Have Starship, Will Travel
The Newsletter of the Interstellar Research Group
Issue 27
Jan 2023

Newsletter Contents

RED PLANET GREEN THUMB: INNOVATIVE TECHNIQUES FOR GROWING CROPS IN MARTIAN SOIL

BY ALEX TOLLEY

Alex Tolley is co-author (with Brian McConnell) of A Design for a Reusable Water-Based Spacecraft Known as the Spacecoach (Springer, 2016), focusing on a new technology for Solar System expansion. In the article that follows, he looks beyond propulsion at another key aspect of moving the human presence to other worlds. His subject is an unusual effort growing out of discussions within the Interstellar Research Group to examine the possibility of making Martian soil suitable for agriculture. A path forward through simulation and experiment could help us narrow the options for what may be possible for future colonists. Herewith the origins and growth of a project called MaRMIE -- the Martian Regolith Microbiome Inoculation Experiment.

Image: The Martian Base: Painting for The Exploration of Space by Arthur C Clarke. Credit: Leslie Carr.

With the advent of the space age, there has been speculation about future human settlements on other worlds, of which Mars was the most desirable. Currently, the idea of humans on Mars is waxing again with the increased presence of robots on Mars. The private entrepreneur Elon Musk has targeted Mars settlement in the near future, in advance of NASA, and China has plans for a Mars base.

Successful settlement of distant locations requires living off the land, which requires resourcing food. Failure can lead to disaster, as experienced by some of the early American colonies. While near Earth space settlements could be supplied with packaged food, this would be too costly for an expanding Mars base over the long term. Food and air must be supplied from local sources, a point that has been emphasized by the Mars Society's president, Robert Zubrin (Zubrin, 2011).

In the mid-20th century, it was assumed that agriculture on Mars would be like that on Earth, with crops growing in the Martian soil, but under clear domes to maintain air pressure, and light for photosynthesis. As a result, the focus for settlement was on the shiny technologies of transport and the design of Martian bases and cities.

This rosy picture of farming on Mars was disturbed after the Apollo missions when it became apparent that plants did not grow well in lunar regolith samples. The Phoenix lander's discovery of perchlorates on the surface of Mars meant that the Martian regolith would be toxic to plant growth without remediation. Perchlorates are found on Earth, for example in the Atacama desert, but in far lower concentrations than the 0.5-1.0% concentrations found on the surface of Mars. Perchlorates are used in industry, and the US EPA regulates perchlorate contamination because of its toxicity.

Because of the adverse nature of regolith on plant growth, the focus shifted to soilless agriculture using hydroponics or aquaponics, as this article in *Centauri Dreams*; on Martian agriculture makes clear.(Kokkinidis 2016). However, there are limitations on the use of hydrodroponics. Plants with extensive root systems needed for support, especially trees, can't be grown this way, eliminating the availability of tree fruits and nuts. Most of our grains cannot be grown using current hydroponic methods either. It really would be useful if the regolith could be altered to make it suitable for traditional agriculture, perhaps more like the farms in arid areas, such as the Middle East.

In 2022, after participating in a panel discussion on establishing a sustainable human presence on Mars at a science fiction convention (LibertyCon) in Tennessee, members of the Interstellar Research Group (IRG) including Doug Loss, Joe Meany, and Jeff Greason, considered how some experiments could be done to test how best the regolith might be treated to remove the perchlorates with bioremediation using bacteria, and convert the sterile regolith into soil suitable for agriculture. Some species of bacteria metabolize chlorates and perchlorates for energy, and therefore could be used to remediate the regolith. Relatively small, low mass cultures could be brought from Earth and exponentially cultured to meet the requirements for the volumes of regolith to be treated.

Bioremediation of perchlorate contaminated soils is established practice (Hatzinger 2005), suggesting that if it could be adapted to Martian conditions, this may be a viable solution to remove the perchlorates and solve the toxicity issue. This use of bacteria, a low mass approach to remediate the regolith was the inspiration for core IRG members to propose a project, the Martian Regolith Microbiome Inoculation Experiment (MaRMIE).

Mars is almost certainly too dry and cold to just irrigate the regolith on the exposed Martian surface with an inoculant of perchlorate metabolizing organisms. Knowledge about the required conditions for successful large-scale regolith bioremediation, especially of temperature and pressure, was required, as well as the issue of UV and ionizing radiation.

