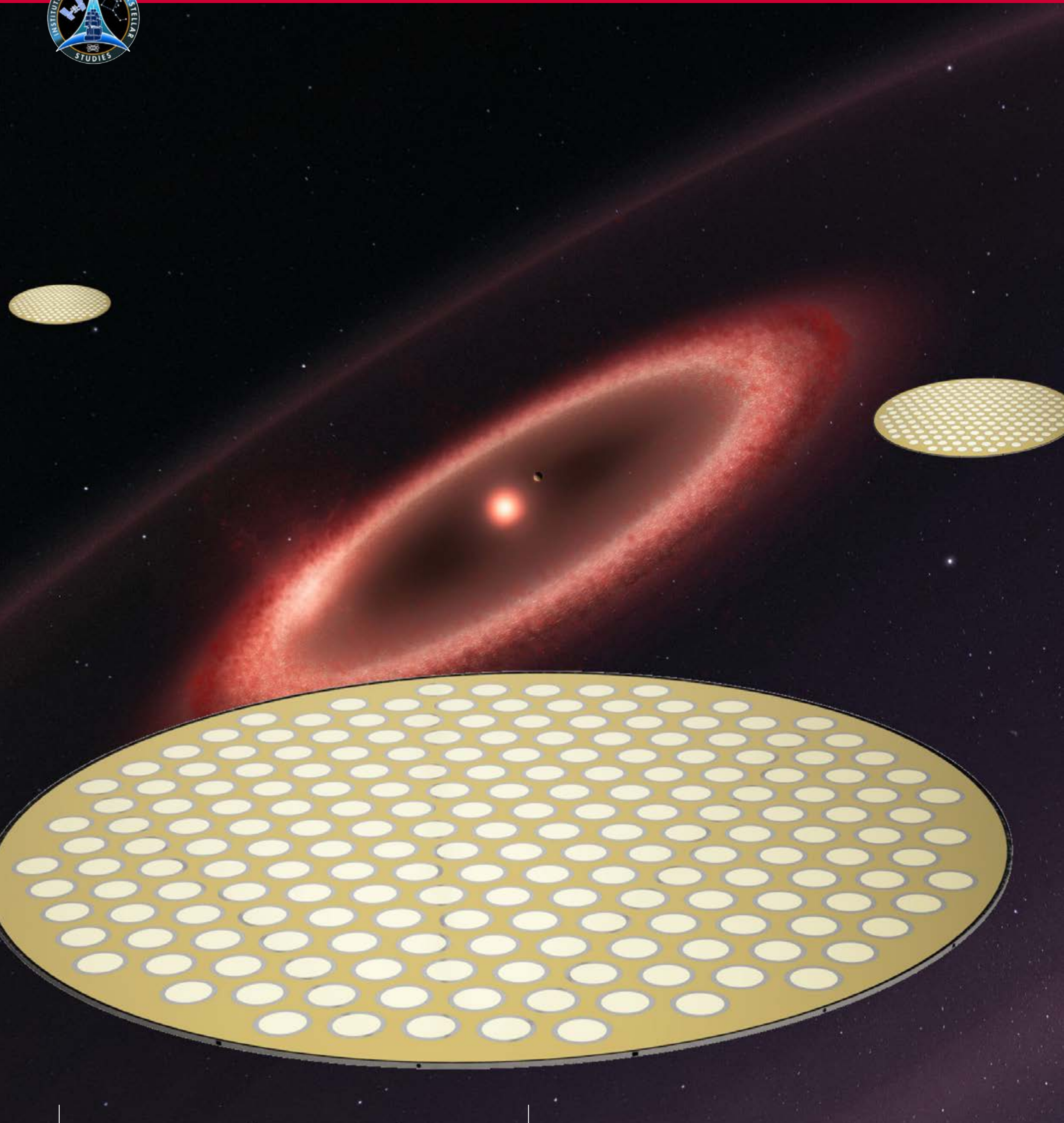
PRINCIPIUM

The Initiative and Institute for Interstellar Studies | Issue 45 | May 2024



Lead Feature: Book Review: A Traveler's Guide to the Stars

Book Review: Contact with Extraterrestrial Intelligence and Human Law

News Features: Glasgow 24 SF Worldcon: An i4is update, Royal Institution April 2024, Biological intelligence vs AI - and the Fermi Paradox

Interstellar News

The Journals: JBIS and Acta Astronautica

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EDITORIAL

Welcome to issue 45 of Principium, the quarterly magazine of i4is, the Initiative and Institute for Interstellar Studies. Our Lead Feature is a book review: *A Traveler's Guide to the Stars*.

We have three news features *Glasgow 24 SF Worldcon An i4is update*, *Royal Institution April 2024* and *Biological intelligence vs AI - and the Fermi Paradox*. Also 11 pages of Interstellar News and five pages of our regular summary of relevant peer-reviewed papers in *The Journal of the British Interplanetary Society* (JBIS) and *Acta Astronautica*.

We have another book review - *Contact with Extraterrestrial Intelligence and Human Law - The applicability of rules of war and human rights* by Professor Michael Bohlander of Durham University, contributed by members of the Space Law team at KCL Space, the space society of Kings College London.

The front cover image is *Oblique view of a metamaterial probe* - based on i4is/Space Initiatives work. The rear cover image *The Problem of Space Travel: The Habitat Wheel* based on advanced thinking from almost a century ago. More about both in *Cover Images* inside the rear cover.

As always we have the i4is members' page and our regular call to action, *Become an i4is member*.

Next time, P46 in August 2024, we will have two postponed items a survey of *Current FTL Thinking* by Dr Dan Fries and *Doubling Human Lifespan - implications for the interstellar enterprise*. We will have an *IAC 24 Preview: Anticipating the International Astronautical Congress 2024* in Milan in October. *IRG/i4is Interstellar Symposium Preview* explaining what we expect at the First European Interstellar Symposium in December at the University of Luxembourg (see poster on page 46) and *Aerographene and Aerographite - the metamaterials for an interstellar probe?* by Dr Andreas Hein.

And the usual Interstellar News and journal reports. More details on P46 in *Next Issue* at the end of P45.

And if you would like to help with any part of ***Working towards the real Final Frontier*** then please take a look at our poster on page 18.

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Patrick Mahon, Deputy Editor, patrick.mahon@i4is.org

MEMBERSHIP OF i4is

Please support us through membership of **i4is**. Join the interstellar community and help to reach the stars! Privileges for members and discounts for students, seniors and BIS members. Details in *Become an i4is member* in this issue and at i4is.org/membership.

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The views of our writers are their own. We aim for sound science but not editorial orthodoxy.

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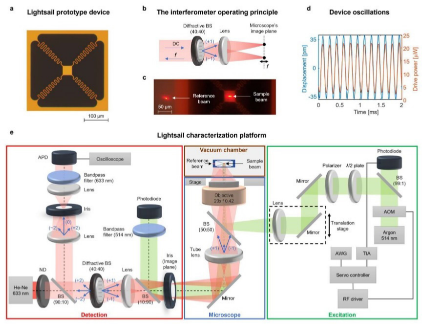

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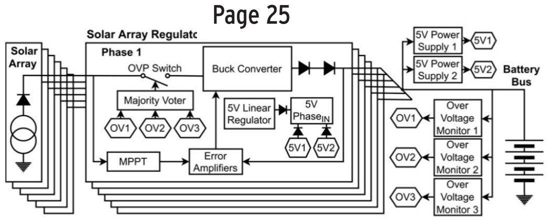
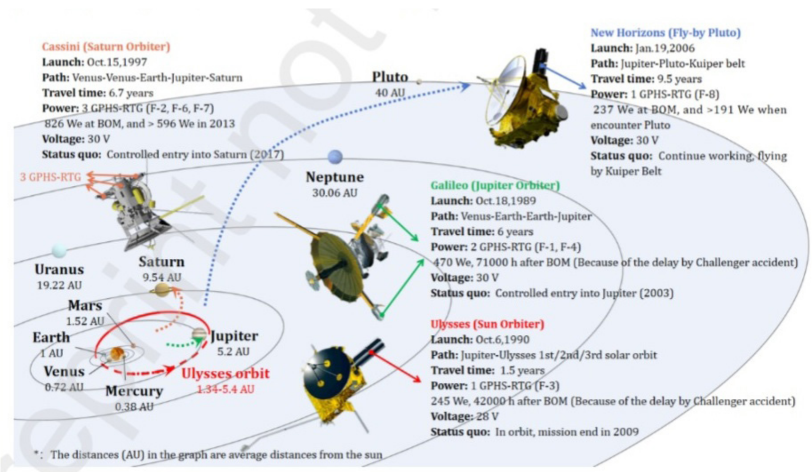




Radioisotope Power
in Interstellar News, Page 27

BOOK REVIEW: *A Traveler's Guide to the Stars*

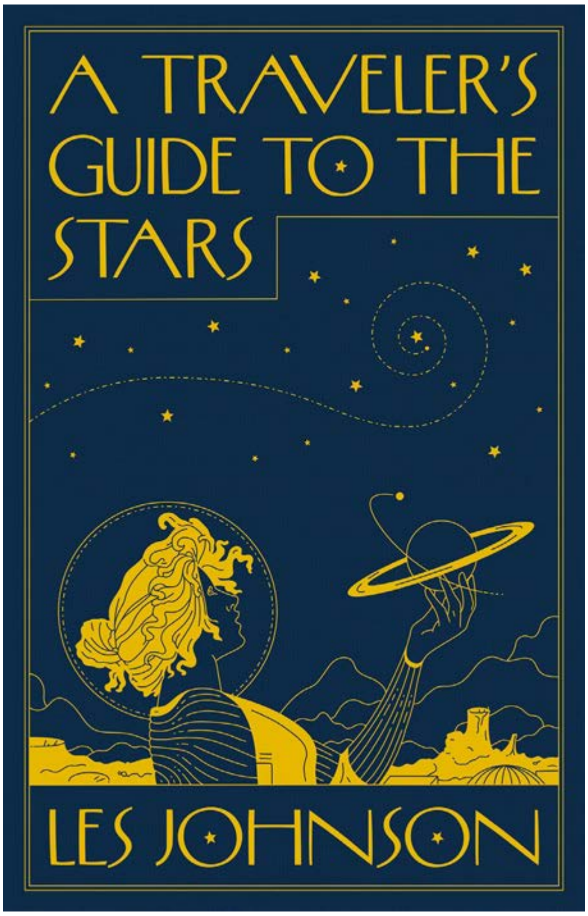
by Les Johnson (Princeton University Press)

Reviewed by Patrick Mahon

The whole "interstellar thing", with which i4is and its sibling organisations are concerned, can be obscure and technically challenging. Here Patrick Mahon reviews a book written by one of the most prominent advocates of the subject, Les Johnson, which provides an accessible and up to date introduction to the subject [1].

Context

One of the challenges that faces those of us who become interested in interstellar exploration is the relative lack of accessible introductory material on the basics of the *how* and *why* of the subject. This is particularly true when compared to the much larger volume of information that is readily available if you want to know about spaceflight within our own solar system. Countless books have been written about space travel and astronautics, ranging from board books for babies through detailed volumes for the interested general reader, such as the well-known range of *Haynes* manuals, to highly technical academic texts for those studying the subject.



However, if you want to understand the additional challenges involved in sending a spacecraft beyond the solar system and on to other stars, the range of reading matter suitable for a non-specialist is very limited. There are a number of detailed technical books available for those studying the subject academically, but most of these presume a working understanding of maths, physics and engineering. For the general reader, eager to get an overview of the realities of interstellar travel, as opposed to the fantastical visions presented in most science fiction, whether on the page or screen, only one book comes readily to my mind, and that is *The Starflight Handbook: A Pioneer's Guide to Interstellar Travel*, by i4is's friend and colleague Greg Matloff and the late Eugene Mallove. I got a copy soon after it was published in 1989, while I was at university, and I read it voraciously. Trouble is, that book came out thirty-five years ago, and has been out of print for a long time.

[1] press.princeton.edu/books/hardcover/9780691212371/a-travelers-guide-to-the-stars

So it is not a moment too soon for Les Johnson's new book, *A Traveler's Guide to the Stars*, to be published. And although it comes from an academic publisher – Princeton University Press, no less – Johnson is keen to make clear early on that this is a popular science book aimed at the general reader.

The author

I imagine that many *Principium* readers will already know who Les Johnson is. For those that don't, he is a physicist and engineer who has worked at NASA for over a quarter of a century. As he explains in the preface to the book, his interest in interstellar exploration began in 1999, when he was put in charge of NASA's Interstellar Propulsion Research Project. Since then, he has worked on many of the advanced concepts and technologies that will be necessary to reach the stars, most recently focusing on solar sailing. On top of his day job at NASA, Johnson is a member of the worldwide community of those passionate about interstellar travel, and he's also an author of both non-fiction and science fiction. He's therefore an ideal person to take us on this journey.

The book

The book is split into eight chapters, book-ended by an introduction and an epilogue. I'll give a brief summary of each below.

Introduction

In the introduction, Johnson gives the rationale for the book, pointing out that it's only in the last thirty years that we have had definite observational evidence for the existence of any planets outside our solar system. However, now that we know of over 5,000 confirmed exoplanets orbiting other stars, with several thousand more candidates currently under investigation, it is unsurprising that people are starting to ask whether it may one day be possible to send a spacecraft to one or more of them. In particular, a small proportion of these exoplanets may be habitable by humans. In the popular imagination, one of these habitable exoplanets might be a future destination for humans to travel to, explore, and settle on, as depicted recently in the films *Interstellar* (2014) [1] and *Passengers* (2016) [2].

