

Artificial Gravity for Human Habitation

If humans as presently constructed are to live "off planet" for extended periods, for example in artificial habitats or, ultimately, in world ships to take us to other stars then we must provide a way to avoid the adverse effects of microgravity on the human body. A new paper, *A Review of Challenges & Opportunities: Variable and Partial Gravity for Human Habitats in LEO* [1] by Dr Ronke Olabisi, UC Irvine, and Dr Mae Jemison, 100yss.org, reviews the requirements, human biology, and possible solutions - spacecraft engineering, to achieve this goal. Sponsored by Orbital Assembly (orbitalassembly.com) the report outlines the current situation and discusses in detail -

- Impact of Microgravity on Physiological Systems
- Impact of Microgravity on Human Activities
- Impact of Microgravity on Habitat Systems
- Reviews of Artificial Gravity Literature
- Benefits and Challenges of Variable and Partial G Habitats
- Opportunities and Considerations for Designing a Rotating Artificial Gravity Habitat

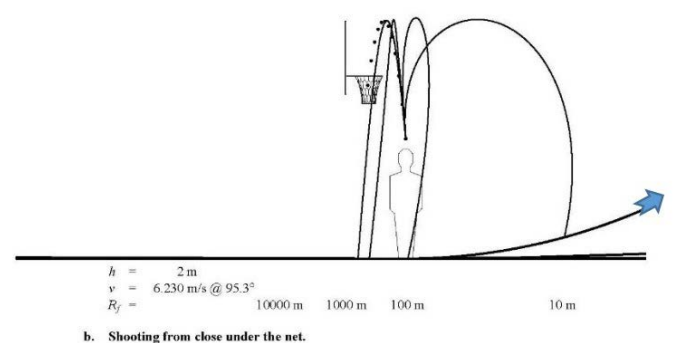
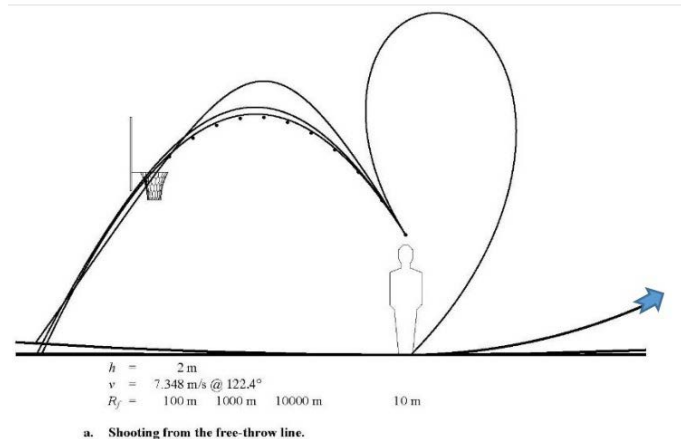
The report concentrates on the human aspects of the problem but does not neglect the engineering issues.

One particularly illuminating section covers the effects of Coriolis forces under rotational artificial gravity. These have often been discussed and, at low rotational radii, produce significant physiological effects. But here the authors also include a striking graphical illustration effects on a less obvious but essential part of normal human society, sport. The example given, basketball, allows for a particularly powerful illustration.

The effect on hand-eye coordination for more mundane but vital tasks can be imagined - and the authors cite the example of surgery.

The effects at low rotational radii look bizarre but even at quite large radii would require players to adjust their reflexes (and the basketball example here is simply a shot parallel to the direction of rotation, imagine the shot at 45 degrees, 90 degrees and 180 degrees). The same would apply to football in all its varieties and just about all physical sports and, beyond Coriolis, imagine the 100m record for races run with and against the direction of rotation!

Other points raised in the practical provision of rotational artificial gravity include use of visual clues to mitigate Coriolis effects, curving wide floors (and I guess large tables?) and the direction of apparently vertical surfaces to match the essentially cylindrical orientation of the gravity field, the possibility that 0.3 to 0.5 g would be sufficient (might the upcoming Moon expeditions help?) and the necessity for a transdisciplinary approach extending beyond space medics and engineers to behaviourists, artists, athletes, wider health professionals, architects, investors, chemists and ecologists.



Basketball in artificial gravity. The dots represent a successful shot in Earth gravity. The curves represent identical shots in 1-G rotating environments with radii of 10 m, 100 m, 1,000 m, and 10,000 m. The blue arrows indicate the direction of rotation. Credit (image and caption): Olabisi and Jemison, Figure 40

[1] orbitalassembly.com/gravity and <https://news.orbitalassembly.com/2022/artificial-gravity-may-offer-a-myrriad-of-benefits-to-humans/>

Finding your interstellar way - and finding dark matter

In *Autonomous Navigation of Relativistic Spacecraft: Theory and Applications* (ecommons.cornell.edu/handle/1813/112098), PhD student Doga Yücalan introduces some thinking about autonomous spacecraft navigation methods and how relativistic effects on a spacecraft could identify dark matter. He observes that "A spacecraft designed to detect acceleration could sense the gravitational effects of nearby dark matter." And that "a space exploration mission aiming to detect dark matter needs to employ spacecraft located far enough away from ordinary matter's gravitational interactions within the solar system." -and, of course, the Sun and the planets are the most powerful effects. To achieve results within a lifetime would require missions accelerating to significant fraction of the speed of light such as the proposed Breakthrough Starshot probes.

