectrum where most of the power is conveyed.

> "An optimal bandgap of >12 eV for the hottest OSV star type leads to 47% Shockley-Queisser photo conversion efficiency (SQ PCE), whereas a narrower optimal bandgap of 0.7 eV leads to 23% SQ PCE for the coldest red dwarf MO, MS.SVe, and M8V type stars. This energy range matches the frequency range in peak flux, which is proportional to temperature ($E = h\nu = hc / \lambda \alpha kT$)."

He points to the Shockley–Queisser limit setting the maximum theoretical efficiency of a solar cell (en.wikipedia.org/wiki/Shockley%E2%80%93Queisser_limit) on photo conversion efficiency (PCE) for various stellar radiation spectra.
He also discusses the different but connected topic of photon sail efficiency using the Breakthrough Starshot example - including some of the most challenging problems such as sail robustness under the onslaught of hundreds of GigaWatts of photons.
He also uses Adam Hibberd's system transit diagram from the i4is paper and the Principium report *News Feature: i4is delivers Communications Study to Breakthrough Starshot* (P41 May 2023 i4is.org/principium-41/).

SELECTION OF NEWS FROM OUR MEMBERS' NEWSLETTER

Our Members' Newsletter Editor, Parnika Singh, sends news about i4is and matters interstellar to our members each month. Here is a selection of the latter from her January 2024 Issue.

Chasing Down Oumuamua

On January 12th, Cosmos magazine published an article titled "We have a plan to chase down our first known interstellar visitor" by Jamie Seidel featuring an interview with i4is's very own Adam Hibberd. The article discusses Project Lyra, a plausible means of sending a space probe to observe 'Oumuamua. Although it had been over seven years since the project was originally formulated, an updated plan outlines how existing technology – including the Space X Falcon Heavy and NASA's Space Launch System – can propel a probe toward Jupiter. The gas giant can then correct the probe's inertia relative to 'Oumuamua before falling back towards the Sun for a slingshot into a pursuit trajectory.

The article provides additional background information on Oumuamua and its strange pancake-like shape and fast speed. The article also discusses the many merits of sending a probe to Oumuamua, particularly the astrobiology implications. The full article can be found here: cosmosmagazine.com/space/astronomy/we-have-a-plan-to-chase-down-our-first-known-interstellar-visitor/.

And for those curious about Project Lyra's orbital mechanics, an entertaining fan video can be found here: www.youtube.com/watch?v=ICUB_qgDoyA.

Laser-Thermal Propulsion

TU Delft University published a master's thesis by Emmanuel Duplay titled "Argon Laser-Plasma Thruster: Design and Test of a Laboratory Model" on January 15th. This report first introduces the concept of laser-thermal propulsion, highlighting its potential as a high-specific impulse, high-thrust deep-space propulsion system competing with proposed nuclear-thermal thruster concepts. A brief summary of past literature on LPT is provided, with notable studies discussed. The paper notes that although LPT has been tested experimentally before, most studies used CO2 lasers operating at 10.6 μm, while current thinking on directed-energy propulsion favors 1.06-μm fiber lasers, which is what this thesis uses.

The paper then documents the design process of the test facility in detail, discussing available laser equipment and diagnostics apparatus. It gives the top-level requirements for the test section and thrust stand as well as modelling parameters. The thesis provides a comprehensive summary of the results of the many experiments attempted, as well as attempts at optimizing the thruster. To conclude, it notes future advancements to be made in laser-thermal thrusters. The full thesis can be found here: repository.tudelft.nl/islandora/object/uuid:3a853f2e-2d8c-496b-a016-9e9855e8069c.

Radioisotope Power for Interstellar Missions

On January 11th, Elsevier's pre-print server SSRN released a paper titled "Comprehensive Modeling and characterization of the General-Purpose Heat Source Radioisotope Thermoelectric Generator (GPHS-RTG) for Application in the Solar System Mission" by Li Tailin et al. A radioisotope thermoelectric generator (RTG) is a spacecraft power source that relies solely on radioactive decay for its energy and generates power through the thermoelectric effect. RTGs are therefore ideally suited for operation in the harsh environments of space, especially for interstellar missions. The GPHS-RTG represents the RTG with the largest output power and highest conversion efficiency ever built. While not the newest RTG design, the higher output GPHS-RTG remains quite attractive for future interstellar missions.

This paper provides a detailed analysis of the GPHS-RTG to determine a conservative safe application range and its performance for solar-system missions and beyond. The study finds that within the Earth orbit (1 AU), the distance of the mission area from the sun and the angle of light incidence significantly affects the thermoelectric performance of the GPHS-RTG, and too close proximity to the sun can jeopardize the temperature safety of the GPHS-RTG. Therefore, this technology would not be able to be used for solar "slingshot" maneuvers. Additionally, it was found that the temperature is not uniform in the RTG's thermoelectric arrays because of solar illumination and the thermopile design. The full paper can be found here: papers.ssrn.com/sol3/papers.cfm?abstract_id=4692116.