Les Johnson - from his personal site - www.lesjohnsonauthor.com/

[1] Reviewed by Keith Cooper in Principium 9 May 2015 i4is.org/principium-9/
[2] Reviewed by John I Davies in Principium 16 February 2017 i4is.org/principium-16/

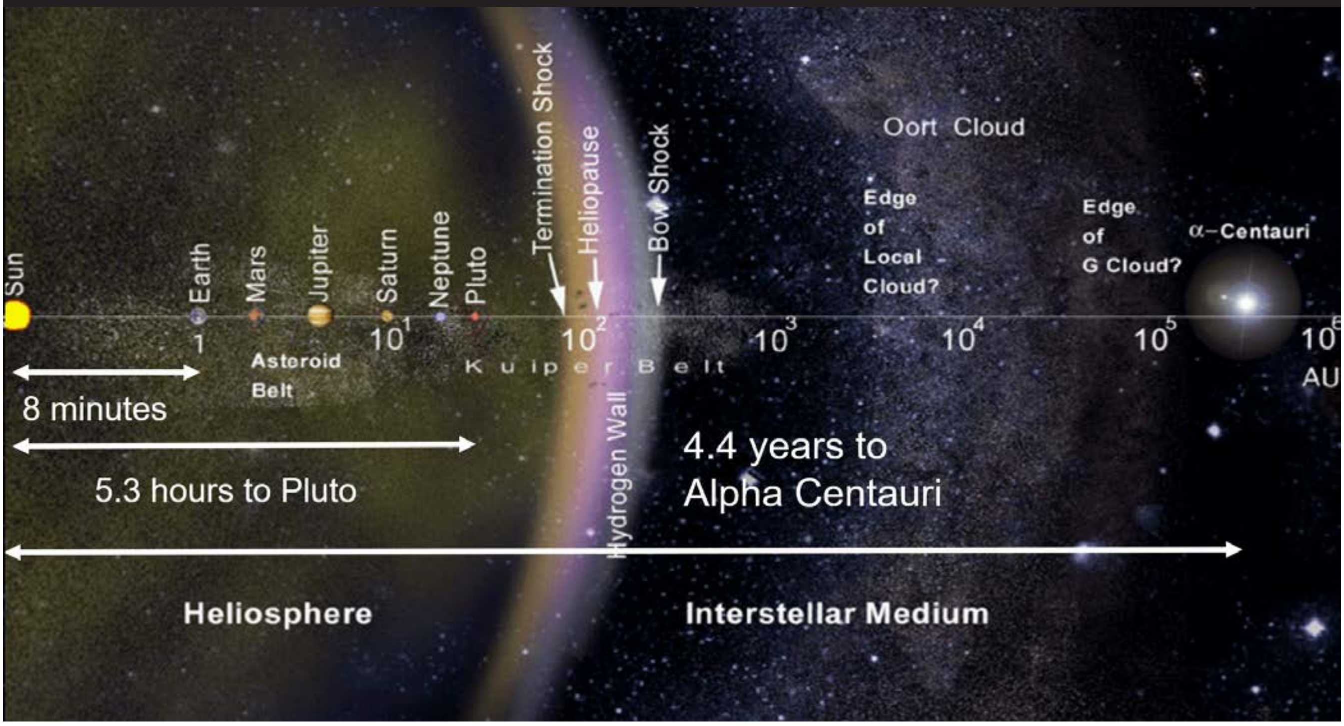
However, getting there won't be easy or quick. As Johnson explains, even the nearest star beyond our own Sun, Proxima Centauri, is 4.2 light years away, equivalent to 269,000 Astronomical Units (1 AU being the distance between the Earth and the Sun). The spacecraft that's travelled further from Earth than any other to date is Voyager 1, launched in 1977. As at April 2024, it is 163 AU away. But it has taken 46 years to get that far, and is currently travelling at about 3.6 AU per year. At that speed, if it was pointed in the right direction (which it isn't), it would take about 70,000 years to reach Proxima Centauri. So we will need completely new technologies if we are to send spacecraft at the much higher speeds that will be needed to reach even the nearest exoplanet within a reasonable timeframe.

Before digging into the *how* of interstellar travel in detail, Johnson finishes off his introduction by addressing the *Why* question. As a scientist, his principal justification for interstellar exploration is to expand human knowledge. However, he also notes that the technical advances that will be necessary are likely to provide real-world benefits back on Earth, just as so many innovations originally developed for the space programme over the last sixty-odd years have had spin-off benefits for the rest of us.

Johnson ends by saying that interstellar travel looks technically feasible, even if it will be incredibly challenging. He invites his readers to find out the scale of that challenge by reading the rest of the book.

This is a short but powerful introduction to the topics that Johnson intends to cover. It certainly made me keen to read the rest of the book.

The scale of the problem. Logarithmic scale of Astromical Units - with light travel time - minutes to years.
Credit: From i4is "Skateboards to Starships" for the Royal Institution 2018-2024 based on an image by Johns Hopkins Applied Physics Laboratory (APL) www.jhuapl.edu/



Chapter 1: The Universe Awaits

Chapter 1 expands on the material of the introduction, going into more detail about how those thousands of exoplanets have been discovered, and how around 60 of them (to date) have been identified as being potentially habitable. However, most exoplanets are *much* further away than Proxima Centauri, so Johnson spends some time helping the reader get a handle on the literally astronomical distances between the stars. After that, he points out that the space that our interstellar voyager will have to travel through is not completely empty. It includes small amounts of dust, the solar wind (comprised of charged particles), magnetic fields and cosmic rays. Each of these could pose a potential risk to our spacecraft. The first chapter ends with four questions. Where should we go? How will we get there? What is deep space like, compared to the space environment nearer our Sun? And when might we be able to make the trip?

This first chapter provides a user-friendly introduction to the challenge of thinking about the vast distances between the stars, and what that means for physical exploration.

Chapter 2: Interstellar Precursors

Chapter 2 starts by recognising that crewed trips to distant exoplanets are a very long way into humanity's future, whatever *Star Trek* might have to say on the matter. In the more immediate future, we should focus on interstellar precursor missions – that is to say, robotic exploration of the space environment beyond the eight planets of our solar system, all of which sit within about 30 AU of the Sun. Johnson gives a brief summary of the history of robotic and crewed space exploration since Sputnik 1 in 1957 and Yuri Gagarin in 1961. He focuses in on the five robotic missions to date that have or will end up in interstellar space – Pioneers 10 and 11, Voyagers 1 and 2, and more recently the New Horizons probe that flew past Pluto in 2015. A key point about all five spacecraft is that they and their scientific instruments were designed for their primary missions within the solar system. Any scientific results we obtain from them as they reach interstellar space are a lucky bonus. Our next step, however, should be a mission specifically designed to study the interstellar medium (or ISM), using the most appropriate scientific instruments for that task.

In passing, Johnson notes that although telescopes can do a lot – including discovering all those exoplanets – there are other things that can only be discovered through in-situ measurements. He notes that this is how the Van Allen radiation belts were discovered (by Explorer 1 in 1958), how Saturn's moon Methone was discovered (by the Cassini mission in 2004), and how the largest known glacier in the solar system was discovered (on Pluto, in 2015, by New Horizons). There is no reason not to think that the same will prove true with an interstellar precursor mission.

Such a mission will need to be able to travel much faster than its five predecessors, so that it can reach the heliopause (the boundary between the area of space dominated by the Sun's radiation pressure, and true interstellar space) and beyond during the working careers of the scientists who design and launch it.

Johnson notes that although the idea for such a mission has been under consideration for decades, it may now be close to realisation. NASA have provided funding to Johns Hopkins University's Applied Physics Laboratory (JHU APL) to produce a design study [1] for exactly such a precursor mission, aimed to travel at between 15 and 20 AU per year, some 4 to 6 times faster than Voyager 1.

I think Johnson does an excellent job here of motivating the need for a dedicated interstellar precursor mission. In the process, he also provides a handy summary of the five spacecraft that have already started that journey.

[1] Details of JHU APL's Interstellar Probe project are at interstellarprobe.jhuapl.edu/ .

Chapter 3: Putting Interstellar Travel into Context

In Chapter 3, Johnson discusses three important contextual issues, to illustrate the scale of the challenge: energy, time, and ethics. On energy, he calculates that the amount of energy that would be needed to accelerate just one kilogramme to one-tenth of the speed of light would be about 450 trillion joules, which is roughly equivalent to the energy you would get from 170 train trucks fully loaded with coal. And that's just for a single kilo! Rapid interstellar travel, at appreciable fractions of the speed of light, will require enormous amounts of energy.

On time, he notes that our perceptions of what a 'long' or 'short' period of time is varies between societies, with residents of a relatively young country like the USA often thinking that a period of, say, two centuries is a long time, while a typical European, having grown up in a country whose cathedrals may be many hundreds of years old, might consider a long time to be more like a thousand years. Johnson observes that those of us interested in interstellar missions will need to adopt a more European attitude to time if we are to have the patience to wait for a probe to reach its destination and then send its data back to Earth.

Johnson then turns to the ethical questions that will need to be addressed, assuming that the first interstellar probe is publicly funded. These are the same questions that are raised in opposition to any large spending programme to do with space. Probably the most frequent is 'Wouldn't the money be better spent on Earth?', to which the answer, of course, is, 'it is'. Slightly more interesting is 'Do we have any right to go to a habitable exoplanet and mess up that biosphere, given how badly we've treated our own one?' Johnson's view is that we should take precautions against contaminating places in the solar system which may still harbour primitive life (eg the surface of Mars, or the oceans of Enceladus). At the same time, we should acknowledge that, to date, the Earth is the only place we've found that definitely harbours life. Most everywhere else we've looked so far appears to be completely dead. If we think that life is a good thing, then wouldn't it be good to spread it to other places in the universe, if they are currently dead?

Johnson highlights three vital questions here. The one question he doesn't address in any detail, probably for good reason, is value for money. It seems likely that any interstellar mission will be hugely expensive. Inevitably, there will need to be a discussion around the benefits or value of spending a large fraction of the space budget on such a mission, compared to the benefits that could be gained by spending that money on another space mission within the solar system. It may be too early to have that discussion in detail now, but I personally think the interstellar community will need to prepare the ground for it in the not too distant future. Nonetheless, it's probably not a topic that would fit neatly within the aims of Johnson's book.

Chapter 4: Send the Robots, People, or Both?

Chapter 4 addresses another question that pops up frequently in discussions on space exploration. Should we send robotic probes, or should we send humans? Johnson's answer is 'both', on the basis that each has their pros and cons. Robots are easier to send (as they don't require life support, amongst many other reasons), and they are much more robust than humans, in terms of their tolerance of high g-forces during launch, and challenging environmental conditions at the destination. The recent swathe of Martian rovers has shown just how much they can do.

At the same time, we don't yet have any fully autonomous rovers, so their pace of discovery is slow, as every movement has to be planned out by ground control, to avoid losing a billion-dollar rover to a silly accident. And rovers don't have human intuition, of the kind that astronaut and professional geologist Harrison Schmitt brought to the Apollo 17 mission to the Moon in 1972. Schmitt happened to see what turned out to be one of the most interesting rock samples to be returned to Earth across the entire Apollo programme. His intuition led him to ignore his instructions from Mission Control (which involved going to a different set of rocks), and to follow his hunch instead. No robotic rover is capable of doing that (yet). And in addition to those two points, a final argument for sending people is that humans have an underlying need to experience things for themselves. Johnson notes that although these days we can all see close-up pictures via the internet of the *Mona Lisa*, or Mount Everest, or just about anything else, without leaving home, it doesn't stop thousands of people from spending time and money visiting these sights each year, to experience them in person.

To Johnson's mind, the correct answer to the question, in relation to interstellar exploration, is a three-fold one. Start by sending fly-by missions that can take images and get data as they fly past the target, without the huge complications of the engineering necessary to slow down at the destination. Next, send robotic spacecraft that slow down into orbit on arrival, and perhaps send sub-probes down to land on the planet(s) or moon(s) of interest. And finally, armed with all of that information, send a human crew.

Given that a crewed mission is likely to be much larger – and slower – than a robotic mission, we then have to consider the ethics of sending humans off to a destination that the first generation of astronauts won't even live to see. Unless we develop a safe form of hibernation or suspended animation, which genuinely stops the astronauts from ageing, a crewed mission that lasts many decades, or even hundreds of years, will arrive at its destination with the descendants of the – now deceased – original astronauts on board. Is it ethical to send people on a mission whose end they will never see? Equally, is it ethical to 'condemn' the descendants of those astronauts to a life away from Earth that they didn't choose?

Putting these ethical issues to one side, how many people, and of what sort, should you send on such a mission? Here, Johnson quotes some of the results from a 2020 paper in *Acta Futura*, written by i4is Executive Director Andreas Hein and several collaborators. That paper suggests that a population of 10,000 might be reasonable. Having decided on the numbers, you then need to design the worldship that they will travel on. And this isn't just about the engineering, as tricky as that will be. There will also need to be a lot of thought put into the psychology, sociology and politics of such a mission. How do you keep the crew happy, healthy and working together in harmony, across multiple generations? These are huge questions, and they will need a lot of serious thought.

I thought Chapter 4 was particularly good. Johnson tackles the 'robots or humans' question head-on, and provides strong answers. It's also good to see that he's not afraid to raise some of the more challenging questions that we'll have to address when it comes to the planning of a long duration crewed mission.

Chapters 5 and 6 cover the central issue of propulsion, with Johnson choosing to separate it out into rockets (Chapter 5) and lightsails (Chapter 6). I imagine that this is the material that will be most familiar to many *Principium* readers, so I will summarise these two chapters only briefly.

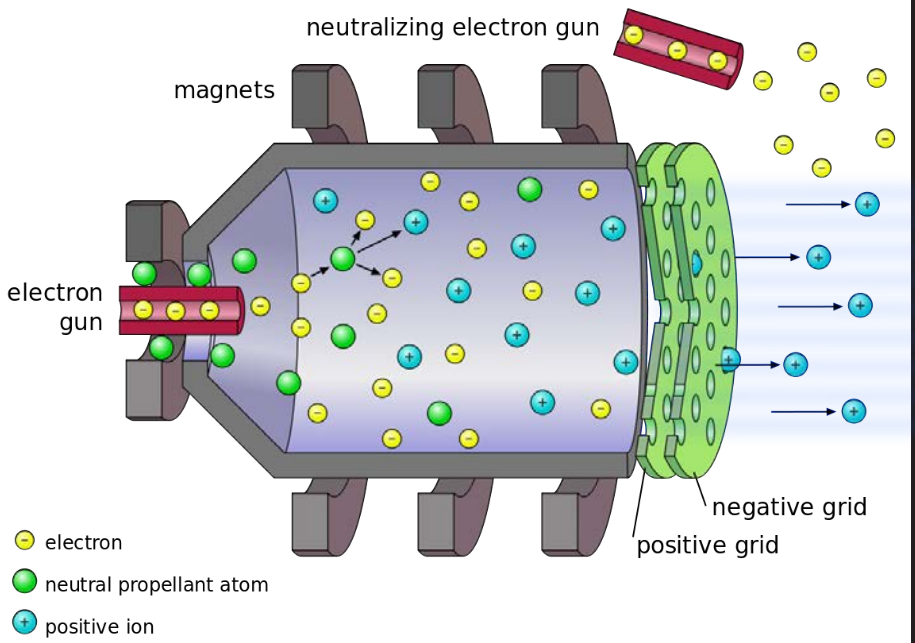
Chapter 5: Getting There with Rockets

In Chapter 5, he discusses the basic physics of rockets, which is to say, conservation of momentum. He introduces the concept of a rocket's *specific impulse*, which is a measure of the efficiency with which it uses its propellant, and explains that if we want to go interstellar with rockets, we will need the specific impulse to be extremely high.