Doga observes that current means of autonomous navigation for spacecraft include NASA's AutoNav,

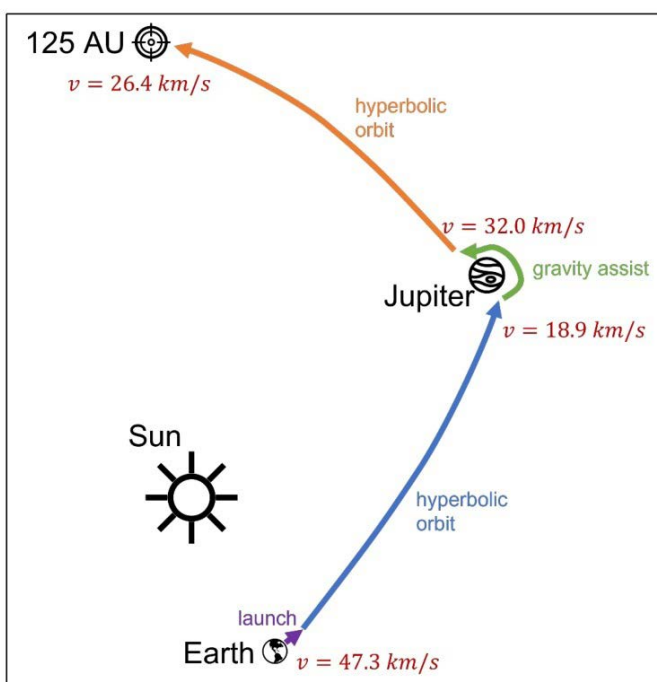


Illustration of the dark matter explorer spacecraft's proposed trajectory from Earth to 125 AU (not to scale). Included speeds denote spacecraft's speed relative to the Sun at points of interest.

Credit (image and caption): Doga Yücalan

which tracks nearby objects using optical sensors to navigate, and its XNAV algorithm, using X-ray emissions from pulsars. Doga also cites several other autonomous navigation algorithms based on Newtonian mechanics which are in development. But none of these navigation technologies are adequate for a future interstellar mission, including the uncertain nature of the interstellar medium (ISM). For the very high speed required, relativistic effects also become significant. The paper aims to suggest both improved methods for acquiring navigational inputs (with a recursive algorithm to continuously update the onboard star catalogue) and an Interstellar Dark Matter Explorer Mission using known technologies to detect deviations in the dark matter distribution near the heliopause with mission duration around 25 years. This would not be a cheap mission. The paper assumes a SpaceX Starship launch into a 500 km orbit delivering a 150 ton vehicle with mass ratio of about 150/8 (18.75) for an initial velocity to Jupiter of 12,494 m/s [1] at a total cost of about \$1.6 bn.

Practicalities of Antimatter

Antimatter is a favourite of writers of "hard" science fiction (sf-encyclopedia.com/entry/antimatter) but is it a serious possibility as a very powerful store of energy?

Antimatter and Its Application-Collecting Antimatter and Storage It as Energy Source [2] is a survey of the prediction and discovery of antimatter, its properties as store of energy, how to collect and store it, its most useful form (suggesting antiprotons) and its application to propulsion. The writer is Ruichen Zhang, TianJin University, China.

[1] The required exhaust velocity can be calculated applying a transposed Tsiolkovsky equation $V_e = \Delta V / \ln \text{MassRatio}$. This yields $12,494 / \ln 18.75 = 12,494 / 2.93 = 4,264 \text{ m/s}$.

[2] iopscience.iop.org/article/10.1088/1742-6596/2386/1/012074

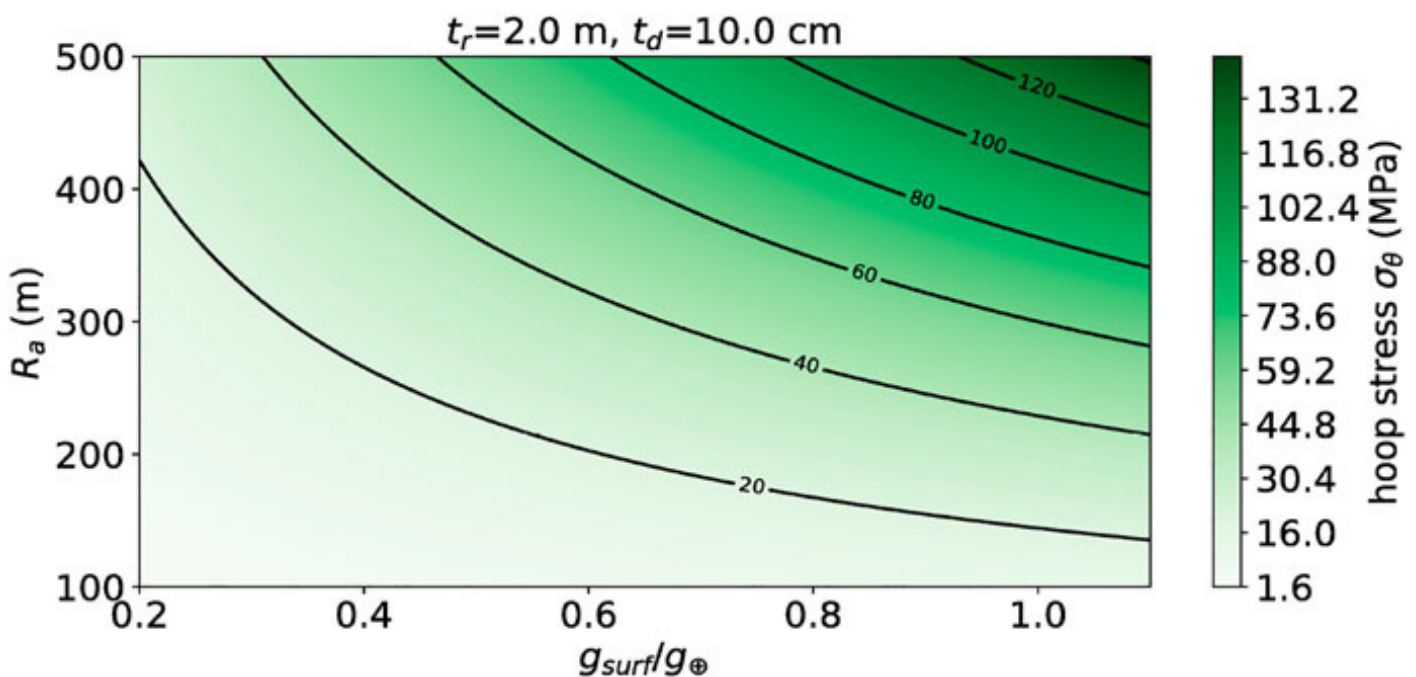
Avoiding the Great Filter - via fundamental physics

In *Avoiding the "Great Filter": Extraterrestrial Life and Humanity's Future in the Universe* [1], Federico Re of Universita di Milano Bicocca, suggests that if and when a "Theory of Everything" [2] is found this can act as a "Great Filter". After a useful tour of possible explanations for the Fermi Paradox Re suggests that "The myth of an unlimited scientific progress comes from the principle (in philosophy of science) that all scientific theories are falsifiable." This appears to derive from his idea that any overarching "fundamental Law of Nature" is itself not falsifiable but "we must suppose that the Law exists". He suggests that this leads to an examination of the Fermi Paradox which is independent of human culture (ie the idea that we, and all similar civilisations, will make mistakes which will lead to our extinction).