The initial idea was to run experiments in a sealed chamber that mimicked the Martian surface environment to determine whether a terrestrial type soil might be created in which agriculture could be practiced. This Mars simulation chamber would contain a Martian regolith simulant (MRS) with added perchlorate, and inoculated with suitable bacteria. If the bacteria could break down the perchlorate, it would indicate that this approach could, in principle, be used to remediate the regolith from the surrounding area, which would then be used inside a greenhouse to grow the food crops. By doing so, the mass, complexity, and likely equipment failures of a hydroponic system could be avoided, and a more traditional agricultural approach could be practiced. This was a far more scalable solution than a technical one, allowing food production anywhere it would be needed, and was in much closer alignment with ISRU.

The initial idea was to design the experiment and have an outside PI with expertise and funding to refine the design and run the experiments. The IRG would publish a review article, and at some point participate in writing a paper on the results. At this point, the initial group decided to invite others who might be interested in providing input and expertise to investigate the biological remediation of regolith. Of particular importance was the need to design experiments that could be done at suitable facilities. IRG hopes the guidelines that develop out of this work may be of use to anyone pursuing research into agriculture for future use on Mars, and offers them to any organization that chooses to draw on them.

Prior work had identified various bacteria that had the genes that encoded the enzymes to reduce the [per]chlorate and extract energy from it (Balk 2008, Bender 2005, Coates 2004). As the genes coding for the various enzymes for perchlorate metabolism were known it has been suggested that by just liberating the oxygen from the perchlorate the regolith could be a useful source of life support and rocket fuel oxidant (Davil 2013), therefore offering another avenue of ISRU using an engineered bacterium.

Will bioremediation need to be taken inside the base, and if so, can or should it be done as close to Martian conditions as possible, or should it be done as close to the living or working conditions, and plant growing conditions in the agricultural greenhouse? Would it be better to grow the bacteria in a bioreactor rather than in situ, or even extract the enzymes to treat the regolith, thus controlling the bacteria growth and both reducing the perchlorates and liberating the oxygen as a useful side product? These questions can only be answered with experiments testing the various bacterial inoculants under varying conditions from terrestrial to Martian, as well as applying economic and other analyses to determine the more effective way to use bioremediation on the regolith as an initial step to making it a proactive soil for farming.

While bioremediation is one approach to removing perchlorates, the fact that they are readily water-soluble suggests that if free water is available, the regolith could be simply washed to flush out the perchlorates. This would require more plant to wash the regolith and then remove the salts to recycle the water. This method would work more effectively on regolith than soil and would not require the controlled conditions of bacterial growth and the time to build the culture. The Phoenix lander detected the perchlorates as they deliquesced on exposure. Experiments have shown that the perchlorates will deliquesce under Martian conditions (Slank 2022). Removal of the toxic perchlorates is just the start of the process to make the regolith fertile. There have been a number of experiments with regolith simulant to grow a variety of plants and crops under terrestrial conditions of temperature and pressure, the sort of conditions that might be expected in a Mars greenhouse that has humans managing the farm. By far the best results have been achieved by increasing the illumination to terrestrial levels and adding carbon-rich soils to the regolith, which now will also include the many soil organisms that improve the soils. A partial solution that has also worked is to grow cover crops like alfalfa grass or reuse the waste from prior crops to be added into the regolith to improve its water retention and nutrient supply. (Kasiviswanathan 2022).

So far none of these crop growing experiments have been attempted at pressures and temperatures that differ from optimal terrestrial conditions. There is considerable space to repeat these experiments under different conditions, especially if it proves important to build structurally lighter greenhouses, or even use artificial illumination in below-ground farms, much like container farming today. While oxygen can be extracted from Martian air, water and rocks, nitrogen is less readily available, as is phosphorus. These macronutrients and the other micronutrients will have to be found and extracted to support plant growth whatever farming method is used.

As a result of all these questions, the MaRMIE project has expanded in scope beyond bioremediation, to include crop growth experiments under non-terrestrial conditions. As of September, the project has generated an outline of the experiments that might be done, starting with bioremediation, and extending out into the more general issue of agriculture under conditions that differ from terrestrial ones. Even this is the tip of the iceberg as geoeengineered organisms might well be better adapted to conditions on Mars, reducing containment costs, nutrients, and allowing faster scale-up to support an expanding settlement.