This is unfortunately not the case with the rockets we use currently, and have used in the past, such as those used on the Space Shuttle, on SpaceX's various rockets, and on the rockets launched by Russia, China and others. All of these are 'chemical rockets', which use the energy released in a chemical reaction (such as combining hydrogen and oxygen to create water, as was used in the Space Shuttle's main engines) to accelerate the rocket. Chemical rockets have high thrust, enabling them to overcome the rocket's weight at launch and get into the air at all, but their specific impulse is rather low.

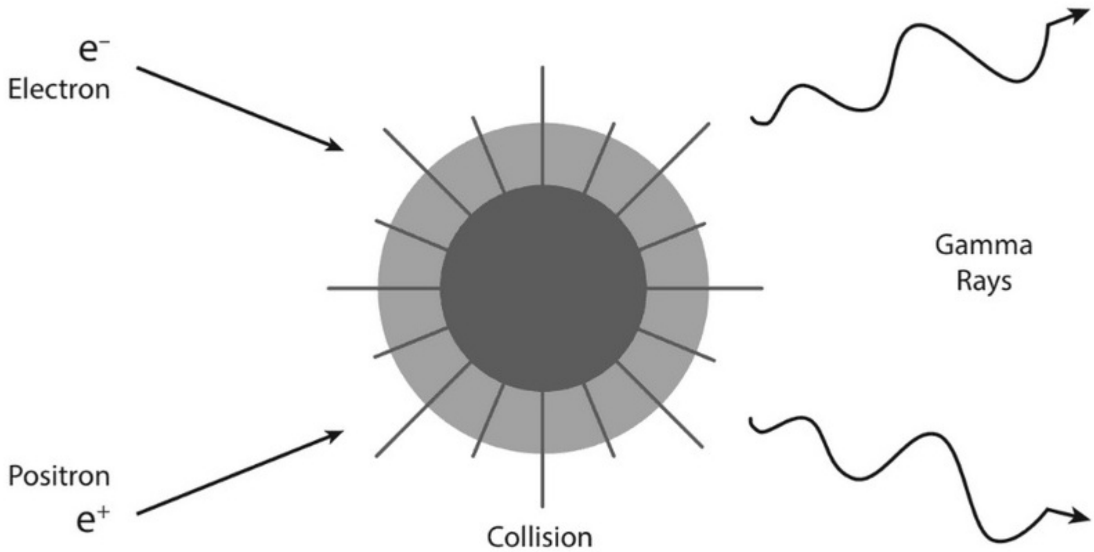
If we want to use rockets to get to the stars, we will need to do much better than this. Johnson explains the various options for generating higher levels of specific impulse, including nuclear fission and fusion, electromagnetic thrusters, and antimatter. Some of these are already possible, while others need more development, or are still speculative.

High efficiency but low thrust: Ion propulsion (Johnson: Chapter 5)



Johnson Figure 5.2: Electric rockets seem more complicated, and they can be, but in principle they are the same as any other rocket. Exhaust expelled from one side results in a net force pushing the rocket in the opposite direction. In this example, high- energy electrons are fired into a chamber filled with a charge-neutral gas. The incoming electrons strip away electrons from the neutral gas atoms, giving some a net positive electrical charge. An externally applied magnetic field then accelerates these positively charged atoms (to the right in the drawing), expelling them as exhaust. To keep the charged atoms moving away from the spacecraft, additional electrons are injected into the exhaust, which, if the energy levels are appropriate, can attach to the positively charged ions and again make them charge neutral.
Credit :Oona Räisänen, Wikimedia Commons (image), Les Johnson (caption)

High efficiency and high thrust but where to find the fuel? Antimatter propulsion (Johnson: Chapter 5)



Johnson Figure 5.3: Antimatter Annihilation. When an electron and a positron collide, all of their rest mass energy is converted into energy in the form of gamma rays.
Image created by Danielle Magley.

Chapter 6: Getting There with Light

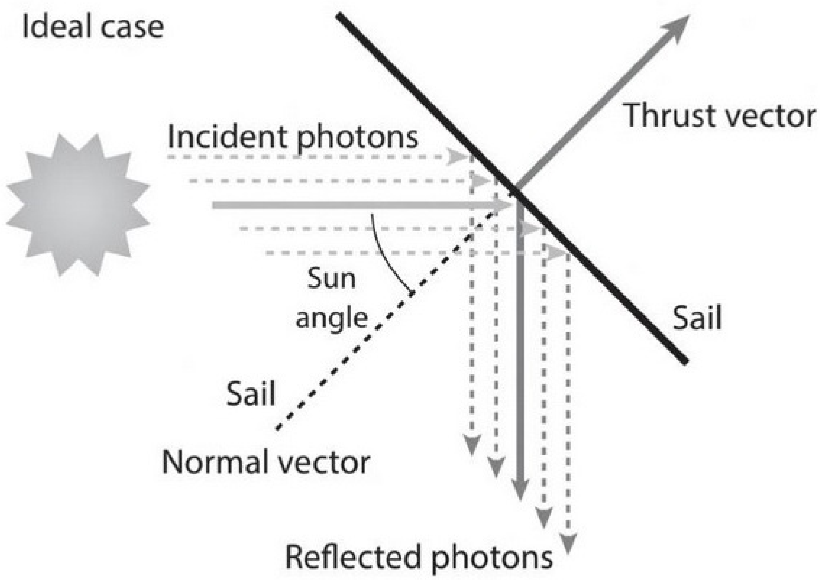
The central problem for almost all rockets is the requirement to carry all their propellant with them. One alternative, explored in Chapter 6, is to use the fact that light carries momentum.

If you shine a torch at a mirror, the torchlight bounces off the mirror, changing its direction and momentum. Since momentum is always conserved, the change in the light's momentum is matched by a very small change in the mirror's momentum. Lightsails work using this principle. The key benefit is that you don't need to carry the light with you, unlike with rocket propellant. The key problem is that the amount of momentum transferred is tiny. So a lightsail needs to be highly reflective and extremely large in area, to capture as much light as possible, whilst simultaneously being incredibly light.

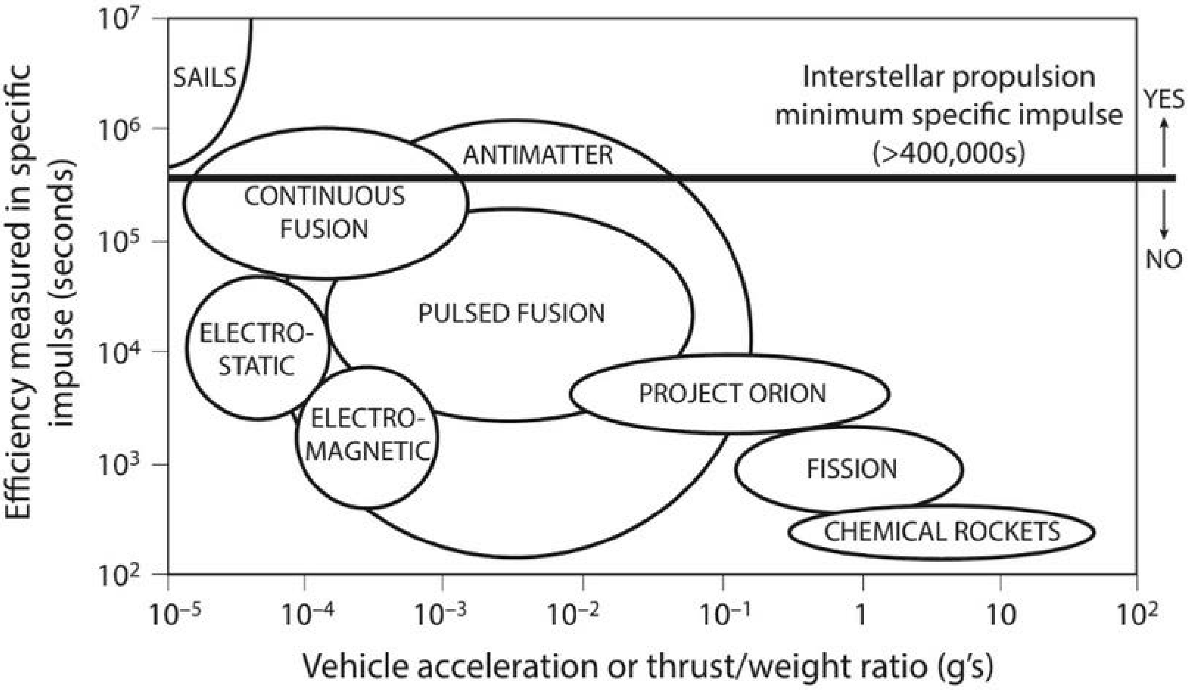
If you're near the Sun, then that forms an ideal source of light photons. So-called solar sails are real, and have flown on several missions in recent years, with more planned. Unfortunately, our interstellar mission would take us ever further from the Sun. If we want to accelerate lightsails when the Sun's light is no longer powerful enough, we could instead contemplate building a powerful laser, either on the ground or in orbit, and use the light from that to accelerate our lightsail instead. Such 'laser sails' are central to several of i4is's own ideas, including Project Lyra and Project Glowworm.

Alternatively, we could switch from visible light to microwaves. This has the advantages that microwave generators are both more efficient and cheaper than laser generators for the same power output. Unfortunately, the source of the microwaves would have to be huge – larger than the diameter of the Earth – and very power hungry. Consequently it would be extremely difficult and expensive to construct. There are also a couple of other ways to generate thrust without fuel, including magsails, which use the fact that there are magnetic fields in space, and e-sails, which do the same for electric fields.

Johnson ends the chapter by bringing us back to our interstellar objective. For this, we need an extremely high specific impulse. His conclusion is that, on the propulsion front, we are likely to need to adopt either nuclear fusion, antimatter, or lightsails.



Johnson Figure 6.1: How Solar Sails Work. Solar sails are not rockets, but they, too, operate under the same basic physical principle of rocketry— the conservation of momentum— and they do this in a really interesting way. Consider the solar sail as a perfectly reflective flat plate, with the sun to the left. No matter what angle the sail is tilted, the incident particles of light (photons) will reflect from it, producing a net thrust on the sail that depends upon that angle and the energy of the incident photons. As the photons reflect from the sail, they lose a little energy (and actually change color in the process). The energy lost by the photons is transferred to the sail as momentum, accelerating it.
Credit (image and caption): Les Johnson



Johnson Figure 6.3: Propulsion Systems Comparison. Known space propulsion technologies are categorized according to the performance metrics of specific impulse (a measure of propellant utilization efficiency) and acceleration (or thrust-to-weight ratio). Interstellar missions will need both values to be as high as possible. The horizontal line at a specific impulse of 400,000 seconds represents the minimum value needed for interstellar propulsion at 0.1 c by concepts with onboard propellants. It should be noted that there are many fusion- and antimatter-based propulsion concepts, but only certain implementations are theoretically capable of achieving 0.1 c. The ideal propulsion system would be at the top-right corner with very high thrust and extremely high efficiency. Credit (image and caption): Les Johnson

Chapters 5 and 6 provide a strong introduction to the many different options available for a propulsion system. Although I'm sure much of it will be well known to our readers, it strikes me as a hugely valuable primer for anyone coming to the interstellar exploration topic for the first time.

Chapter 7: Designing Interstellar Starships

Once we've made the choice of propulsion method, we will need to design the rest of the spacecraft. That's the topic of Chapter 7. Johnson splits this into two, focusing first on the main systems that will be needed on a robotic spacecraft, before adding in the additional complexities of a crewed vehicle.

An uncrewed robotic probe will need four main systems. First, it needs a source of power that will work for decades, if not centuries, when it's in deep space, well away from the Sun. Second, it will need to be able to communicate with the Earth, both during the journey and, most importantly, when it is sending back its scientific data after reaching its destination. Given the distances involved, this will be a major challenge. Third, the probe needs to be able to navigate accurately to its destination. And fourth, it will need to be protected against the various forms of radiation that it will encounter on the journey. Finally, for the robotic probe, all of these systems will need to function reliably for the entirety of the journey if it is to be able to complete its mission on arrival. Given the time periods involved, that will be a huge engineering challenge.

Once you start to consider a crewed interstellar mission, everything gets even more difficult. i4is colleagues will be pleased to note that much of what follows has been adapted by Johnson from the worldship papers that have been published in JBIS, *Acta Futura* and elsewhere by our Executive Director, Professor Andreas Hein and his collaborators. A further three systems are likely to be vital to a crewed mission. The first and most obvious is life support, where the developments in closed-loop environmental control and life support systems on the International Space Station are reasonably encouraging, although much more remains to be done. Second is artificial gravity, most easily produced through a rotating ship, as a means to reduce or avoid the many health problems caused by extended exposure to a microgravity environment. And third is 3D printing, a technology which Johnson sees as likely to be a game-changer in terms of the reliability of a crewed vessel.

I really enjoyed reading Chapter 7. It's good to put propulsion – the topic that normally gets the lion's share of time and attention in interstellar discussions – to one side, and focus for a while on all the other issues that will need to be addressed if a mission is to be successful.

Chapter 8: Scientific Speculation and Science Fiction

The final chapter of the book moves beyond the current state of knowledge, and considers the more speculative options that have been put forward, most frequently in science fiction. As a physicist, Johnson chooses to split these ideas into two categories: those that are fictional, but based on real science, and those that involve inventing your own science. Unsurprisingly, he has more time for the former than the latter.