Build your house from rubble

That's if you want to be a pioneer on "The High Frontier", Gerard K O'Neill's book *The High Frontier* (1976) suggested we build vast habitats to populate the space between the planets. But how do you build the first human habitats in space?

Researchers from the University of Rochester (Rochester, New York) suggest that so-called rubble pile asteroids might make a good start. O'Neill envisaged processing raw materials into construction elements and others have advocated hollowing out asteroids as a faster route avoiding the need for the processes of in-situ resource utilisation (ISRU) but Peter M Miklavcic et al [3] point out that the spin rate required to give the artificial gravity to suit human biology would cause known asteroids to fly apart under centrifugal forces. They therefore advocate starting with asteroids which are only loosely bound by gravity, rubble piles, and binding them with high tensile strength materials before spinning them to the required rates of rotation.



Hoop stress for an asteroid spun up to form a cylindrical shell of thickness 2 m and contained in a scaffold of thickness 10 cm. The asteroid is assumed to have a uniform density of 1 g/cm³. The vertical axis is the radius R_a of the asteroid, in meters. The horizontal axis is the surface gravity of the asteroid in units of Earth surface gravity.

Credit (image and caption): Peter M Miklavcic et al

[1] www.researchgate.net/publication/365374857 Can the Theory of Everything be the Great Filter

[2] A hypothetical union of general relativity and quantum theory. They describe the universe and its smallest constituents respectively and have been at odds since they were first discovered and codified about 100 years ago. More in en.wikipedia.org/wiki/Theory_of_everything and *The Great Filter - Are We Almost Past It?* mason.gmu.edu/~rhanson/greatfilter.html

[3] *Habitat Benu: Design Concepts for Spinning Habitats Constructed From Rubble Pile Near-Earth Asteroids* in *Frontiers in Astronomy and Space Sciences* www.frontiersin.org/articles/10.3389/fspas.2021.645363/full



Canopus Awards and NEXUS™ NAIROBI

100 Year Starship (100YSS), the advocacy and campaigning organisation led by former astronaut Dr Mae Jemison, has published its annual Canopus awards (canopusawards.org). They recognise recent fiction and non-fiction. Categories are Published Long-Form Fiction, Published Short-Form Fiction, Published Long-Form Nonfiction, Published Short-Form Nonfiction, Published Digital Presentation, Original Short-Form Fiction and Original Local Short-form Fiction.

In the category Published Long-Form Nonfiction we noted *A Traveler's Guide to the Stars* by Les Johnson and *Extraterrestrial* by Avi Loeb. In the category Published Short-Form Nonfiction we noted *Artificial Intelligence for Interstellar Travel* by Andreas M Hein and Stephen Baxter (JBIS 2018). Stephen is a long-established friend of i4is and Andreas is the i4is Executive and Technical Director. All awards are listed at canopusawards.org/?page_id=166.

We'll be looking at the award winners in later issues of Principium. Awards were presented at Nexus Nairobi January 31 - February 4, 2023. (nexusnairobi.org). Winners at locusmag.com/2023/02/2023-canopus-awards-winners.

Chasing Nomadic Worlds

In Chasing Nomadic Worlds: A New Class of Deep Space Missions [1], Manasvi Lingam (Florida Institute of Technology and University of Texas at Austin), Andreas M Hein (University of Luxembourg and i4is.org) and T Marshall Eubanks (Space Initiatives Inc) discuss missions to nomadic worlds, objects not bound to any star, given their great interest to planetary science and astrobiology. They evaluate the prevalence of nomadic worlds with radii, R , of 100 km to 10,000 km, which might permit habitable conditions. The cumulative number density n , for radii above R appears to

follow a heuristic power law given by $n \propto R^{-3}$. Therefore, smaller objects should be much more numerous than the largest rocky nomadic planets, and thus statistically more likely to have members relatively close to the inner Solar system. Their results suggest that tens to hundreds of planet-sized nomadic worlds may populate the spherical volume centred on Earth and circumscribed by Proxima Centauri, and thus may comprise closer interstellar targets than any stellar planetary system. They analyse the feasibility of exploring these unbounded celestial bodies via deep space missions and investigate what near-future propulsion systems could theoretically enable us to reach nomadic worlds (of radius $> R$) on a 50-year timescale. Objects of radii approximately 100 km are accessible using multiple propulsion methods such as electric sails, laser electric propulsion, and solar sails, but nomadic worlds with $R > 1,000$ km are accessible only by laser sails (or perhaps fusion propulsion). Their result is summarised -

Approximate radius of nomadic worlds reachable by propulsion systems in 50 years

c	Terminal speed (in AU/yr)	Radius (in km)
Solar sails	~ 20	~ 75
Laser sails	≤ 63 to $\geq 6.3 \times 10^3$	≤ 230 to $\geq 2.3 \times 10^4$
Magnetic sails	~ 20	~ 75
Electric sails	~ 25	~ 93
Magneto-plasmadynamic thrusters	≤ 63	≤ 230
Laser electric propulsion	~ 40	~ 150
Nuclear fusion	~ 63 to ~ 6.3×10^3	~ 230 to ~ 2.3×10^4
Chemical propulsion	~ 9	~ 34

Additional notes: More precisely, nomadic worlds of radius $> R$ (third column) can be reached by a given propulsion system in 50 years. The last column is estimated by invoking [heuristic equation $v_t \sim 0.27 \text{ AU/yr } (R/1 \text{ km}) / (\Delta t/50 \text{ yr})$], setting $\Delta t = 50 \text{ yr}$, and substituting the terminal speed (second column) to solve for R . All values should be viewed as strictly heuristic. Credit (table and Additional notes): Lingam, Hein, Eubanks - Table 1.