The experimental framework encompassing the ideas to date has 4 phases:

1. Remediating perchlorates in the regolith, and any problematic chemicals produced as a result of the remediation. This requires acquiring Martian regolith simulants (MRS) and the addition of perchlorates, testing a number of bacterial and microfungal agents to remediate the MRS under terrestrial conditions, and then in stages of pressure and temperature modified towards Martian conditions.

2. Developing a microbiome tailored to Martian conditions with which to inoculate the regolith. The microbiome should lessen or remove tendencies toward cementation of the regolith as well as gradually convert it into actual soil, if possible. “Actual soil” implies the provision of required nutrients for plant growth. This includes testing microbiomes to add to the MRS along with testing pioneer plant species to condition the regolith to become more like soil.

3. Testing plant growth in microbiome-inoculated regolith under Martian lighting levels and atmospheric conditions, gradually

increasing the atmospheric pressure until plant growth is acceptable.

4. Continuing plant growth testing per #3, but gradually lowering ambient temperatures toward Martian levels until plant growth diminishes unacceptably.

5. Developing agricultural structures to provide appropriate conditions, with inoculated regolith, lighting levels, atmospheric pressure, and temperature levels previously determined, and with shielding from ionizing radiation.

As for output, the initial idea to publish some sort of review paper on the known issues and prior work, indicating the direction of experimental work needed, is still in process. As noted at the outset, the IRG cannot execute these experiments and offers this work as a contribution to the field of planetary studies. IRG hopes that this framework will be seen and used as a structure for designing experiments and building on the results of previous experiments, by any researchers interested in the ultimate goal of viable large-scale agriculture on Mars.

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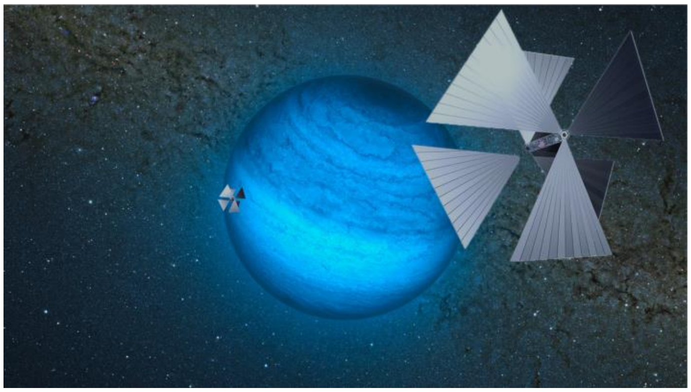
CHASING NOMADIC WORLDS – OPENING UP THE SPACE BETWEEN THE STARS

BY ANDREAS HEIN

Ongoing projects like JHU/APL’s Interstellar Probe pose the question of just how we define an ‘interstellar’ journey. Does reaching the local interstellar medium outside the heliosphere qualify? JPL thinks so, which is why when you check on the latest news from the Voyagers, you see references to the Voyager Interstellar Mission. Andreas Hein and team, however, think there is a lot more to be said about targets between here and the nearest star. With the assistance of colleagues Manasvi Lingam and Marshall Eubanks, Andreas lays out targets as exotic as ‘rogue planets’ and brown dwarfs and ponders the implications for mission design. The author is Executive Director and Director Technical Programs of the UK-based not-for-profit Initiative for Interstellar Studies (i4is), where he is coordinating and contributing to research on diverse topics such as missions to interstellar objects, laser sail probes, self-replicating spacecraft, and world ships. He is also an associate professor of space systems engineering at the University of Luxembourg’s Interdisciplinary Center for Security, Reliability, and Trust (SnT). Dr. Hein obtained his Bachelor’s and Master’s degree in aerospace engineering from the Technical University of Munich and conducted his PhD research on space systems engineering there and at MIT. He has published over 70 articles in peer-reviewed international journals and conferences. For his research, Andreas has received the Exemplary Systems Engineering Doctoral Dissertation Award and the Willy Messerschmitt Award.



Imaginary scenario of an advanced SunDiver-type solar sail flying past a gas-giant nomadic world which was discovered at a surprisingly close distance of 1000 astronomical units in 2030 by the LSST. The subsequently launched SunDiver probes spotted several potentially life-bearing moons orbiting it. (Nomadic world image: European Southern Observatory; SunDivers: Xplore Inc.; Composition: Andreas Hein).