Chapter 8 includes interesting discussions of many ideas, including *Star Trek*'s warp drive, the hyperdrive from *Star Wars*, and other ways of travelling faster than the speed of light, including 'jump drives' and 'traversable wormholes'. Johnson then looks at the fictional technologies associated with travelling slower than the speed of light, including worldships, and briefly considers space drives (such as the *Em Drive*) that would allow rapid travel, generally by breaking one or other of the laws of conservation of energy or momentum. Next, he looks at the technologies that might support a long duration crewed mission, such as suspended animation. And he ends with some observations on what life might be like for the crew when they arrive at their destination, as well as considering what, if any, alien lifeforms they might encounter, should their destination be a habitable one. In both cases, he makes the important point that we should probably not base our speculations on the majority of science fiction TV shows and films, which generally show alien planets with similar environmental conditions to Earth (including the same strength of gravity), and whose aliens are mostly humanoid (often looking remarkably like actors in makeup and costumes). The reality, for both the human crew and for any alien lifeforms they might meet, are likely to be far different.

This final chapter provides a fascinatingly different set of issues for readers to think about, compared to the more scientifically rigorous ones discussed earlier in the book. It's good to see these more speculative ideas being considered through a scientific lens, particularly after the reader has been exposed to the rest of the book. I'm sure that it will help those new to the interstellar discussion to have a better understanding of why the extremely elegant and seemingly logical approaches to flight between the stars that we find in books, in movies and on TV, are unlikely to work in reality. That is, unless there's a revolution in our understanding of how the universe works. (Here's hoping – it might make our job a lot easier!)

Epilogue

The book concludes with a short epilogue, suggesting that although there's a huge gap between where spaceflight is now and where it will need to get to if we are to achieve an interstellar future, it's never too early to start the planning and research. It's a view that I think all of us at i4is would echo, and a suitable rallying cry for recruiting the next generation of interstellar pioneers.

Conclusion

Les Johnson has, in my view, done all of us in the interstellar exploration community a great service. Next time a friend, relative or work colleague expresses interest in this unusual hobby of yours, I suggest you buy them a copy of Johnson's book. It should help them to understand not only why a journey to the stars is more than just a pipe dream, but also how such a journey may one day be achieved.

Book Review: Contact with Extraterrestrial Intelligence and Human Law

The Applicability of Rules of War and Human Rights

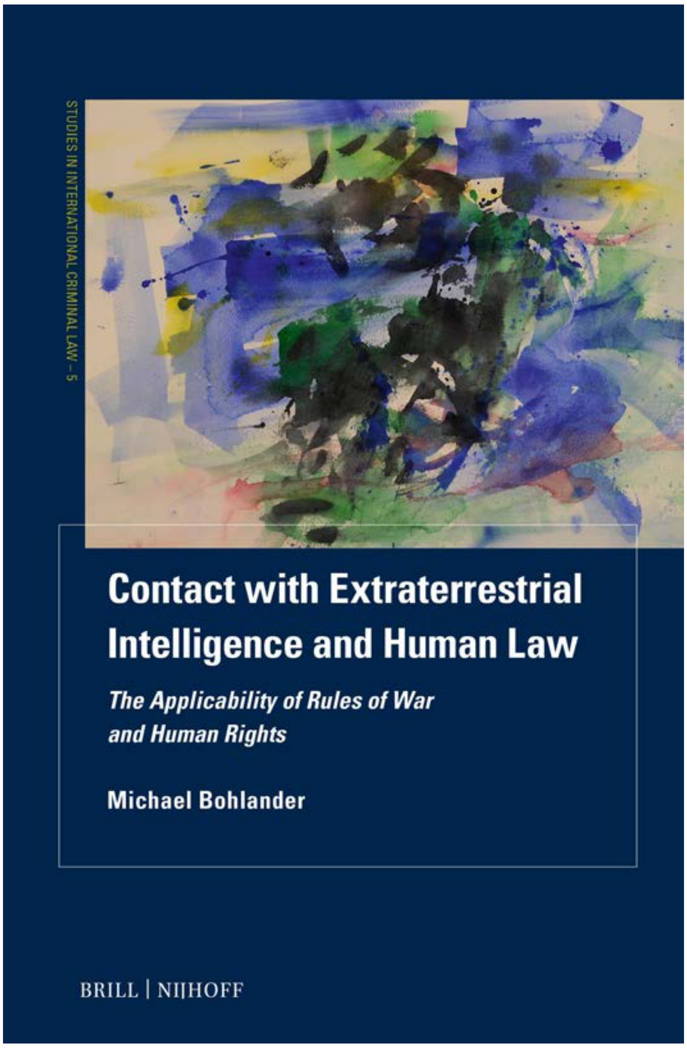
Michael Bohlander

Reviewed by Ketevani Gamtkitsulashvili and Bharati Manukonda

The application of terrestrial law to near-Earth space and even the Solar system has been the subject of much examination. However the larger context of how to deal with Extraterrestrial Intelligence has been less discussed (in Principium, see six pieces by Max Daniels [1]).

i4is became aware of the work of Professor Michael Bohlander in late 2023 and he kindly provided access to his book (www.durham.ac.uk/departments/academic/law/news-and-events/news/2023/september/contact-with-extraterrestrial-intelligence-and-human-law-/) via his publisher, Brill (brill.com). Professor Bohlander is Chair in Global Law and SETI Policy in the Durham Law School (www.durham.ac.uk/staff/michael-bohlander/).

Ketevani Gamtkitsulashvili and Bharati Manukonda of KCL Space, Space Law Group (www.kclspace.com), have contributed this review of the book for Principium - page references are to the current Brill edition.



[1] *Territory in Outer Space*, Principium 24 February 2019, *The Artemis Accords: what comes after the Moon?* Principium 32 February 2021, *Finding new ways to share resources in space* Principium 37 May 2022, *Book Review: Freedom in outer space* Principium 39 November 2022, *IRG 23: Constraints on Interstellar Sovereignty* Principium 43 November 2023, *IRG 23: 'Metropolis' Revisited…and Coming: a summary* Principium 44 February 2024. All by Max Daniels.

Approach

The book examines the complexities of how the human race might navigate interactions with Extraterrestrial Intelligence (ETI). The author addresses this question while acknowledging our limited understanding of ETI, considering aspects such as their physical form, intelligence, and motivations. To bridge this knowledge gap, the author draws on examples from various media sources and science fiction literature, dissecting fictional interactions between humans and alien species.

The interaction that the book is focusing on is between Extraterrestrial Intelligence and Human Law. In this interaction, there are two main actors: ETI and humans. To examine what form this interaction will take, the author examines how each side would react to it. To do so the author relies on historical analysis, science fiction, and existing domestic and international legal frameworks.

The examples from science fiction serve as a canvas for the author to explore the potential forms ETI might assume and the diverse motivations that could drive their interactions with humans. Moreover, they provide an insightful backdrop to scrutinise human reactions to these hypothetical scenarios. Despite the effectiveness of this approach in shedding light on ETI from various perspectives, the author acknowledges a crucial point – these imaginative works remain products of human creativity. It is important to remember that while human imagination may seem boundless, there exists the possibility of encountering a reality vastly different from our imaginings.

Nevertheless, these imaginative scenarios lay a robust foundation for the author's subsequent discussion on the role of human-made laws in such circumstances, probing into the legal implications within the framework of current international laws. The book uses an interesting strategy by introducing science fiction literature in a preceding chapter, leveraging these narratives to formulate hypotheses about potential forms of alien invasion and how the international community might respond.

In essence, the book not only offers an engaging exploration of the speculative aspects of human-ETI interactions but also strategically integrates science fiction as a conceptual tool to propel discussions on the legal dimensions of these encounters. This approach offers a fascinating glimpse into how humanity might react to different scenarios, recognizing the limitations of human knowledge about the true nature of potential extraterrestrial entities.

Theoretical Scenarios

In the realm of science fiction, alien species often mirror human tendencies, such as the notion of extraterrestrial entities discovering Earth and initiating colonisation (as demonstrated in the youth literature trilogy, The Tripods) (p 77). However, given the inherent uncertainty in comprehending alien species, it becomes crucial not to directly attribute human-like behaviours, whether positive or negative, to them. It is important to recognize that the current understanding of SETI is constrained by human creativity rather than factual knowledge. Nevertheless, by observing human behaviour throughout history, we gain solid evidence upon which assumptions can be made regarding the roles humans might play in interactions with the unknown.

Science fiction serves as a valuable tool in exploring potential scenarios of human-ETI interaction. However, it is important to, in parallel, examine how the international community and the human race have influenced the development of international laws and established customary norms to regulate interstate relations. By considering both fictional narratives and real-world legal frameworks, a more comprehensive understanding of the complexities surrounding human-ETI encounters can be attained.

This exploration provides insights into how individuals from diverse backgrounds overcome their differences and form a system where they can coexist. Scrutinising historical examples offers valuable insights into how humans react to novel circumstances and this analysis provides a solid foundation for speculating on the role that humans will play in these interactions.

International law

The examination of international humanitarian law (IHL) in the context of potential hostilities with ETI adds another dimension to the book. The exploration of how existing laws might apply to interactions with non-human entities challenges conventional legal thinking and prompts readers to consider the adaptability of international law to unprecedented scenarios. Currently, nations are bolstering their defensive capabilities to encompass space due to the escalating threat posed by other states. This underscores the ongoing trend of human-driven inter-state conflict and competition, now extending its reach into space. A notable example of this trend is the establishment of the United States Space Force, a new branch of the US Armed Forces primarily tasked with addressing issues such as cyber-attacks and satellite interferences (p 142). The creation of this branch highlights that the primary source of threats faced by humanity remains other humans, with the scale of conflict expanding to include space as a new frontier. The author utilises these examples to explore the improved defensive stances the states could take against potential hostile ETI.

The Lack of Preparation from the International Community

In his comprehensive analysis, the author highlights the lack of preparedness in the existing legal frameworks when confronting the possibility of contact with ETI. However, the author also sheds light on recent policy advancements aimed at addressing the challenges posed by the SETI and existing post-detection disclosure protocols. The author starts his examination with Rio and San Marino scales (p39), pivotal frameworks designed to quantify and assess the significance of detected evidence of ETI. While the Rio scale focuses on the impact of various contact scenarios, the San Marino scale evaluates the potential consequences of active SETI transmissions. These frameworks, along with others like the SETI Protocol II (p42) and the DISC Quotient Model (p45), are instrumental in managing new evidence and estimating how well it will be received by governments, scientists, or society. Despite their importance in assessing the risk associated with first contact, these protocols often lack clear directives on how the international community should proceed when faced with high-risk evidence of extraterrestrial intelligence.

The author of this book argues that existing laws and precedents are insufficient to handle scenarios involving contact with Extraterrestrial Intelligence (ETI). Highlighting the inadequacy of relying on current legal frameworks, the author demonstrates the strategic and technological vulnerabilities that render humanity unprepared to defend or manage the planet in the event of such contact.

The book delves into the critical discourse surrounding the need for comprehensive laws governing contact with ETI. It initiates a crucial conversation about the necessity of establishing international laws and regulations within the realm of space law, addressing the unique challenges posed by potential encounters with extraterrestrial entities. The author argues convincingly for proactive measures, emphasising the imperative of preparedness in the face of the potentially existential risks associated with contact with ETI.

The Perceived Lack of Urgency of the Issue

The author states, "There is currently no binding legal framework regarding SETI," (p61) delving into the rationale behind this absence. The dearth of an international legal framework for the Search for Extraterrestrial Intelligence (SETI) is largely attributed to a prevailing scepticism about the imminent materialisation of this issue.

The author goes on to advocate for a treaty to regulate SETI, contending that while it would make eminent sense, many states may lack interest in preparing for a scenario perceived as unlikely to occur soon. Moreover, the author suggests that diverting resources from more pressing United Nations (UN) activities might hinder international engagement. Concerns are raised about the dominance of a few spacefaring states in treaty development, posing a risk of insufficient ratifications.

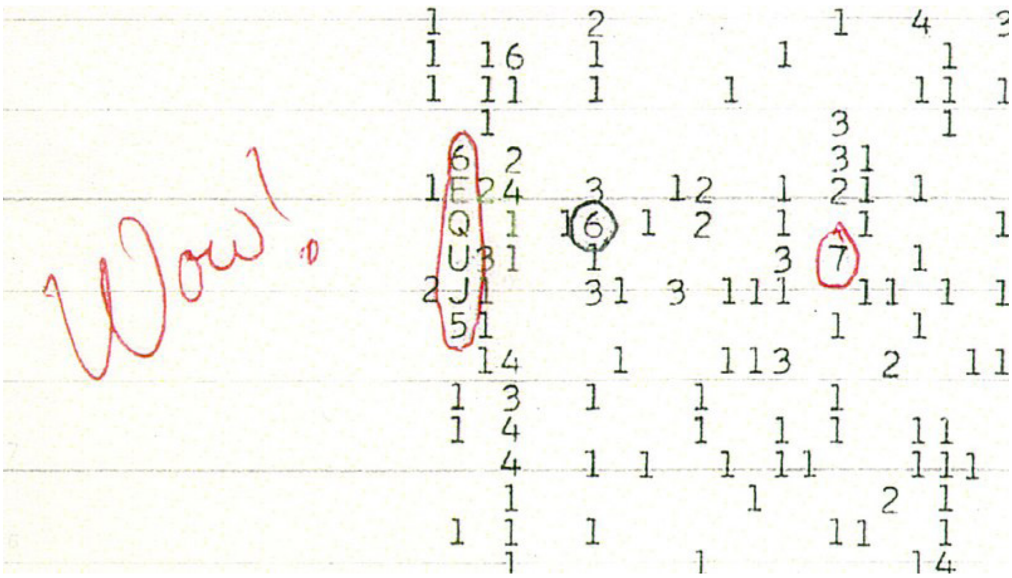
Despite these challenges, the author underscores the observance of SETI protocols in practice, citing confirmation from a member of the European Space Agency (ESA). The author proposes "soft law" alternatives, such as non-binding declarations or resolutions by the UN General Assembly, as more feasible pathways to international consensus. The argument is framed within the context of the potentially remote chances of contact with extraterrestrial beings, juxtaposed against the profound risks and impacts such an encounter could pose to the human species.

Central to the author's thesis is the overwhelming impact and far-reaching consequences that a hostile contact with ETI could result in for the human species. This scale of potential repercussions becomes a rallying point for the author's call to action, urging international actors to prioritise preparedness under such extraordinary circumstances.

One of the book's notable discussions revolves around the potential negotiability of international human rights laws in the event of contact with ETI. The author navigates this complex terrain, examining the adaptability and flexibility of established human rights frameworks in the face of unprecedented challenges posed by interactions with extraterrestrial beings.