Plenty of room at the bottom

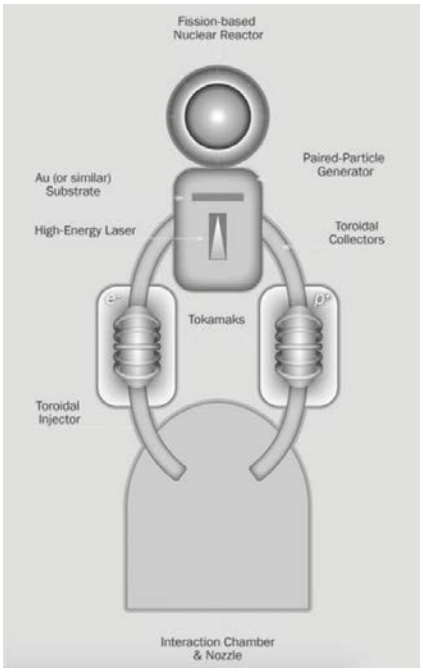
In *Hyper-Fast Communication within General Relativity*, Lorenzo Pieri of Createc Ltd and Oxford Brookes University (UK), arxiv.org/abs/2311.12069, wonders if warps can be scaled down far enough to make the negative energy requirements feasible. He suggests that a by-product of warp deceleration would be the emission of a ray of high-energy particles and the detection of such particles could be used as the backbone of a faster-than-light communication device. He aims to show that the total energy requirement for Planck-sized small bubbles can be satisfied with a Casimir device of reasonably large size. He tells us that the total negative energy requirement grows as the square of the bubble radius (so, as Feynman remarked in another context. There is "plenty of room at the bottom" [1]). He suggests that as little as one bit per warp bubble might be achieved in which case a lot of bubbles would be required to deliver even a very modest bitrate.

He is cautious in his claim of feasibility, observing that there are other avenues in physics which might be more fruitful and very substantial engineering challenges would remain.

However it's worth observing that artificial intelligences would certainly be capable of travelling at the speed of light and that "Hyperwave" would thus allow much less latency though at the cost of bandwidth as envisaged in this paper.

Matter/Anti-Matter Propulsion

In *Matter/Anti-Matter Propulsion* (www.intechopen.com/chapters/86283), Mark Pickrell discusses experiments at the Lawrence-Livermore National Laboratory (LLNL) [2] and the Max Planck Institute for Plasma Physics (MPIPP) [3]. Fuelling a rocket in this way seems to provide the maximum possible exhaust velocity as input to the Tsiolkovsky equation which limits all forms of reaction propulsion. He reviews this limit observing that the exhaust in this case is 511 keV gamma rays and thus the exhaust velocity is the speed of light, c. He takes us through some fundamentals of the physics of electromagnetic radiation and reports experiments at the LLNL showing that large quantities of positrons could be produced by high-energy, short-burst lasers striking high-atomic-mass targets. Together with the storage of electrons and positrons in an optimised dipole stellarator, suggested by the MPIPP he suggests we have a potential way to generate and store antimatter. He outlines a configuration for such a propulsion system -



System concept (courtesy Mustang Publishing). Figure 7. Credit (image and caption): Pickrell

Pickrell suggests the power source for the system is probably going to be a fission-based nuclear reactor, the paired-particle generator would be based on the Max Planck Institute design, the storage system will probably consist of twin tokamaks (one for storing electrons and one for storing positrons) and the annihilation chamber will be similar to the rocket nozzles that are used on chemical rockets.

On board antimatter production would mean that probes would not require a storage system. Pickrell's "thought experiment" assumes a 10,000 kg probe which would accelerate at approximately 1.9 m/s^2 achieving 20% c in a year. He mentions issues to be overcome including experimental determination of an optimised paired-particle generator's capacity to produce the particles and whether the target substrate or the laser used is lost in the Bethe-Heitler Process (bremsstrahlung or braking radiation). Pickrell is President of Albireo Scientific Corporation, established to further experimental testing of matter/anti-matter propulsion.

[1] Our headline on this news item borrows from the thinking of Richard P Feynman who remarked "There's Plenty of Room at the Bottom" and introduced the idea of scaling machines down to molecular levels and anticipated nanotechnology.
[2] *Billions of Particles of Anti-matter Created in Laboratory*. www.llnl.gov/news/billions-and-billions-particles-anti-matter.
[3] *Electrons and Positrons in an Optimized Stellarator*. 2020 www.ipp.mpg.de/4793936/nwg-19.