If you think about our galaxy as a vast ocean, then the stars are like islands in that ocean, with vast distances between them. We think of these islands as oases where the interesting stuff happens. Planets form, liquid water accumulates, and life might have emerged in these oases. Until now, interstellar travel has been primarily thought in terms of dealing with how we can cross the distances between these islands and visit them. This is epitomized by studies such as Project Daedalus and most recently Breakthrough Starshot, Project Daedalus aiming at reaching Barnard's star and Breakthrough Starshot at Proxima Centauri. But what if this thinking about interstellar travel has missed a crucial target until now? In this article, we will show that there are amazing things hidden in the ocean itself – the space between the stars.

It is frequently believed that the space between the stars is empty, although this stance is incorrect in several ways, as we shall elucidate. The interstellar community is firmly grounded in this belief. It is predominantly focused on missions to other star systems and if we talk about precursors such as the Interstellar Probe, it is about the exploration of the interstellar medium (ISM), the incredibly thin gas long known to fill the spaces between the stars, and also features of the interaction between the ISM and our solar wind, such as the heliosheath, or with its interaction with microscopic physical objects or phenomena linked to our solar system. However, no larger objects between the stars are taken into account.

Today, we know that the space between the stars is not empty but is populated by a plethora of objects. It is full of larger flotsam and smaller "driftwood" of various types and different sizes, ejected by the myriads of islands or possibly formed independently of them. Each of them might hold clues to what its island of origin looks like, its composition, formation, and structure. As driftwood, it might carry additional material. Organic molecules, biosignatures, etc. might provide us with insights into the prevalence of the building blocks of life, and life itself. Most excitingly, some important discoveries have been made within the last decade which show the possibilities that could be obtained by their exploration.

In our recent paper (Lingam, M., Hein, A.M., Eubanks, M. "Chasing Nomadic Worlds: A New Class of Deep Space Missions"), we develop a heuristic for estimating how many of those objects exist between the stars and, in addition, we explore which of these objects we could reach. What unfolds is a fascinating landscape of objects - driftwood and flotsam - which reside inside the darkness between the stars and how we could shed light on them. We thereby introduce a new class of deep space missions.

Let's start with the smallest compound objects between the stars (Individual molecules would be the smallest objects). Instead of driftwood, it would be better to talk about sawdust. Meet interstellar dust. Interstellar dust is tiny, around one micrometer in diameter, and the Stardust probe has recently collected a few grains of it (Wetphal et al., 2014). It turns out that it is fairly challenging to distinguish between interstellar dust and interplanetary dust but we have now captured such dust grains in space for the first time and returned them to Earth. The existence of interstellar dust is well-known, however, the existence of larger objects has only been hypothesized for a long time. The arrival of 1I/'Oumuamua in 2017 in our solar system changed that; 1I is the first known piece of driftwood cast up on the beaches of our solar system. We now know that these larger objects, some of them stranger than anything we have seen, are roaming interstellar space. There is still an ongoing debate on the nature of 1I/'Oumuamua (Bannister et al., 2019; Jewitt & Seligman, 2022). While 'Oumuamua was likely a few hundred meters in size (about the size of a skyscraper), larger objects also exist. 2I/Borisov, the second known piece of interstellar driftwood was larger, almost a kilometer in size. In contrast to 'Oumuamua, it showed similarities to Oort Cloud objects (de León et al., 2019). The Project Lyra team (https://i4is.org/what-we-do/technical/project-lyra/) we are part of has authored numerous papers on how we can reach such interstellar objects, even on their way out of the solar system, for example, in Hein et al. (2022).