Conclusion

In conclusion, this book provides a thought-provoking exploration of the challenges and implications surrounding human interactions with Extraterrestrial Intelligence (ETI). By examining the intersection of science fiction, real-world legal frameworks, and international cooperation, the author highlights the need for proactive measures to address the profound uncertainties of potential ETI contact. The book underscores the importance of humility in acknowledging our limited understanding of ETI and advocates for the establishment of comprehensive legal frameworks to govern such interactions. Ultimately, it serves as a compelling call to action for policymakers and the international community to prioritise preparedness and proactive engagement in navigating the complexities of Extraterrestrial Intelligence.



The "Wow!" signal (1977) - probably the nearest to a plausible ETI communication yet received - and still under discussion [1].
Credit: Big Ear Radio Observatory and North American AstroPhysical Observatory (NAAPO).

[1] For example: *Could the 'Wow' signal have originated from a stochastic repeating beacon?* Monthly Notices of the Royal Astronomical Society, Volume 515, Issue 1, September 2022 academic.oup.com/mnras/article-pdf/515/1/1122/45032327/stac1807.pdf, See also Google Scholar search: Kraus J. , 1979 , CosSe , 1 , 31

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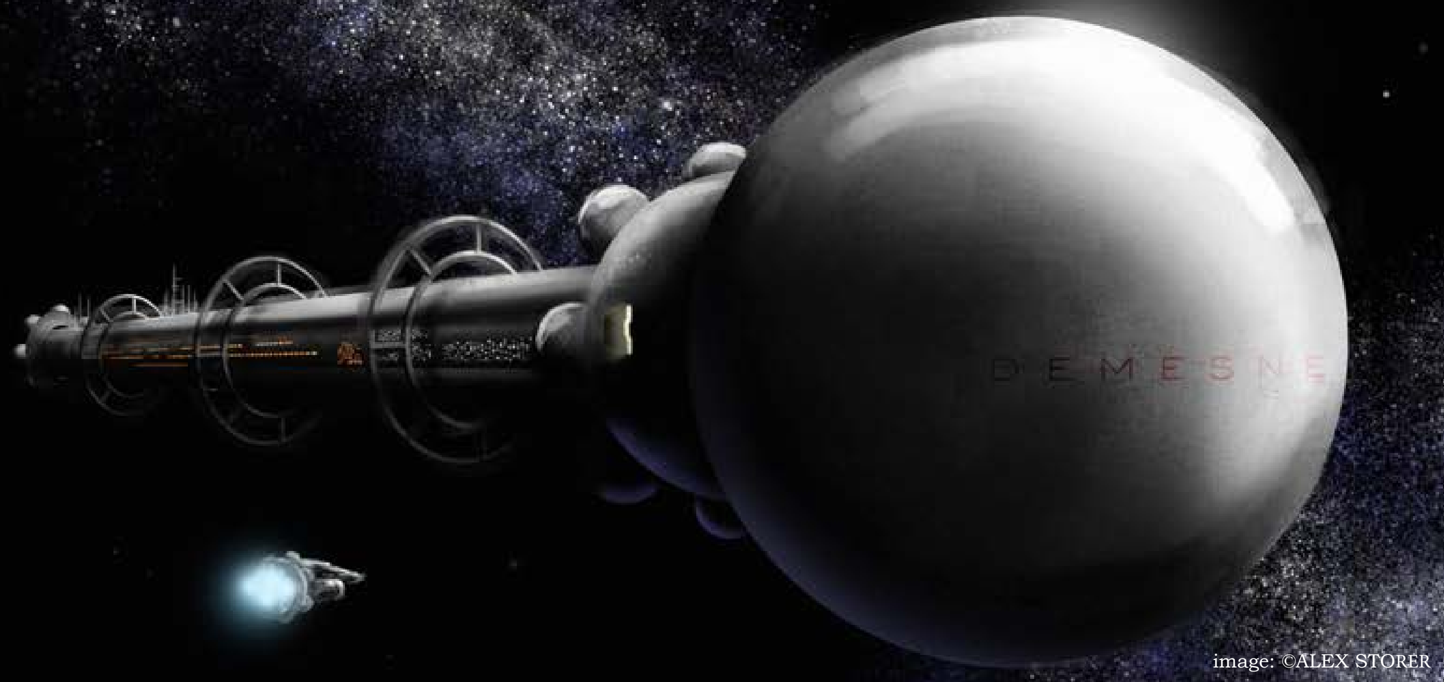

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INTERSTELLAR NEWS

Parnika Singh reports on recent developments in interstellar studies

First European Interstellar Symposium

The University of Luxembourg's First European Interstellar Symposium will take place in December 2024, with the IRG's input and guidance [1]. The Symposium and an Interstellar Art Show will be held at the European Convention Center in Luxembourg City, Luxembourg. This symposium will feature many of the leading voices in space exploration, culture, and more.

The theme for the event is *Building Our Home Among the Stars*. Thus, there will be a particular focus on potential near-term demonstrations and missions that align with the technologies and systems required for future interstellar travel. This European Interstellar Symposium aims to bring together a multi-disciplinary community dedicated to interstellar travel, and all interested parties are welcome to submit abstracts of their papers related to interstellar travel. More information can be found on the IRG website.

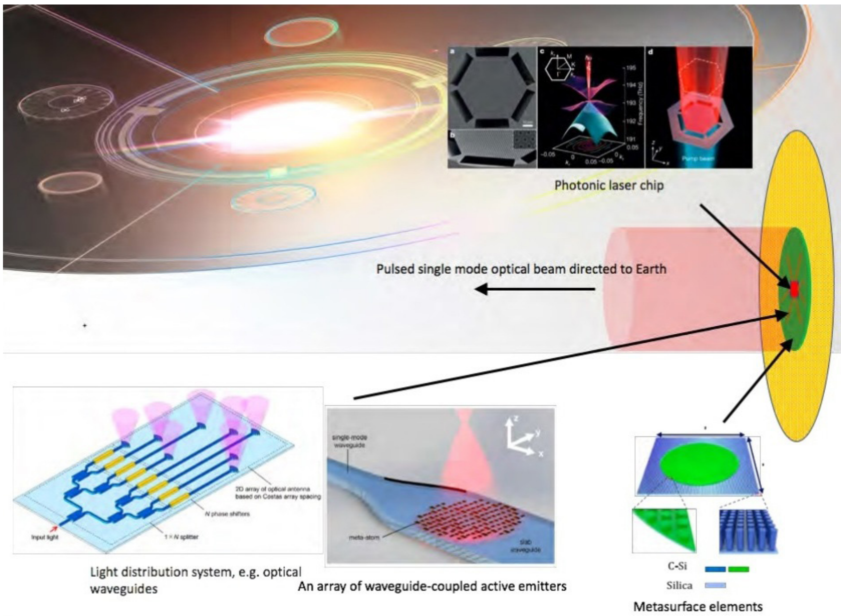
Interstellar Radioisotope and Modular Architecture

A recent paper by Christina M Decker et al titled *Interstellar Radioisotope and Modular Architecture (IRMA)* [2] explores a conceptual mission with the idea of venturing out into interstellar space. The primary mission would essentially begin past the Kuiper Belt, at the frontiers where Voyager missions are going to conclude around the year 2025. The primary objective is to confirm and improve the data analysis collected by each Voyager spacecraft, whilst utilizing newly developed equipment, such as CubeSats, and using pieces of the original Voyager equipment for inspiration. Two spacecraft (IRMA I and II) are expected to be programmed to investigate the Shapiro Time Delay test, which is crucial in accurately determining the distance to planetary probes, alongside Voyager's primary objectives of exploring Jupiter and Saturn. The secondary objectives of the mission focus on investigating the unsolved problems in astrophysics. They include Kuiper Cliff analysis, flyby anomaly investigation, the study of ultra-high energy cosmic rays, the investigation of the heliosphere and heliopause, and finally the discovery of the potential Planet 9.

Developing a Low-Mass Interstellar Communications System

In *SPIE Proceedings: Technology Development for a Low-Mass Interstellar Communications System*. many researchers – including i4is's Space Initiative partner T Marshall Eubanks, and i4is's own Andreas M Hein, Adam Hibberd and Robert G Kennedy III – explore the requirements and associated technology development plan for the communications data link from low mass interstellar probes [3]. This work is motivated by several proposed deep-space and interstellar missions, with an emphasis on the Breakthrough Starshot project. The Starshot project is an effort to send the first low-mass interstellar probes to nearby star systems and transmit back scientific data acquired within the time scale of a human lifetime.

[1] irg.space/first-european-interstellar-symposium/
[2] arc.aiaa.org/doi/10.2514/6.2024-1151
[3] www.researchgate.net/publication/378909992_Technology_development_for_a_low-mass_solar_system_and_interstellar_communications_system



Components of the on-board transmitter system include:
i) a signal source such as a high peak power photonic chip laser (eg top insert),
ii) a signal distribution system such as low profile free space optics or a network of optical waveguides integrated into the sailcraft (eg bottom left insert) and
iii) a high filling factor phase control metasurface (eg bottom right).
Credit: Mauskopf et al Figure 2.

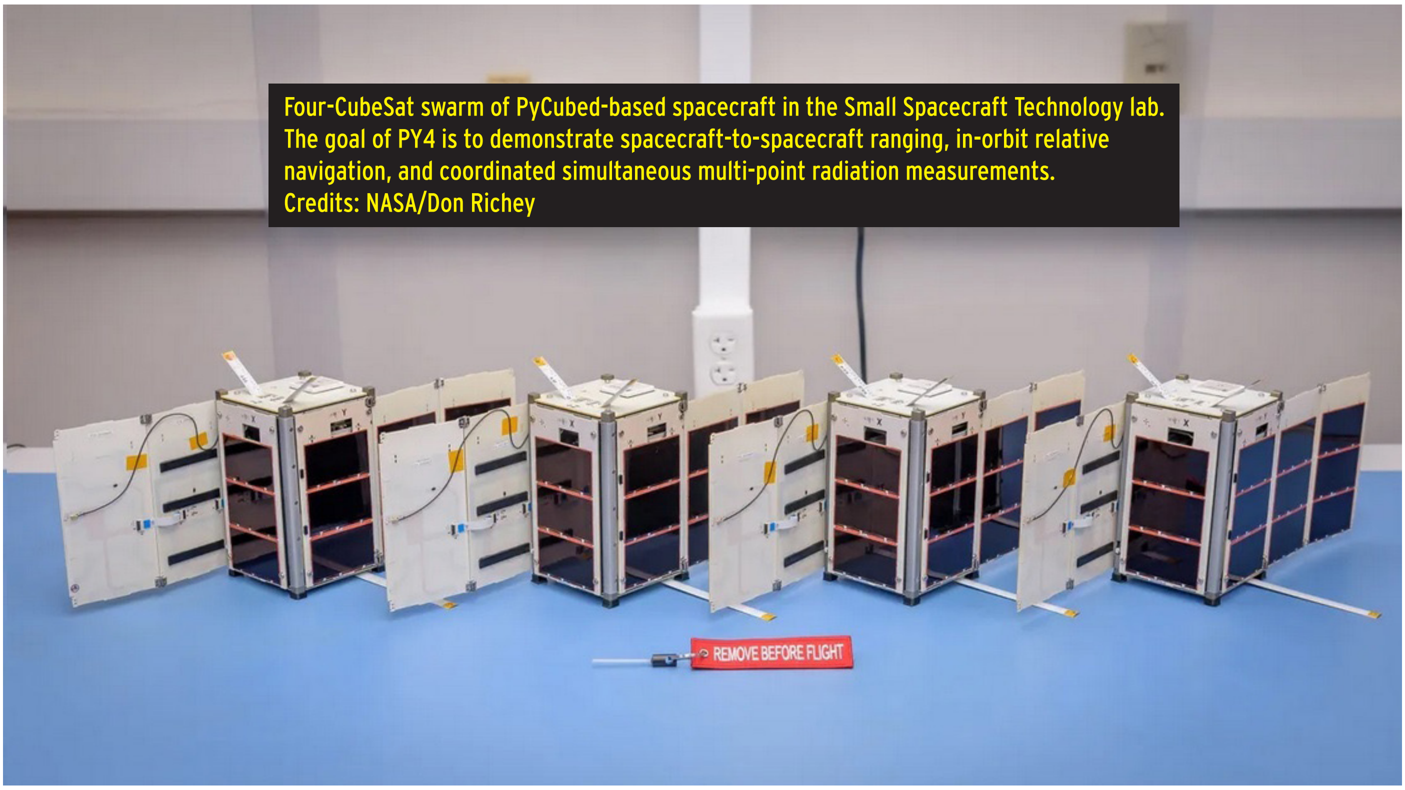
The paper provides a comparison of the communications systems in current and upcoming solar system probes – New Horizons and Psyche – against the requirements for Starshot and defines "Figures of Merit" for the communications capability in terms of data downlink rate per unit mass and unit transmitted power. It also describes current and future technology developments required for the onboard attitude control and signal transmission systems and for the near-Earth communications receiver, including a roadmap for technology development to meet the goals for future interstellar communications.

NASA to Demonstrate Miniature CubeSat Swarm Technology

NASA has deployed a mission that will test cost-efficient spacecraft swarm technology. The mission, called PY4, sent four CubeSats to low Earth orbit aboard SpaceX's Transporter-10 mission [1]. PY4 seeks to demonstrate spacecraft-to-spacecraft ranging, in-orbit navigation, and coordinated simultaneous multi-point radiation measurements at low size, weight, power, and cost. It uses a unique avionics platform called PyCubed that integrates power, computing, communications, attitude determination, and orbit control functionalities into a single board system. The PyCubed system is also open-source, programmable entirely in the Python programming language, and uses affordable commercial off-the-shelf components.

On Nov 8, 2023, Max Holliday, creator and maintainer of the PyCubed avionics platform, prepares one of the four PY4 spacecraft for installation into the dispenser supplied by Maverick Space Systems ahead of vibration testing.
Credits: NASA/Don Richey

[1] www.nasa.gov/directorates/stmd/small-spacecraft-technology-program/nasa-to-demonstrate-miniature-cubesat-swarm-technology/



Four-CubeSat swarm of PyCubed-based spacecraft in the Small Spacecraft Technology lab. The goal of PY4 is to demonstrate spacecraft-to-spacecraft ranging, in-orbit relative navigation, and coordinated simultaneous multi-point radiation measurements. Credits: NASA/Don Richey

In addition to the PY4 demonstration, NASA is also testing critical swarming technologies via the agency's ongoing Starling mission that launched in 2023. PY4 could dramatically reduce the cost of small spacecraft swarming capabilities and make demonstrating technologies like the autonomous navigation system tested via Starlink more widely accessible by offering a flight-ready hardware and software platform. This could then also be applied to Marshall Eubank's recent proposal with i4is of sending a swarm of laser-powered lightsail spacecraft to our nearest star system, Proxima Centauri.