[1] www.researchgate.net/publication/365298186 Chasing Nomadic Worlds A New Class of Deep Space Missions

Faster than the (Solar) Wind

In *Dynamic Soaring as a Means to Exceed the Solar Wind Speed* [1] a team from McGill University and Tau Zero Foundation suggest a way to achieve very high speeds which, at first sight, looks like "pulling yourself up by your own bootstraps" - something our parents (and our physics teachers) always warned us would not work - except metaphorically - where it was, of course, universally recommended. The paper suggests that using a plasma magnet technique rather than a magnetic or electric sail will better exploit the charged particles which comprise the solar wind. And they tell us that "Several structures in the solar system offer wind gradients large enough for dynamic soaring maneuvers to extract energy." They report that "dynamic soaring can deliver payloads to 2% of c , essentially "for free" (meaning, without expenditure of propellant or significant power) and that "this technique is ideally suited to deliver reaction mass that can be used for additional stages of propulsion capable of even greater speeds." A variant of this technique, the wind-riding plasma magnet, could, for example, allow a mission to the solar gravitational lens (SGL) distance (> 550 AU) in 7 years from launch.

Just to get around the "by your bootstraps" worry, here's a video DYNAMIC SOARING EXPLAINED (www.youtube.com/watch?v=SVN-oF6tPLc).



Radio controlled gliders can now approach supersonic speeds using this technique (www.youtube.com/watch?v=nv7-YM4wno8) and the US Air Force has had a go (www.youtube.com/watch?v=xIPI0A0j5MI) but not quite that fast yet. But albatrosses worked this one out a few million years ago. It's still hard for us humans to do better than evolution - but then we haven't been around that long!

Finding ET in Gravitational Waves

In *Searching for Intelligent Life in Gravitational Wave Signals Part I: Present Capabilities and Future Horizons* [2], researchers from The Advanced Propulsion Laboratory at Applied Physics (New York), UCLA, Israel Institute of Technology, Lund University (Sweden) and Carnegie Mellon University state that the instrument which first detected naturally occurring gravitational waves may also detect signs of very high speed propulsion, via the gravitational waves resulting from their acceleration. The Laser Interferometer Gravitational Wave Observatory (LIGO) can detect gravitational waves (GWs) from accelerating astrophysical sources, such as binary black holes, and the authors suggest it provides the potential to detect extra-terrestrial mega-technology, such as Rapid And/or Massive Accelerating spacecraft (RAMAcraft) and that LIGO is sensitive to RAMAcraft of one Jupiter mass accelerating to a fraction of the speed of light (eg 10%) up to about 100 kpc (100*3,262 light years - so beyond our home galaxy). They observe that existing SETI searches probe on the order of thousands to tens of thousands of stars for human-scale technology such as radio signals, whereas LIGO can probe all 10¹¹ stars in our galaxy for RAMAcraft and that planned space-based instruments could look even further. However they caution that a candidate detection of a RAMAcraft signal should be treated with scepticism since other phenomena could produce similar burst signals though matched-filtering (MF) detection will be more conclusive but still vulnerable to false positives. Once the shape of the signal can be analysed sufficiently it should become possible to reverse-engineer propulsion methods.

[1] *Dynamic Soaring as a Means to Exceed the Solar Wind Speed*, arxiv.org/abs/2211.14643, Mathias N Larrouiturou and Andrew J Higgins of McGill University, Montréal, and Jeffrey K Greason, Tau Zero Foundation

[2] *Searching for Intelligent Life in Gravitational Wave Signals Part I: Present Capabilities and Future Horizons*, Sellers et al, December 2022, arxiv.org/abs/2212.02065

Hive or Brain? Hoyle's Black Cloud and Telepathy

A posting by the perennially interesting Paul Gilster, Life from Elsewhere (www.centaury-dreams.org/2022/12/13/life-from-elsewhere/), reported below, is mainly focused on panspermia but, in passing, he remarks "Hoyle was interested not just in the nature of consciousness but likewise the matrix in which it can be embedded". In Fred Hoyle's novel, *The Black Cloud*, the scientists who first establish that the cloud contains intelligence speculate about the distribution of that intelligence within the enormity of the cloud and whether it was, in fact, a community or a "hive mind". They conclude that since the entities forming the intelligence communicated by electromagnetic means (light, radio or other frequencies) that the bandwidth of communication would make it inevitable that the entity would be a single intelligence. To steal from Arthur C Clarke we might conclude that "Any sufficient telepathic bandwidth between minds is indistinguishable from a single mind". However, even the simplest computer system can deal with multiple simultaneous tasks and this is more than just the ability to "walk and chew gum at the same time" [1] since this capability allows any number of levels of priority between tasks and is possible within a single processor system by allocating slices of time between tasks.

Replacing Greenwich

In *Establishing A Landmark in Space - Spacetime Zero* [2], Gregory A Harrison, proposes establishing Spacetime Zero as a benchmark based on the concept of Universal Spacetime. He suggests that current timekeeping methods are too Earth-centric and that we require an interstellar coordinate system. He suggests that "At zero-time, the locations and orientations of everything in the universe is considered to be known and established". This reporter is not qualified to comment on the plausibility of this but Dr Harrison has a long career in aerospace and this appears to be related to his subsequent enterprise, "Gravitronics". No doubt citations in future will test the plausibility versus current understanding of spacetime, light cones and the shape of the universe.