Now comes the big driftwood – the interstellar flotsam. Think of the massive rafts of tree trunks and debris that float away from some rivers during floods. We know from gravitational lensing studies that there are gas planet-sized objects flying on their lonely trajectories, unbound by a host star through the void. Such planets, unbound to a host star, are called rogue planets, free-floating planets, nomads, unbound, or wandering planets. They have been discovered using a technique called gravitational microlensing. Planets have enough gravity to "bend" the light coming from stars in the background, focusing the light, brightening the background star, and enabling the detection even of unbound planets. Until now, about two hundred of these planets (we will call them nomadic worlds in the following) have been discovered through microlensing. These detections favor the more massive bodies, and so far objects with a large mass (Jupiter-sized down to a few Earth masses) have been detected. Although our observational techniques do not yet allow us to discover smaller nomadic worlds (the smallest ones we have discovered are a few times heavier than the Earth), it is highly likely that smaller objects, say between the size of the Earth and Borisov, exist. Fig. 1 provides an overview of these different objects and how their radius is correlated with the average distance between them according to our order of magnitude estimates. Note that microlensing is good at detecting planets at large interstellar distances, even ones thousands of light years away, but it is very inefficient (millions of stars are observed repeatedly to find one microlensing event), and with current technology is not likely to detect the relative handful of objects closest to the Sun.

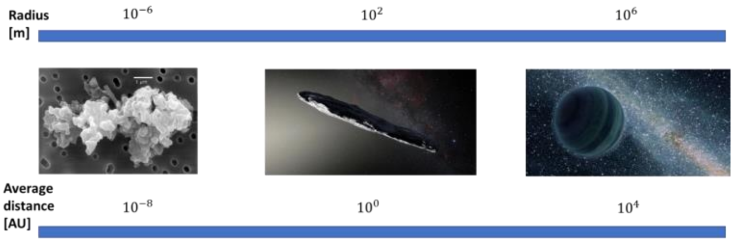


Fig. 1: Order of magnitude estimates for the radius and average distance of objects in interstellar space

We have already explored how to reach interstellar objects (similar to 1I and 2I) via Project Lyra. What we wanted to find out in our most recent work is whether we can launch a spacecraft towards a nomadic world using existing or near-term technology and reach it within a few decades or less. In particular, we wanted to find out whether we could reach nomadic worlds that are potentially life-bearing. Some authors have posited that nomadic worlds larger than 100 km in radius may host subsurface oceans with liquid water (Abramov & Mojzsis, 2011), and larger nomadic planets certainly should be able to do this. Now, although small nomadic worlds have not yet been detected, we can estimate how far such a 100 km-size object is from the solar system on average. We do so by interpolating the average distance of various objects in interstellar space, ranging from exoplanets to interstellar objects and interstellar dust. The size of these objects spans about 13 orders of magnitude. The result of this interpolation is shown in Fig. 2. We can see that ~100 km-sized objects have an average distance of about 2000 times the distance between the Sun and the Earth (known to astronomers as the astronomical unit, or AU).

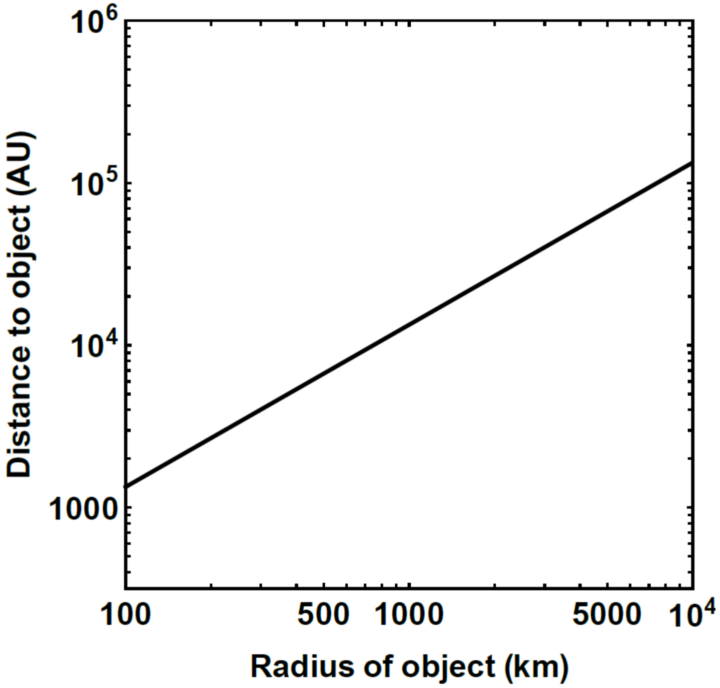
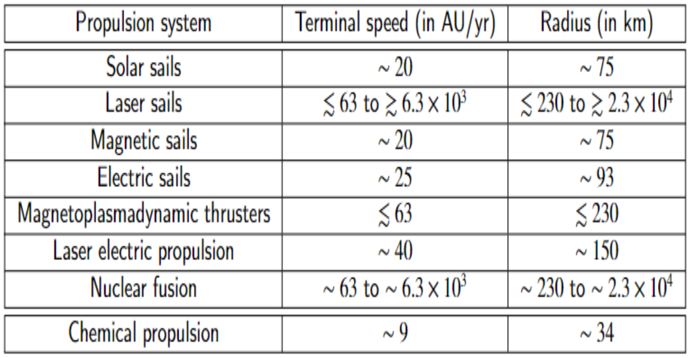