Stories from Space: Swarming Proxima Centauri

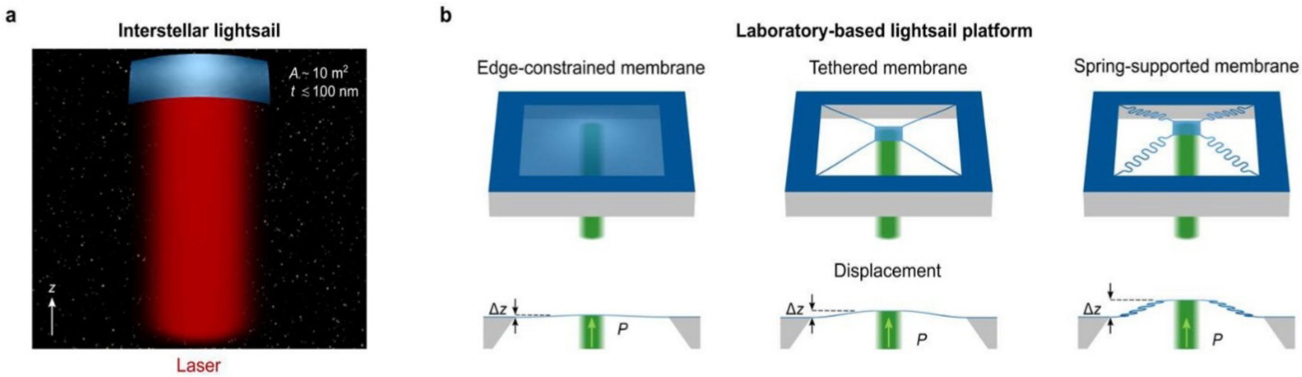
In this podcast episode, Marshall Eubanks - our Space Initiatives partner - discusses how his Swarming Proxima Centauri mission concept was awarded the phase one development grant from NASA as part of the NASA Innovative Advanced Concepts Program [1]. He discusses the necessity of laser beam propulsion for future space missions, as we near the limits of what may be accomplished through chemical rockets. He explains the swarm proposal in detail and the exciting possibility of life on Proxima b. He also discusses much of his work with other i4is related projects - such as Project Lyra and Project Dragonfly.
It is interesting to note that creating the small spacecraft that would be used for such a mission will likely be quite cheap, as they only weigh a few grams. The bulk of the cost would lie in building the laser, however, the laser could ger reused for multiple different missions, helping to justify the cost.

[1] Transcript at: storiesfromspace.simplecast.com/episodes/swarming-proxima-centauri-a-conversation-with-marshall-eubanks-stories-from-space-podcast-with-matthew-s-williams/transcript
[2] Michaeli et al arxiv.org/abs/2403.00117

Measuring Lightsail Membranes

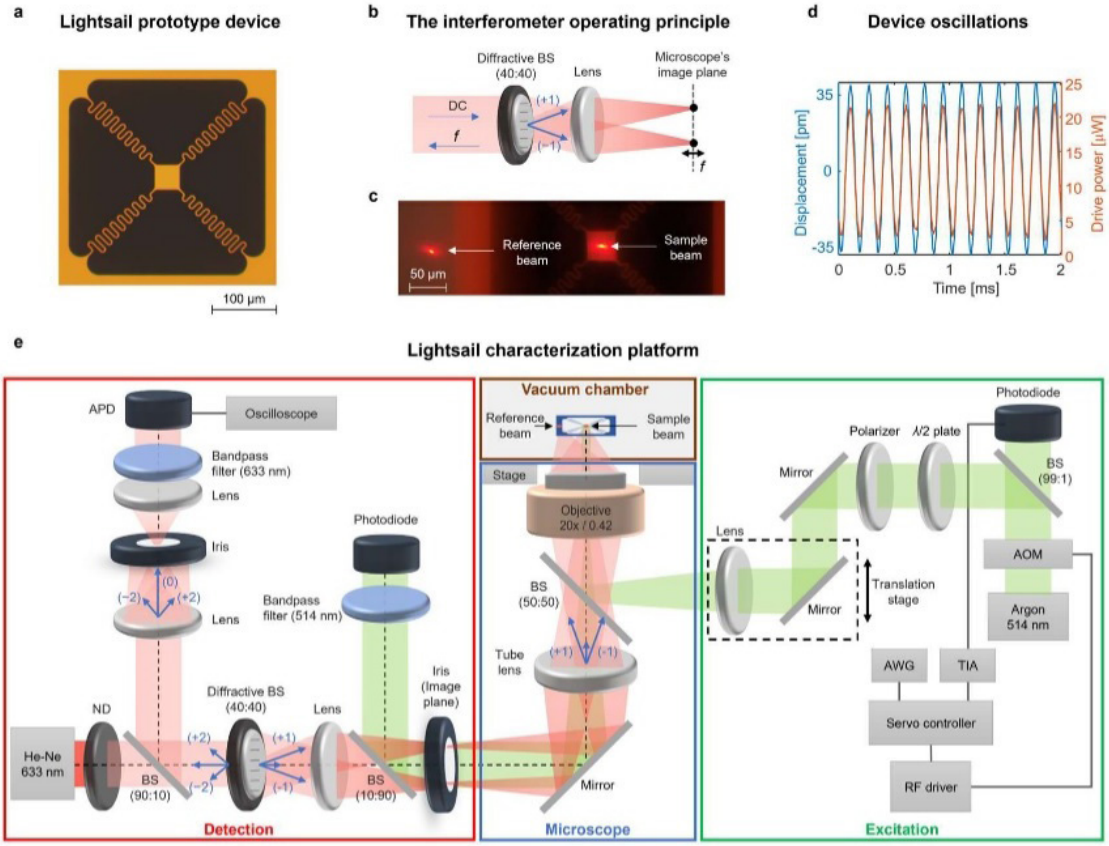
Ultrathin lightsails propelled by laser radiation pressure to relativistic speeds are currently the most promising route for flyby-based exoplanet exploration. However, a recent paper, Direct Radiation Pressure Measurements for Lightsail Membranes, by Lior Michaeli et al discusses the notable lack of experimental characterization of key parameters essential for lightsail propulsion [1]. Therefore, a model platform for optomechanical characterization of lightsail prototypes made from realistic materials is needed – which this paper works to fulfill (see diagram on next page).

The paper's model simultaneously measures the optical forces and driving powers, which capitalizes on the multiphysics dynamics induced by the driving laser beam. By modelling the lightsail with a 50 nm thick silicon nitride membrane suspended by compliant micromechanical springs, the paper quantifies force from off-resonantly driven displacement and power from heating-induced mechanical mode softening. As lightsails will inevitably experience non-normal forces, the paper also quantifies the effects of incidence angle and spot size on the optical force and explains the non-intuitive trend discovered by edge scattering. The paper's findings stress the need for a self-stabilizing mechanism to support the sail during flight.



From interstellar lightsails to laboratory-based lightsail platforms.
a, Concept of laser-propelled interstellar lightsail of 10 m^2 in area and 100 nm or less in thickness.
b, Laboratory-based lightsail platforms relying on edge-constrained silicon nitride membranes (left), linearly tethered membranes (middle) and spring-supported membranes (right).
Removing the edge constraint allows to decouple the effects of optical force and membrane deformation, model lightsail dynamics, and study optical scattering from the edges. Suspending lightsails by compliant serpentine springs rather than linear tethers significantly increases its mechanical susceptibility to laser radiation pressure of the same power P, resulting in larger out-of-plane displacement Δz for more precise detection.
Credit: Michaeli et al, Fig 1

[1] Michaeli et al arxiv.org/abs/2403.00117



Lightsail prototype device and experimental characterization platform.
a. Microscope image of the fabricated 50 nm-thick lightsail prototype device based on a spring-supported silicon nitride membrane.
b. The operating principle of the common-path interferometer with high immunity to ambient noise. The unmodulated (DC) probe laser beam is split into two beams (-1 and +1) using a diffractive beam splitter (DBS) and subsequently focused onto the microscope's image plane. This results in two closely spaced, nearly diffraction-limited spots, with one positioned on the pad and the other on a reference area (silicon nitride on silicon substrate). The reflected laser beam undergoes phase modulation corresponding to the pad's out-of-plane motion at frequency f.
c. Microscope image of the detection and reference beams on the sample plane.
d. Measured time-resolved pad displacement bandpass-filtered around the drive frequency. The motion is in phase with the incident drive signal, confirming operation in the quasi-static regime.
e. The experimental setup comprises three parts: an excitation path with a pump laser beam from an Ar-ion laser (514 nm) modulated in intensity using feedback-controlled acousto-optic modulator (AOM), a detection path based on a common-path interferometer with a probe laser beam from a stabilized He-Ne laser (633 nm), and a vacuum stage with ultra-high vacuum (5×10^{-9} mbar) on an inverted microscope platform containing the lightsail prototype. The drive frequency is set to 4 kHz, below the fundamental resonance of the lightsail at 9.4 kHz. Collimation of the excitation beam on the pad is achieved by focusing the beam onto the back-focal plane of the objective, with its incidence angle controlled by a linear translation stage.
Credit: Michaeli et al Fig. 3

Berkeley Low-cost Interplanetary Solar Sail Project

In *BLISS: Interplanetary Exploration with Swarms of Low-Cost Spacecraft*, Alexander N Alvara et al propose a fleet of autonomous, low-cost, small solar sails for interplanetary exploration in a venture named the Berkeley Low-cost Interplanetary Solar Sail (BLISS) project [1]. The undertaking aims to utilize small-scale technologies to create a fleet of tiny interplanetary femto-spacecraft for rapid, low-cost exploration of the inner solar system. This paper describes the specific hardware required to build a ~10 g spacecraft using a 1 m^2 solar sail steered by micro-electromechanical systems (MEMS) inchworm actuators. The trajectory control to a near-earth object, 101955 Bennu, is detailed along with the low-level actuation control of the solar sail and the specifications of proposed onboard communication and computation. Two other applications are also shortly considered: sample return from dozens of Jupiter-family comets and interstellar comet rendezvous and imaging. The paper concludes by discussing the fundamental scaling limits and future directions for steerable autonomous miniature solar sails with onboard custom computers and sensors.

Exiting the Heliosphere

In *Deep Space Trajectories: Exiting the Heliosphere*, Paul Gilster of Centauri Dreams discusses the challenges associated with spacecraft exiting the heliosphere and traversing through interstellar space [2]. Given that our knowledge of the realm beyond the heliosphere is almost entirely the result of remote sensing and indirect measurements, having an actual spacecraft on the scene would take us far beyond our modelling and involve a host of unpredictable issues. Thus, to accomplish an interstellar mission, we must first learn more about our own heliosphere. However, currently, predicting its effects, and even more significantly its shape and size over time, is all but impossible. Small variations in model parameters and properties measured in the heliosphere lead to significant differences in the projected shape. The shape and size of the heliosphere is additionally expected to fluctuate with solar activity and therefore solar cycle, further adding a level of unpredictability.

To facilitate mission planning, we must continue indirect measurements of the outer heliosphere, emphasizing the heliotail, and measurements of interstellar ions that penetrate the heliosphere, including cosmic rays in the heliotail region. For the in-situ measurements, the largest differences between the suggested shapes of the heliosphere would appear in the tail region. Our probe would thus do its best to exit through the side of the heliosphere's tail.

Ethics of Interstellar Travel

In the recent paper *Toward the Stars: Technological, Ethical, and Sociopolitical Dimensions of Interstellar Exploration*, Florian Neukart explores the multifaceted aspects of interstellar travel – from technology, to ethics, to cultural significance [3]. Although the technological side of interstellar travel tends to get the most attention, it is important to recognize that the endeavour of interstellar exploration is a convergence of technical innovation and profound ethical inquiry, challenging humanity to extend its reach beyond the confines of our solar system while contemplating the moral implications of such a leap.

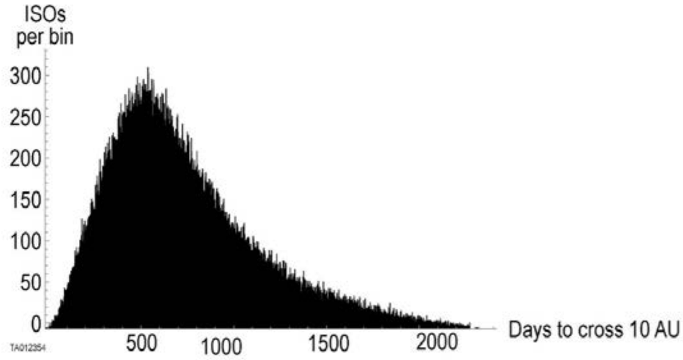
Following the introduction, it reviews the current technology state and theoretical frameworks underpinning interstellar travel in the Technical Foundations section. It then proceeds to the section on Ethical Considerations, examining the moral dilemmas posed by extending human presence beyond Earth or interacting with alien life forms. The Sociopolitical Implications section explores the governance and societal impacts of space colonization – including robotic colonization. In contrast, Philosophical and Evolutionary Perspectives elaborates on the existential questions and potential evolutionary trajectories for space exploration. Finally, the conclusion discusses the challenges and opportunities that lie ahead, asserting the importance of ethical stewardship and innovative thinking in navigating humanity's future among the stars.

[1] Acta Astronautica, Volume 215, February 2024 www.sciencedirect.com/science/article/abs/pii/S0094576523005969
Open access arxiv.org/abs/2307.11226
[2] www.centauri-dreams.org/2024/04/03/deep-space-trajectories-exiting-the-heliosphere/
[3] arxiv.org/abs/2402.15536

Intercepting Interstellar Objects

A recent paper by S Alan Stern et al titled *A study of an interstellar object explorer (IOE) mission* investigates how a space mission to reconnoiter an interstellar object (ISO) moving through our solar system can be designed [1]. It provides a detailed discussion of the scientific objectives and merits of such a mission, namely investigating the early origins of our solar system and others. Thus, the paper also outlines the necessary payload to achieve these goals, including a colour imager, UV spectrometer, and IR mapping spectrometer.