The Ethics of Directed Panspermia

The idea of using technology to spread life deliberately is far out on the horizons of our technology and we take great care to clean anything biological from all planetary landers. But what if the answer to Arthur C Clarke's two possibilities for ETI is that there is nobody else, at least in our galaxy? Should we seed the galaxy with

life if and when we can? Paul Gilster [3] draws on *Interstellar Objects in Our Solar System*, a recent collection of papers and specifically *Directed Panspermia Using Interstellar Comets* [4], Christopher P McKay (NASA), Paul C W Davies (Arizona State University), and Simon P Worden (Breakthrough Initiatives). The paper observes that the detection of interstellar objects in our solar system provides evidence of a possible mechanism for the spread of life including, possibly, that on our own planet. But should this process be initiated deliberately rather than as a random natural event? The authors cite numerous earlier works analysing mechanisms, probability and ethics, though not, curiously, the work of Prof Dr Claudius Gros - cited in a number of Principium articles over the past four years notably *Long duration Genesis-type missions to exosolar planets* in the IAC18 (Bremen) report in issue 23 and *Why planetary and exoplanetary protection differ: The case of long duration Genesis missions to habitable but sterile M-dwarf oxygen planets* (arxiv.org/abs/1901.02286) reported in issue 25.

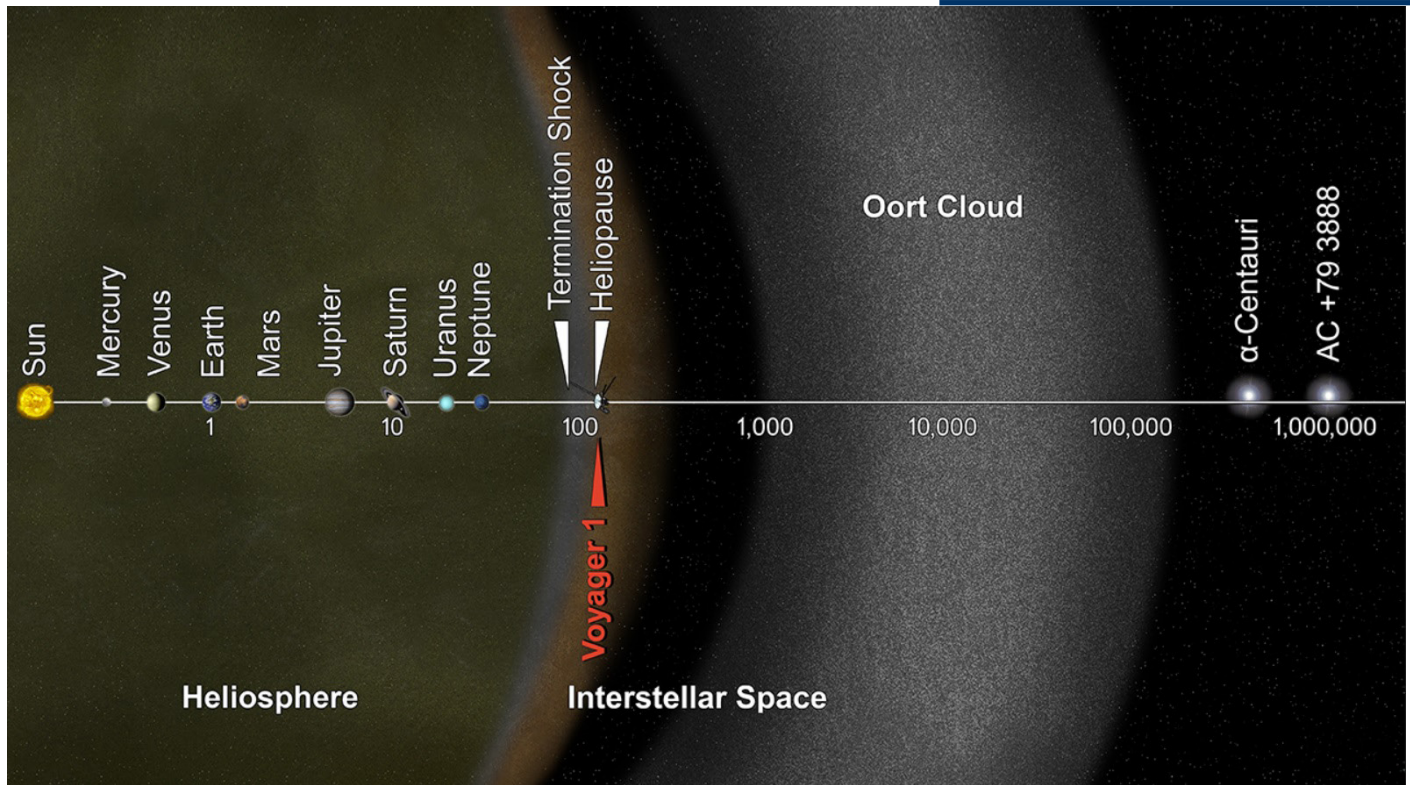
The paper "raises many technical and ethical questions" in a field which is purely investigatory at the moment but which becomes a very live question as soon as we have the capability to send anything to destinations beyond our solar system,

[1] Lyndon B Johnson was believed to have remarked in 1973 that Gerald R Ford could not accomplish this, allegedly because he had played a lot of American football in his youth - and did not wear a helmet. Johnson had decided not to run for a further term as president. Ford became president upon the resignation of Richard M Nixon. Ford had, despite the football, graduated third top of his class at Yale Law School so Johnson's remark clearly exhibited more wit than truth.

[2] www.researchgate.net/profile/Gregory-Harrison/publication/364475841_Establishing_A_Landmark_in_Space_-_Spacetime_Zero/links/6351b7a86e0d367d91af0a1d/Establishing-A-Landmark-in-Space-Spacetime-Zero.pdf

[3] www.centaury-dreams.org/2022/12/16/the-ethics-of-directed-panspermia/

[4] www.liebertpub.com/doi/10.1089/ast.2021.0188



About 1,000 AU is the inner edge of the Oort cloud.
Credit: NASA www.nasa.gov/mission_pages/voyager/multimedia/pia17046.html

The Pointing Problem

In *Interstellar Communications The Pointing Problem*, Paul Gilster outlines the difficulties of an interstellar downlink [1] are not just the distance (fighting the inverse square law, especially for tiny probes like the Breakthrough Starshot proposals) but also the need to be economical by making sure that as much of the transmitted signal is pointed towards its home receiver on or near Earth. The Johns Hopkins team working on their Interstellar Probe - intended to function all the way to 1,000 AU (the inner edge of the Oort cloud) are thinking of X-band microwave rather than laser for this very reason.