Fig. 2: Radius of nomadic world versus the estimated average distance to the object

This is a fairly large distance, over 400 times the distance to Jupiter and about five times farther away than the putative Planet 9 (~380 AU) (Brown & Batygin, 2021). It is important to keep in mind that this is a rough statistical estimate for the **average** distance, meaning that the ~100 km-sized objects might be discovered much closer or farther away than the estimate. However, in the absence of observational data, such an estimate provides us with a starting point for exploring the question of whether a mission to such an object is feasible. We use such estimates to investigate further whether a spacecraft with an existing or near-term propulsion system may be capable of reaching a nomadic world within a timeframe of 50 years. The result can be seen in Table 1.



Propulsion system	Terminal speed (in AU/yr)	Radius (in km)
Solar sails	~ 20	~ 75
Laser sails	$\lesssim 63$ to $\gtrsim 6.3 \times 10^3$	$\lesssim 230$ to $\gtrsim 2.3 \times 10^4$
Magnetic sails	~ 20	~ 75
Electric sails	~ 25	~ 93
Magnetoplasmadynamic thrusters	$\lesssim 63$	$\lesssim 230$
Laser electric propulsion	~ 40	~ 150
Nuclear fusion	~ 63 to $\sim 6.3 \times 10^3$	~ 230 to $\sim 2.3 \times 10^4$
Chemical propulsion	~ 9	~ 34

Table 1: Average radius of nomadic world reachable with a given propulsion system in 50 years

It turns out that chemical propulsion combined with various gravity assist maneuvers is not able to reach such objects within 50 years. Solar sails and magnetic sails also fall short, although they come close (~75 km radius of nomadic object). However, electric sails seem to be able to reach nomadic worlds close to the desired size and already have a reasonably high technology readiness level. Electric sails exploit the interaction between charged wires and the solar wind. The solar wind consists of various charged particles such as protons which are deflected by the electric field of the wires, leading to a transfer of momentum, thereby accelerating the sail. Proposed by Pekka Janhunen in 2004 (Janhunen, 2004), electric sails have also been considered for interplanetary travel and even into interstellar space (Quarta & Mengali, 2010; Janhunen et al., 2014). Up to 25 astronomical units (AU) per year seem to be achievable with realistic designs (Janhunen & Sandroos, 2007). Electric sail prototypes are currently being prepared for in-space testing (Iakubivskyi et al., 2020). Previous attempts to deploy an electric sail by the ESTCube-1 CubeSat mission in 2013 and Aalto-1 in 2022 were not successful (Slavinskis et al., 2015; Praks et al., 2021).

It turns out that more advanced propulsion systems are required, if we want to have a statistically good chance of reaching nomadic worlds significantly larger than 100 km radius. Laser electric propulsion and magnetoplasmadynamic (MPD) thrusters would get us to objects of 150 and 230 km respectively. Laser electric propulsion uses lasers to beam power to a spacecraft with an electric propulsion system, thereby removing a key bottleneck of providing power to an electric propulsion system in deep space (Brophy et al., 2018). MPD thrusters would be capable of providing high specific impulse and/or high thrust (the VASIMR engine is an example), although it remains to be seen how sufficient power can be generated in deep space or sufficient velocities be reached in the inner solar system by solar power.

Reaching even larger objects (i.e., getting to significantly further distances) requires propulsion systems which are potentially interstellar capable: nuclear fusion and laser sails, as the closest such objects might be distances of as much as a light year. These propulsion systems could even reach nomadic worlds of a similar size as Earth, nomadic worlds comparable to those we have already discovered. The average distance to such objects should still be a few times smaller than the distance to other star systems (~10^5 AU from the solar system, versus Proxima Centauri, for example, at about 270,000 AU). Hence, it is no surprise that the propulsion systems (fusion and laser sail) have a sufficient performance to reach large nomadic planets in less than 50 years, although the maturity of these propulsion system is at present fairly low.