Using simulation software, the paper models the frequency of the occurrence of suitable ISOs and the time available after detection for the creation of a mission. Based on these simulated sets of values, an algorithm is derived for calculating mission trajectories using a storage orbit so the probe would be ready to jump into action as soon as it is feasible. The paper provides a detailed explanation of its decision to use this mission design. Interestingly, the paper finds that the relative intercept velocity of the probes would have to be quite high, at around 100 km/s.

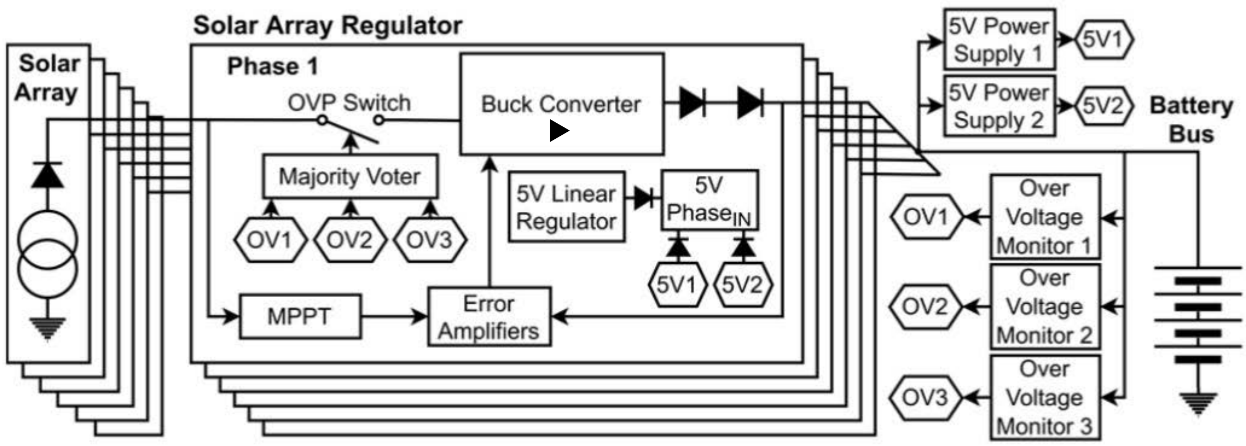


Distribution of time in days for ISOs in this study to cross 10 AU radius sphere centered on the Sun. Vertical axis is the number of ISOs per 1-day bin. This ISO kinematic distribution matches the kinematic distribution of Sun-like stars, biased by the Sun's velocity relative to the Local Standard of Rest. Keplerian Sun-centric trajectories are assumed, ie with no interaction with the planets.
Credit: Stern et al, Fig 1

Solar Arrays in Deep Space

In the paper, *High-Reliability Solar Array Regulator for Deep Space Exploration Micro-Satellites*, author Cristian Torres presents a single-point failure-free solar array regulator design for scientific deep space exploration micro-satellites, where reliability and fault tolerance are critical design aspects [2]. The proposed regulator is composed of six independent dc/dc Buck converters controlled by a double control loop, which can control both the battery end-of-charge voltage if the battery is fully charged, or the power generated by the solar arrays otherwise.

Block diagram of the proposed SAR.
Credit: Torres, Figure 1



[1] www.sciencedirect.com/science/article/pii/S003206332400014X
[2] ieeexplore.ieee.org/abstract/document/10234716

The paper describes the electronic design of the regulator, including a detailed system stability study, as well as the implementation of a 60 W prototype and a thorough overview of the extensive functional tests that have been carried out under different space representative conditions to validate fault tolerance and robustness, as well as their findings supporting the strong performance of this regulator design. Thus, this regulator is a promising technology for future deep space missions.

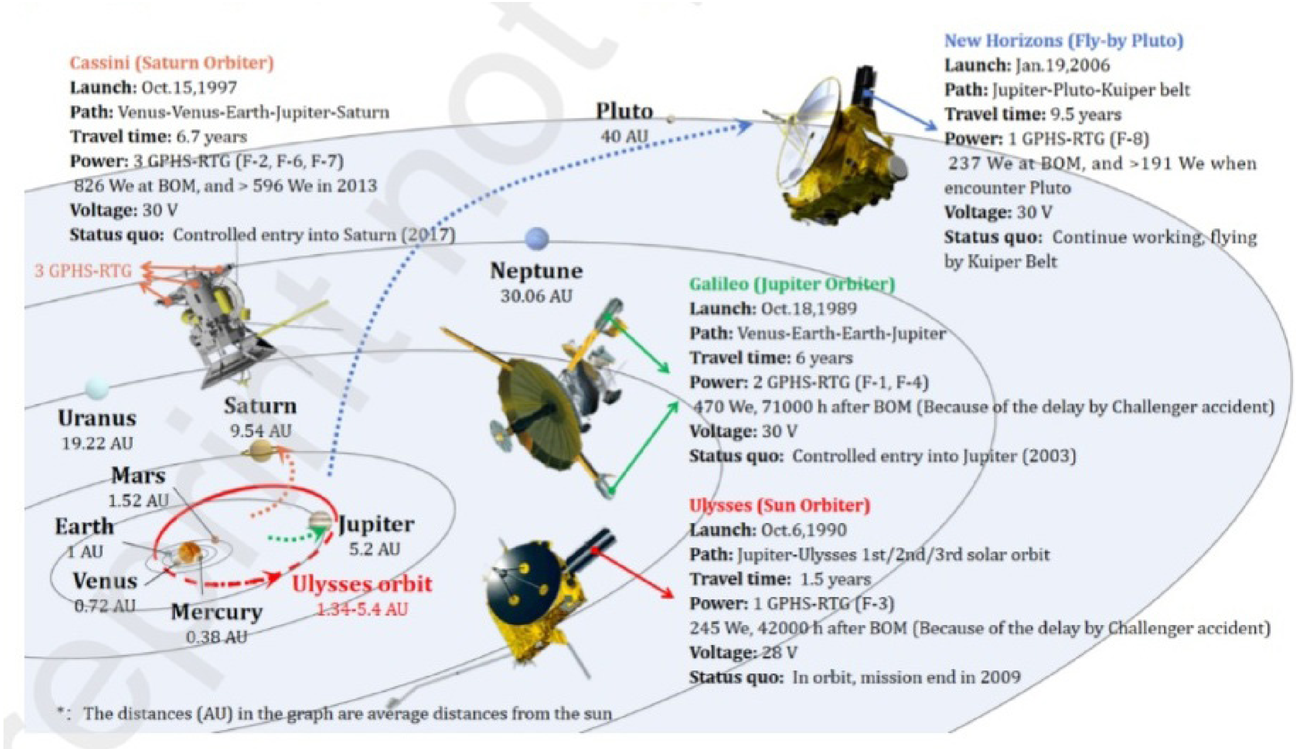
Chasing Down Oumuamua

Cosmos magazine's article *We have a plan to chase down our first known interstellar visitor* authored by Jamie Seidel features 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 has 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 [1]. Moreover, it discusses the orbital mechanics of Project Lyra [2].

Optimizing Solar Sail Trajectories Towards Proxima b

A recent paper by M J Heiligers and T J Rotmans of TU Delft University titled *Photon-Sail Trajectories Towards Exoplanet Proxima b* investigates trajectories within the Alpha Centauri system to reach planet Proxima b [3]. These trajectories come 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) and the classical Lagrange points of the Alpha Centauri C/Proxima b system. The paper seeks these so-called heteroclinic connections using a patched restricted three-body problem method. It applies a genetic algorithm to optimize the linkage conditions between the two three-body systems, focusing on minimizing the position, velocity, and time error at linkage.
The paper then presents and analyzes four different futuristic, graphene-based sail configurations: two sails with a reflective coating on only one side of the sail, and two sails with a reflective coating on both sides. The paper finds that a mission to Proxima b could successfully be completed with a sail with a single-sided reflective coating. However, it finds that the travel time would likely be much longer than the forty-something years mentioned in previous literature.

[1] cosmosmagazine.com/space/astronomy/we-have-a-plan-to-chase-down-our-first-known-interstellar-visitor/
[2] www.youtube.com/watch?v=lCUB_qgDoyA
[3] research.tudelft.nl/en/publications/photon-sail-trajectories-towards-exoplanet-proxima-b
[4] papers.ssrn.com/sol3/papers.cfm?abstract_id=4692116



Information on GPHS-RTG participation in missions. The detailed development and production history of GPHS-RTG in the four missions can be found in Atomic Power in Space II: A history of space nuclear power and propulsion in the United States [1]. ESA Science & Technology - Orbit of Ulysses [2], Galileo - Jupiter Missions - NASA Jet Propulsion Laboratory [3], NASA New Horizons to Continue Exploring Outer Solar System [4], Cassini-Huygens Science - NASA [5]
Credit: Tailin et al Fig I.

Radioisotope Power

In 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*, Li Tailin et al provide a detailed analysis of the GPHS-RTG to determine a conservative safe application range and its performance for solar-system missions and beyond [6]. 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.

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" manoeuvres. Additionally, it was found that the temperature is not uniform in the RTG's thermoelectric arrays because of solar illumination and the thermopile design.

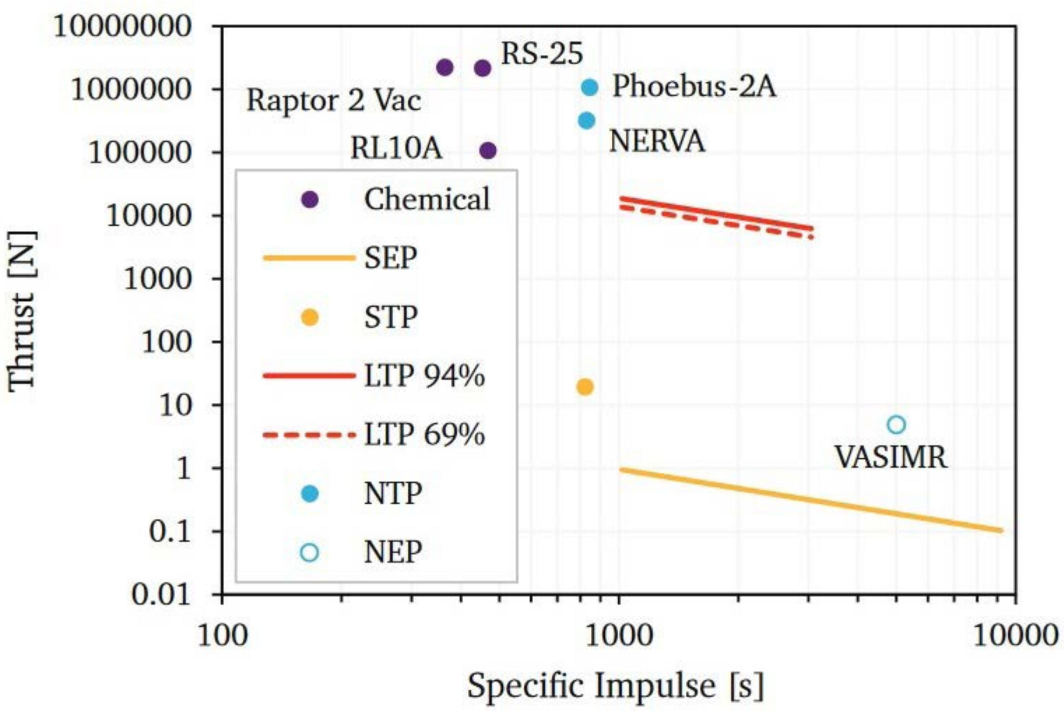
[1] Hula, Greg. www.osti.gov/biblio/1893110
[2] sci.esa.int/web/ulysses/-/42904-orbit-of-ulysses
[3] www.jpl.nasa.gov/missions/galileo
[4] www.nasa.gov/missions/new-horizons/nasas-new-horizons-to-continue-exploring-outer-solar-system/
[5] science.nasa.gov/mission/cassini/?videoID=6
[6] repository.tudelft.nl/islandora/object/uuid:3a853f2e-2d8c-496b-a016-9e9855e8069c

Laser-Thermal Propulsion

Emmanuel Duplay's recently published master's thesis titled Argon Laser-Plasma Thruster: Design and Test of a Laboratory Model provides an overview of the innovative concept of laser-thermal propulsion (LTP) [1].

LTP has potential as a high-specific impulse, high-thrust deep-space propulsion system competing with proposed nuclear-thermal thruster concepts. An LTP system involves a continuous laser which is used to power a laser-sustained plasma core within a thrust chamber. This plasma absorbs laser energy and redistributes it to the propellant gas via conduction and radiation. The heated propellant is then expelled through a high-area ratio nozzle, like any other vacuum-optimized thermal rocket engine.

Although it was first imagined in the 1970s and studied intensively over the following two decades along, LTP faded into the background as laser beam propulsion grew more popular. Thus, while LTP has been tested experimentally before, most studies used old CO_2 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. Through its experiments, it finds that LTP propulsion can achieve high specific impulses, however, cooling the thruster walls is a significant issue. Moreover, achieving ignition consistently is another area for future improvements.



Comparison of various space propulsion systems based on their specific im-pulse and thrust.
References: Chemical, Solar-Electric Propulsion (SEP), Solar-Thermal Propulsion (STP), LTP, NTP, Nuclear-Electric Propulsion 12, 13 (NEP) .
Credit (Image): Duplay Figure 1.1 (Caption): Adapted from Duplay. Further reference links are in the paper.

[1] repository.tudelft.nl/islandora/object/uuid:3a853f2e-2d8c-496b-a016-9e9855e8069c

Superconducting Semi-Cryogenic Fuels for Interstellar Missions

In *A Critical Review on Superconducting Semi-Cryogenic Fuels for Advanced Space Propulsion and Deep Space Missions*, Panta Sasikanth evaluates the potential of superconducting semi-cryogenic fuels as a game-changing approach for spacecraft propulsion [1]. Superconductors, exhibiting zero electrical resistance at low temperatures, offer significant advantages for efficient electromagnetic thrust generation. However, achieving the ultra-low temperatures typically required for superconductivity presents logistical challenges for spacecraft. Thus, semi-cryogenic fuels such as liquid hydrogen and methane can be used instead, enabling operation at more manageable temperatures while leveraging the benefits of superconductivity. Yet these fuels are not without their own challenges, such as boil-off fuel loss. However, there are various mitigation techniques, such as multilayer insulation, 3M glass bubbles, and active cooling systems.