The problem divides into guidance and control. Guidance of the downlink transmitter requires very precise orientation information and star maps look like the best option. Control has several options. Reaction wheels conserve thrust propellant but may be unreliable for a 50 year mission. Will the

interstellar magnetic field provide something to push against? The Hubble telescope, for example, uses reaction wheels as the primary method and magnetic torquers against the Earth's magnet field when the reaction wheels reach their limits. Much more in Paul Gilster's article.

Spotting another 1I/'Oumuamua

In *Physical Considerations for an Intercept Mission to a 1I/'Oumuamua-like Interstellar Object*, Siraj et al [2] primarily discuss detection of another 'Oumuamua-like ISO with some brief consideration of preparations to intercept it. They touch on papers from several sources discussing such missions including three by the i4is Project Lyra team. They mention one existing mission project, the ESA Comet Interceptor. This seems, so far, to be the only definitely committed mission which might intercept an ISO although its primary stated mission is to study a Solar System comet.

[1] www.centaury-dreams.org/2022/12/07/interstellar-communications-the-pointing-problem/ and see also *The Interstellar Downlink* in Principium 31 November 2020

[2] Authors: Amir Siraj, Mark Elowitz, Abigail White and Abraham Loeb (all Harvard), Amaya Moro-Martín (Space Telescope Science Institute and Johns Hopkins University) and Wesley A Watters (Wellesley College), arxiv.org/abs/2211.02120

Space Colonisation and Exonationalism

Jack David Eller of the Global Center for Religious Research (GCRR), Denver, considers *Space Colonization and Exonationalism: On the Future of Humanity and Anthropology* (www.mdpi.com/2673-9461/2/3/10/htm). He suggests that "As humans resume their push into space, anthropology is set to become unbound from the earth itself" and he considers how anthropology contributes to understanding the present and future of space colonisation (beginning at least as early as the 1950s) and current analysis of law, sovereignty, and nationalism in space. He predicts the emergence of exonationalism, in which generations of colonists will shift their affiliations to their non-terran homes and ultimately seek independence from the Earth thus reshaping our definition of the human and hence the practice of anthropology. He suggests Ursula Le Guin's 1974 novel *The Dispossessed* represents a useful thought experiment (in this case establishing a variety of pure communism rather than the Marxist variety). However he seems to be using an example of separation driven by a political motive rather than less ideological European style settlement in America, which subsequently provided a substrate upon which political/religious separation became attractive - as in the Plymouth plantation. He cites early work on space anthropology citing the books, *Toward an Extraterrestrial Anthropology* and *Cultures Beyond the Earth*, 1975, Magoroh Maruyama (Editor) - a citation search for which leads to a fairly extensive literature. Eller reviews anthropology as it has been applied to space in recent years and politics beyond Earth. Longer term he expects "a dramatic cultural rediversification of humankind" [1]. He imagines the likes of SpaceX and Blue Origin as the equivalents of the British and Dutch East India Companies with their own political administration and armed forces but suggests that their independence from the Earth nation from which they came would be hard to thwart - in contrast with the British and Dutch companies which were rapidly nationalised when they proved inconvenient. This looks questionable in the case of the inner Solar System where near-

Earth polities will be kept on a tight rein given their strategic value thus making the exercise of military power as far as Mars a relatively low-energy and short term proposition - with journey times from Earth to Mars being less than those from Europe to India under sail.

This is a substantial and thoughtful piece, perhaps deserving of a more thorough review in Principium.

Systems Design of Nano/Picosatellites

Tiny spacecraft are key to laser propelled interstellar travel and attention to systems engineering is vital. The paper *Systems Design and Integration of Small Scale Nano and Picosatellites* [2] by a team from Cornell University conducts a broad systems review of this technology. Their perspective is Earth satellites but many of the issues would also apply to a tiny probe intended for interstellar mission and the project which is the basis for the paper is specifically focused on the requirements arising from the ideas of Breakthrough Starshot. There are clear parallels with the Glowworm/Pinpoint work of i4is. The suggested design model is a "Vee" diagram (a development of the software engineering "Waterfall" model which formalises top-down design and build followed by bottom-up testing). The paper develops much of a design for chip-sat communication including suggested protocol elements and modulation techniques.

Space Futures Initiative

Principium has devoted attention to relatively short-term non-technical issues which seem relevant to the long term objective of creating a Solar System society as a foundation upon which we can build a long term interstellar future for our species [3]. In *Space Governance: Risks, Frameworks and Futures* Carson Ezell (Harvard) of the Space Futures Initiative (spacefuturesinitiative.org) has published a substantial paper [4] describing the space governance landscape and offering novel long term ideas to "improve the norms, values, and institutional structures that guide future spacefaring".

[1] From *Anthropology and the Humanization of Space*, B R Finney - Acta Astronautica, Volume 15, Issue 3, March 1987 No open source found.

[2] Naumann et al, July 2022, www.preprints.org/manuscript/202207.0368/v1

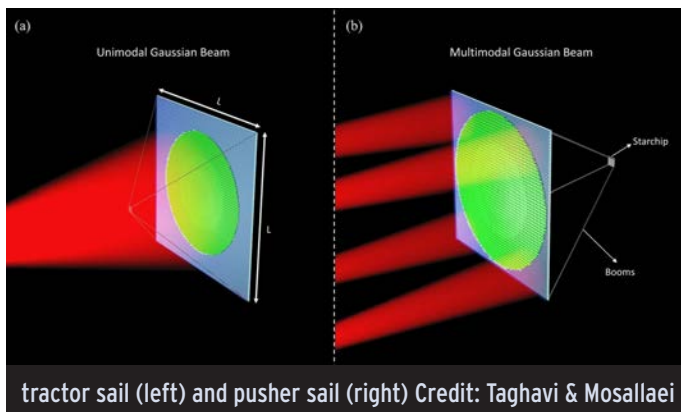
[3] Examples: Max Daniels on *Territory in Outer Space* in Principium 24 February 2019, *The Artemis Accords: what comes after the Moon?* P32, February 2021 and *Finding new ways to share resources in space* P37, May 2022