Laser electric propulsion and MPD propulsion are also on the horizon, although there are significant development challenges ahead to reach sufficient performance at the system level, integrated with the power subsystem.

What does this mean? The first conclusion we draw is that while we develop more and more advanced propulsion systems, we become capable of reaching larger and larger (and potentially more interesting) objects in interstellar space. At present, electric sails appear to be the most promising propulsion system for nomadic planet exploration, possessing sufficient performance and a reasonably high maturity at the component level.

Second, instead of seeing interstellar space as a void with other star systems as the only relevant target, we now have a quasi-continuum of exploration-worthy objects at different distances beyond the boundary of the solar system. While star systems have been "first-class citizens" so far with no "second-class citizens" in sight, we might now be in a situation where a true class of "second-class citizens" has emerged. Finding these close nomads will be a technological and observational challenge for the next few decades.

Third, and this might be controversial, the boundary of what interstellar travel is, is destabilized. While traditionally interstellar travel has been treated primarily as travel from one-star system to another, we might need to expand its scope to include travel to the "in-between" objects. This would include travel to aforementioned objects, but we might also discover planetary systems associated with free-floating brown dwarfs. It seems likely that nomadic worlds are orbited by moons, similar to planets in our solar system. Hence, is interstellar travel if and only if we travel between two stars, where stars are objects maintaining sustained nuclear fusion? How shall we call travel to nomadic worlds then? Shall we call this type of travel "transstellar" travel, i.e. travel beyond a star or in-between-stellar travel? Furthermore, nomadic worlds have likely formed in a star system of origin (although may have formed at the end, rather than at the beginning, of the stellar main sequence).To what extent are we visiting that star system of origin by visiting the nomadic world? Inspecting a souvenir from a faraway place is not the same as being at that place. Nevertheless, the demarcation line is not as clear as it seems. Are we visiting another star system if and only if we visit one of its gravitationally bound objects? While these are seemingly semantic questions, they also harken back to the question of why we are attempting interstellar travel in the first place. Is traveling to another star an achievement by itself, is it the science value, or potential future settlement? Having a clearer understanding of the intrinsic value of interstellar travel may also qualify how far traveling to interstellar objects and nomadic worlds is different or similar.

We started this article with the analogy of driftwood between islands. While the interstellar community has been focusing mainly on star systems as primary targets for interstellar travel, we have argued that the existence of interstellar objects and nomadic world opens entirely new possibilities for missions between the stars, beyond an individual star system (in-between-stellar or transstellar travel). The driftwood may become by itself a worthy target of exploration. We also argued that we may have to revisit the very notion of interstellar travel, as its demarcation line has been rendered fuzzy.

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IRG 2023 SYMPOSIUM

The Interstellar Research Group (IRG) in partnership with the International Academy of Astronautics (IAA) hereby invites participation in its 8th Interstellar Symposium, hosted by McGill University, to be held from Monday, July 10 through Thursday, July 13, 2023, in Montreal, Quebec, Canada. This is the first IRG meeting outside of the United States, and we are excited to partner with such a distinguished institution!

Topics of interest will include:

Physics and Engineering
Propulsion, power, communications, navigation, materials, systems design, extraterrestrial resource utilization, breakthrough physics

Astronomy
Exoplanet discovery and characterization, habitability, solar gravitational focus as a means to image exoplanets

Human Factors
Life support, habitat architecture, worldships, population genetics, psychology, hibernation, finance

Ethics
Sociology, law, governance, astroarchaeology, trade, cultural evolution

Astrobiology
Technosignature and biosignature identification, SETI, the Fermi paradox, von Neumann probes, exoplanet terraformation

Submission of other topics of direct relevance to interstellar travel are also welcome. Examples of presentations at past symposia can be found here: https://www.youtube.com/c/InterstellarResearchGroup/videos

The IRG's 8th Interstellar Symposium Call for Papers can be found at https://irg.space/wp-content/uploads/2022/12/IRG_CALL_FOR_PAPERS.pdf