[4] *Space Governance: Risks, Frameworks, and Futures*. August 2022, spacefuturesinitiative.org/images/Space_Governance_Risks_Frameworks_and_Futures.pdf

◀ Metamaterials for photon sails

In *Increasing the stability margins using multi-pattern metasails and multi-modal laser beams* [1] Mohammadrasoul Taghavi & Hossein Mosallaei of Northeastern University, Boston, explore the use of metasails for nanocraft to reach very high velocities by achieving stable beam-riding, minimising acceleration time and effective thermal management via radiative cooling. They assert that flat macroscopic structures are dynamically unstable - like an egg balanced on its end - but conical and parabolic structures can remain in the beam area during the acceleration period. However there remain materials science challenges which might be overcome using metamaterials which also have attractive optical properties.

They propose two possible configurations with the nanocraft either placed on the beamed side (tractor configuration) or the shadow side (pusher configuration) of the sail.



Their paper discusses in detail - nanoscale photonic unitcell design and an optomechanical analysis framework. It advocates a dual-pattern metasail with uni-modal beam with the nanocraft placed at the back-side of a sail (pusher configuration) using an all-dielectric metasurface.

Worldship ethics for the Next Generation

In *Human Enhancement and Reproductive Ethics on Generation Ships* [2] Steven Umbrello (Delft University of Technology and Eurac Research) and Maurizio Balistreri (Università degli Studi di Torino) look at how genetic enhancement interventions can and should be used not only to ensure that future generations of offspring on the

ships, and eventual exoplanet colonies, live a minimally good life but that their births are contingent on them living genuinely good and fulfilling lives. They go on to suggest that their optimistic conclusion in the worldship scenario implies that this also supports the notion of human enhancement on Earth. They discuss the ethics of human genetic enhancement (a massive subject in itself) and suggest it might mitigate the specific ethical issue of subsequent generations who were not able to choose this inevitably limited environment. These are deep philosophical and ethical waters. The authors suggest that genetic optimisation of the worldship population might relieve some of these difficulties but do not go into the specific modifications which might support this.

The Contact Era

In *The Fermi Paradox revisited: Technosignatures and the Contact Era* [3], Amri Wandel of the Hebrew University of Jerusalem suggests a solution to the Fermi Paradox - that probes or visits from putative alien civilisations are unlikely until a civilisation reaches a certain age after the onset of radio communications which he calls the Contact Era. He suggests that the expanding sphere of our transmissions, the radiosphere, must attract their interest. Therefore, unless civilisations are highly abundant, the Contact Era will be a few hundred to a few thousand years away. He applies this also to transmissions (ie SETI) as well as physical probes and concludes that civilisations are unlikely to be able to intercommunicate unless their communicative lifetime is at least a few thousand years. He argues that alien civilisations will not bother to explore merely biotic planets so our biosignature (a few hundred million years old) will be ignored since biotic life is probably common. Given that Earth-like exoplanets seem to be common he suggests that mere biosignatures may not be uncommon enough to be worth investigating. Since technosignatures will, by default, propagate isotropically, directed anisotropic signals will be very much more likely to lead to first contact and deliberate beams are likely to be directed specifically to us from our radiosphere.

[1] space.us10.list-manage.com/track/click?u=abbef0b5ff9a0ffa23d50307&id=0ce738af34&e=10c386d612

[2] www.nature.com/articles/s41598-022-24681-w

[3] arxiv.org/abs/2211.16505

◀ CETI possibilities

Communication with extraterrestrial intelligence (CETI) is both technically difficult and politically controversial. Applying probability models to the technical issues, Reginald D Smith has published *Communicating extraterrestrial intelligence (CETI) interaction models based on the Drake Equation* [1]. The Drake Equation has always been a "thought experiment" or a "rule of thumb" but early discussions analysed it as potentially deterministic. Smith points to later work which has taken a statistical approach, including Claudio Maccone's 2010 paper, *The Statistical Drake Equation* [2], and its successors. The author applies a Poisson distribution [3] to model how ETI populations are affected by the number which can communicate with each other. He also cites the Allee effect, which observes that animal populations prosper as the number of individuals rise up to a point of overcrowding. This suggests that ETIs profit from intercommunication and, where such civilisations are sufficiently frequent within a communicating volume of space, then the Allee effect modifies the Drake Equation by enabling such a communicating community of civilisations to outlast some or all of its individual members.

Breakthrough Listen at MeerKAT

The Breakthrough Starshot interstellar probe work will be familiar to Principium readers. Another initiative within the Breakthrough programme, Breakthrough Listen, devoted to SETI, has just announced access to the MeerKAT radio telescope array in South Africa [4]. Since the Listen computing system has access to MeerKAT in "commensal" mode this yields a 24*7 year round data stream. The technical challenges the Listen team have overcome to deal, in real time, with this deluge of data can be imagined! More in *The Breakthrough Listen Search for Intelligent Life: MeerKAT Target Selection*, (arxiv.org/abs/2103.16250). Czech et al 2021.

It's not ETI (probably)

The journal *Astrobiology* has a collection of articles, *Special Collection: Interstellar Objects in Our Solar System*, Volume 22, Issue 12 / December 2022. (www.liebertpub.com/toc/ast/22/12).

The covering editorial is *Astrobiological Implications of Interstellar Material in the Solar System* (www.liebertpub.com/doi/full/10.1089/ast.2022.0088).

Here we review just two of the ten in this collection.

Bayes vs Loeb?

Charles H Lineweaver of the Australian National University evaluates the two hypotheses for the origin of 1I/'Oumuamua in *The 'Oumuamua Controversy: Bayesian Priors and the Evolution of Technological Intelligence* (www.liebertpub.com/doi/full/10.1089/ast.2021.0185). He applies the "Sagan Standard" (Carl Sagan in 1980 said "extraordinary claims require extraordinary evidence") via the approach of Thomas Bayes. The Bayesian prior probability that ETIs are detectable is judged very much lower than the prior probability of a natural explanation. Only with such extraordinary evidence to counter the low prior odds can the posterior odds of artificial origin be plausible. He is thus suggesting that, since we have not yet found an alien wristwatch (or perhaps had a flying saucer land on Worthy Farm during the Glastonbury Festival?) we cannot shout "It's ETI!" To show how Bayesian reasoning works he recalls a news item "75% of Americans hospitalized with COVID are overweight" leading to the facile conclusion that the overweight are more vulnerable to COVID. But what if 80% of Americans are overweight? If so it suggests, counter to intuition, that overweight Americans are slightly less vulnerable since the 20% of non-overweight Americans must be contributing disproportionately to the COVID numbers.

He rejects the idea that a single instance of intelligent life, ourselves, significantly increases the

[1] International Journal of Astrobiology, Cambridge University Press: 02 December 2022. Open access at: www.researchgate.net/profile/Reginald-Smith-4/publication/353838345_Communicating_extraterrestrial_intelligence_CETI_interaction_models_based_on_the_Drake_Equation/links/6208075f634ff774f4c6ec7c/Communicating-extraterrestrial-intelligence-CETI-interaction-models-based-on-the-Drake-Equation.pdf

[2] Acta Astronautica, Volume 67, Issues 11–12, 2010

[3] As in the use of random arrival times in queuing theory. Applied to processes as diverse as call frequency at a telephone exchange, loading of a packet switching network and radioactive decay.

[4] See also *Alpha Centauri: Getting There – and What to Expect When We Do* – S Pete Worden in Principium 35 | November 2021 pages 24–25, reported in *Interstellar Research Group Symposium 2021*, Bart Leahy & Joseph Meany and IAC conference reports: Principium 23, November 2018, pages 28, 29, P28, February 2020 pages 27, 31. P30, August 2020, page 37, P38, August 2022 pages 32, 34

prior probability of intelligent life elsewhere. In effect, biology is not physics, since it is not subject to deterministic processes - at least at the macro level. If this is so then the prior probability of intelligent life is uncertain so does not contribute much to the probability that "It's ETI!" But he also points out that a single incontrovertible piece of pro-ETI evidence almost inverts the Bayesian result. It thus 'upsets the applecart'; so despite most of the above he concludes with - "I support SETI and efforts to optimize telescopes to improve searches for interstellar objects (simultaneously improving detection of Near Earth Objects (NEOs)), and to prepare a mission to get close-up images of fast-moving interstellar objects. I support these efforts because when we have the technology to explore new parameter space relatively cheaply, we should do it. And because I agree with Haldane ('The universe is not only queerer than we suppose, it is queerer than we can suppose', 1927)".

Telescopes vs Probes?

Ben Zuckerman argues that *Oumuamua Is Not a Probe Sent to Our Solar System by an Alien Civilization* (www.liebertpub.com/doi/10.1089/ast.2021.0168).

He aims to support the view "that the accomplishments that can be achieved with large space telescopes/interferometers in the alien's planetary system will completely quench any motivation for construction and launch of an 'Oumuamua-like probe. The absence of any such motivation attests that 'Oumuamua is not an alien creation".

In other words, why would they (or we) send a probe when telescopes can tell us all we need to know? He discusses the feasibility of an artificial Oumuamua carrying a large optical telescope without saying why it might need one. He ignores the possibility that Oumuamua may be wreckage of a failed mission - possibly way off course. He assumes a deliberate flyby and "fleeting capabilities of any such flyby probe are vastly inferior to the power of space telescopes operational for eons of time in the interplanetary space of the alien civilization" but appears to cite only a 1979 piece about future space telescope capabilities *An Infinitely Expandable Space Radio Telescope*, Buyakas et al, *Acta Astronautica* 6:175.

In the same issue there are other papers including - *Self Replicating probes - Picogram-Scale Interstellar Probes via Bioinspired Engineering* (www.liebertpub.com/doi/10.1089/ast.2022.0008)

- and others covering broader issues including several on panspermia.

A Nuclear fusion breakthrough?

The news relevant to interstellar studies which hit the headlines was the net production of energy at the US National Ignition Facility [1]. Inertial confinement fusion is one of our best hopes for the propulsion of large scale interstellar probes. In *Nuclear fusion breakthrough: What does it mean for space exploration?* (www.space.com/nuclear-fusion-breakthrough-spacetravel) space journalist Leonard David looks at the achievement in terms of its propulsion applications.

He quotes physicist Fatima Ebrahimi at the Princeton Plasma Physics Laboratory "Fusion energy gain of greater than one is quite an achievement" and Richard Dinan of Pulsar Fusion in the UK "Fusion propulsion is a much simpler technology to apply than fusion for energy. If fusion is achievable, which at last the people are starting see it is, then both fusion energy and propulsion are inevitable,"

- and Ralph McNutt at the Johns Hopkins University Applied Physics Laboratory (JHU-APL), hailing the achievement but cautioning excessive optimism, recalling early attempts to use fission power in space which have yet to produce a working power source in space.

The Economist remains sceptical, stating that *Controlled fusion is little nearer now than it was a week ago* (www.economist.com/science-and-technology/2022/12/13/controlled-fusion-is-little-nearer-now-than-it-was-a-week-ago).

So, a milestone but not yet a winning post - and perhaps not even a lap marker?

[1] *Experimental achievement and signatures of ignition at the National Ignition Facility*, A B Zylstra et al *Physical Review E*. 8 August 2022, <https://journals.aps.org/pre/abstract/10.1103/PhysRevE.106.025202> no open publication found

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Forward Plasma Sensors

Particle Shield & Instrument Boom

Science Payload

High Gain Antenna

Power Fission Reactor

Heat Radiators

Propellant Tanks

Propulsion System / Laser System

Capsule Accelerator

Driver Radiators

Disc Radiation Shield

Annular Radiation Shield

Conical Reaction Exit

Ignition Point

Mirrors

Shield Coil / Shadow shield

Optical Lasers

Superconducting Coils

200 m