The potential performance gains of superconducting semi-cryogenic propulsion systems include significant weight reduction and improved efficiency. However, critical considerations such as radiation exposure necessitate future research. But superconducting semi-cryogenic fuels offer a promising pathway for advancing deep space exploration.

Should We Wait?

As new concepts of sending interstellar spacecraft to the nearest stars are now being investigated by various research teams, crucial questions about the timing of such a vast financial and labour investment arise. If humanity could build high-speed interstellar lightsails and reach the Alpha Centauri system 20 years after launch, would it be better to wait a few years, then take advantage of further technology improvements to increase the speed, and arrive earlier despite waiting? [2] This question, explored in *Relativistic Generalization of the Incentive Trap of Interstellar Travel with Application to Breakthrough Starshot* by René Heller [3], has sparked an internal debate here at i4is.

The paper mentioned attempts to mathematically calculate whether we should wait or not, based on 211 years of historical data. It finds that the speed growth of human-made vehicles, from steam-driven locomotives to Voyager 1, is much faster than previously believed, about 4.72% annually or a doubling every 15 yr. It thus derives the mathematical framework to calculate the minimum of the wait time (t) plus travel time (tau(t)) and extend two exponential growth law models into the relativistic regime. It finds that there is no use waiting for speed improvements once we can reach an object within about 20 years of travel, irrespective of the actual speed. In terms of speed, the t+tau(t) minimum for travel to Alpha Centauri will occur once 19.6% of the speed of light becomes available, in agreement with the 20% proposed by the Breakthrough Starshot Initiative. If interstellar travel at 20% can be obtained within 45 years from today and if the kinetic energy could be increased at a rate consistent with the historical record, then humans can reach the ten most nearby stars within 100 years from today.

[1] acceleron.org.in/index.php/aaj/article/view/AAJ.11.2106-2414 no open publication
[2] en.wikipedia.org/wiki/Interstellar_travel#Wait_calculation
[3] arxiv.org/abs/1705.01481

Glasgow 24 SF Worldcon

An i4is update

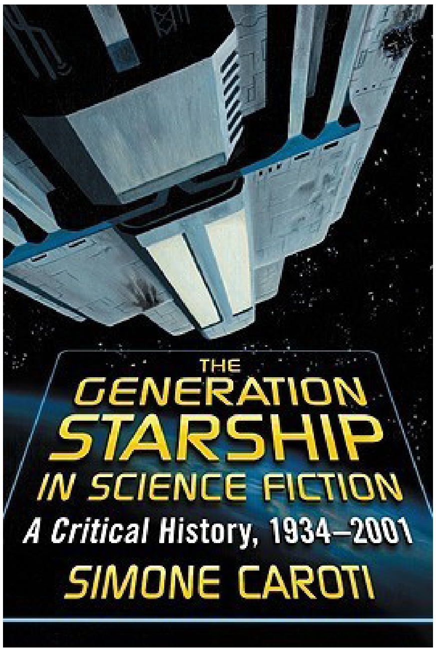
As we announced in our last issue (P44, February) we aim to be very visible at the annual conference of dreamers and creators of dreams which is a Science Fiction Worldcon.

John I Davies

Programme

We have several teams working on this reporting mainly to Gill Norman for the programme, Tam O'Neill for the Big Object (our replica interstellar probe) and John Davies for the exhibition space.

Gill is working with the Con programme team to develop a whole day of presentations and panel sessions. The largest theme will be worldships, driven by Simone Caroti who "wrote the book" *The Generation Starship in Science Fiction: A Critical History, 1934-2001,* Simone Caroti, McFarland & Company 2011.



Simone delivered a lecture, M8-ISR-L10 Worldships in Science Fiction, at the i4is-organised International Space University masters elective 2020 [1]. And we will have a lot more to say about the renewed i4is worldship studies now in preparation.

We will have writers, critics and academics contributing to this and other themes connecting SF and interstellar studies.

i4is banner from 2014 Worldcon

[1] See *News Feature: The 2020 ISU Masters Elective Module: Part 2 of 2* in Principium 31 November 2020

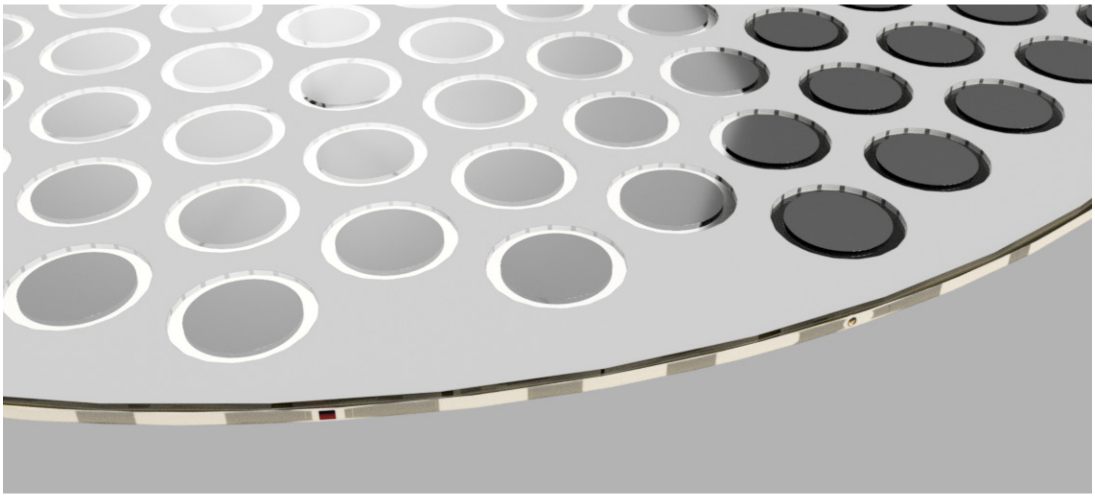
The Big Object

Tam is working with our experts in the practicalities of turning last year's swarming interstellar probe design into a physical replica (the design has prompted a NASA NIAC grant for further design study [1]). Our probe will, we hope, be as striking as the 4 m high monolith we exhibited at the 2014 Worldcon (right).

It's big, black and proportionally correct 1^2, 2^2 and 3^2 = 1, 4, 9 making it 0.44 metres deep, 1.77 metres wide and 4 metres high.

Suspended high above the exhibition space this vision of a laser propelled interstellar probe will draw the attention of Con attendees to relatively near term prospects for interstellar exploration - and perhaps even inspire writers and other creators to consider how such ventures will affect ourselves and even the wider universe. Here's how the antenna side of the probe will look - as visualised by one of the team who are now working to further characterise the whole swarming interstellar probe concept supported this year's NASA NIAC grant, W Paul Blase of Space Initiatives Inc.

For a vision of the probe swarm encountering the Alpha Centauri system see the front cover of this issue and the Cover Images explanation on the inside rear cover. Here's a detail of the visualised design.



Oblique view of a metamaterial probe, showing infrared laserports along the rim for probe-to-probe communications and the downlink antennas, flat optical wells on the upper surface for visible-light laser coms to Earth (blue 432 nm output which is red-shifted by the probe's 0.2c speed to green 539 nm at arrival).

Credit: W Paul Blase, Space Initiatives

[1] See *NASA NIAC funds swarming study - Space Initiatives and i4is team to further their study of interstellar swarming mission* in our last issue, Principium 44 (i4is.org/wp-content/uploads/2024/02/NASA-NIAC-funds-swarming-study-Principium44-2402201033-comp.pdf) and in earlier issues.

Exhibition

John is working with the Con exhibition team and our own team to deliver our exhibition presence including our stand which will be close beneath our replica probe. The i4is team will be there to explain our mission and show its relevance to SF - from which many ideas and inspirations have grown and will continue to grow.
We will have lots of visuals and literature including print issues of Principium. Come along and say Hi!

The i4is corner of the 2014 Worldcon, Excel, London

To be there

We would welcome anyone who is coming to the Con to help with our presence, on our stand, in our programme events and everywhere in the Con where we will be spreading our interstellar message. More at glasgow2024.org and you can sign up via glasgow2024.org/get-involved/memberships- for tickets. You'll meet some weird and wonderful people - some of whom will be members of our team! Get in touch via john.davies@i4is.org, gillian.norman@i4is.org or Glasgow24@i4is.org.

Royal Institution April 2024

Our fifth *Skateboards to Starships* workshop

i4is has been delivering a workshop for school students *Skateboards to Starships* since 2018. This year we were invited back for the Easter break and we involved two groups -
Skateboards to starships (age 13-15) Friday 05 April 2024
Skateboards to starships (age 12-14) Monday 08 April 2024
Here are a few notes from the event and pictures taken by our team.

John I Davies

It was great to be back at the RI again. As always the staff were very helpful and our thanks go to Lisa Derry, who organised things and Irene, who supported the students "on the day".
This year the presenters were John Davies and Rob Swinney with help from Satinder Shergill, Terry Regan and a new team member, Arya Gonullu of KCL Space (www.kclspace.com).
The work for each of the two days was based on our events in earlier years. For example -
i4is.org/wp-content/uploads/2022/08/Skateboards-to-Starships-2022-13-152208301451-opt.pdf.
This year we enhanced much of the content, for example this improved formulation of the simple orbit calculation -

QUESTION

What we are asking you to calculate: What percentage of orbital velocity can you achieve with different amounts of fuel and estimate (or calculate) what fuel required for 100% 'orbital velocity'.

Low earth orbit needs a velocity of about 8 km/sec. Think of your tiny capsule, the rocket payload, as 1000 kg – with only you in it! And let's assume your rocket body and engine mass will be about 5% of your fuel mass. Using liquid oxygen and liquid hydrogen fuel gives your rocket an exhaust velocity of 5,700 m/sec…then what will be the total mass of your fuelled rocket and capsule to get to orbit? (Rocket engineers call this total mass the 'wet mass' and includes the fuel.) Then work through the table.

Tsiolkovsky equation: $\Delta V = Ve\ LN(Mo/Mf)$

Mass of fuel (kg)	Mo	Mf	Mo divided by Mf = Mo/Mf	LN (Mo/Mf)	Multiply by Ve to get ΔV the **Final velocity**	% of orbital velocity
1,000						
1,500						
2,000						
2,500						
3,000						
3,500						
4,000						
4,500						

Mass of rocket body and engine plus fuel plus capsule = Mo
Mass of rocket body and engine plus capsule (no fuel left) = Mf

▶

- and this clearer statement of the balloon exhaust velocity experiment -

Using balloons attached to a wire as your propulsion units, you are to record the distance travelled and the time taken for your balloon rockets.
Using the speed, distance & time equation you can get the average velocity ~Δ(delta)V

You will then use this to calculate the exhaust velocity of your balloon from Tsiolkovsky's equation.
Transpose it!

$$\Delta v = v_e \ln \frac{m_o}{m_f}$$

Given density of air (0.001225 gm/cm^3) and balloon vol~ϖr^2*L work out the balloon exhaust velocity.

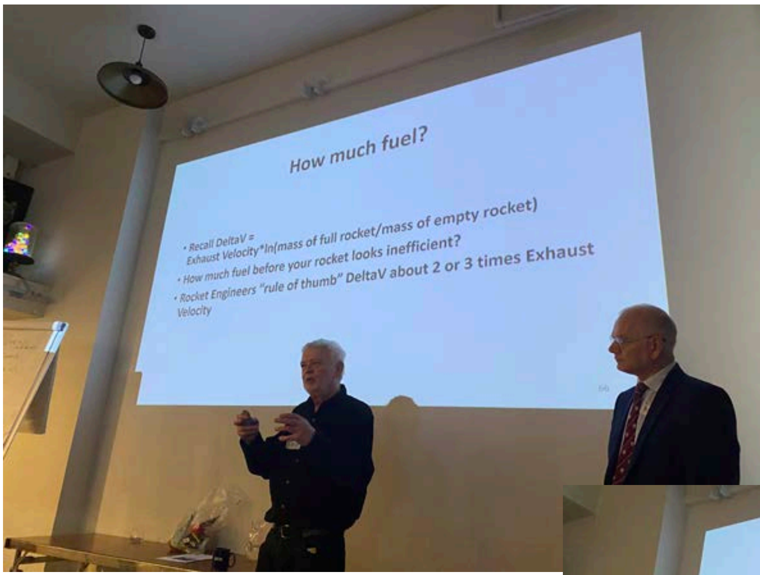
Four tests

Distance (m)	Time (s)	ΔV (m/s)	Initial Mass (kg)	Final Mass (kg)	Balloon exhaust velocity (v_x) m/s

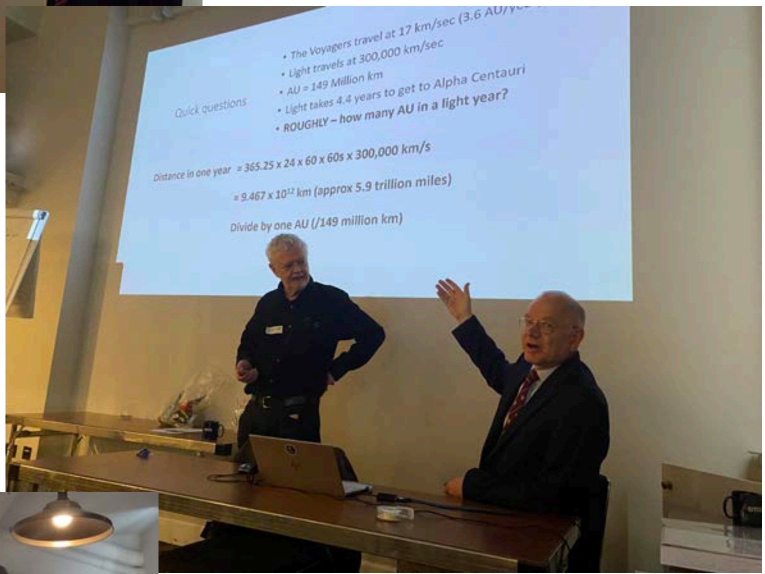
We showed the transposition to the younger group and told both sets of teams to assume 1 gm for the balloon + straw.

Here are some images from the event - note safegaurding guidelines mean you don't see the faces of students -

Here is the team on the second day minus Terry who was unable to join us because of a rail strike.
Left to right - Satinder Shergill, Rob Swinney, John Davies and Arya Gonullu.
Credit: Arya Gonullu (with a little help from RI staff).

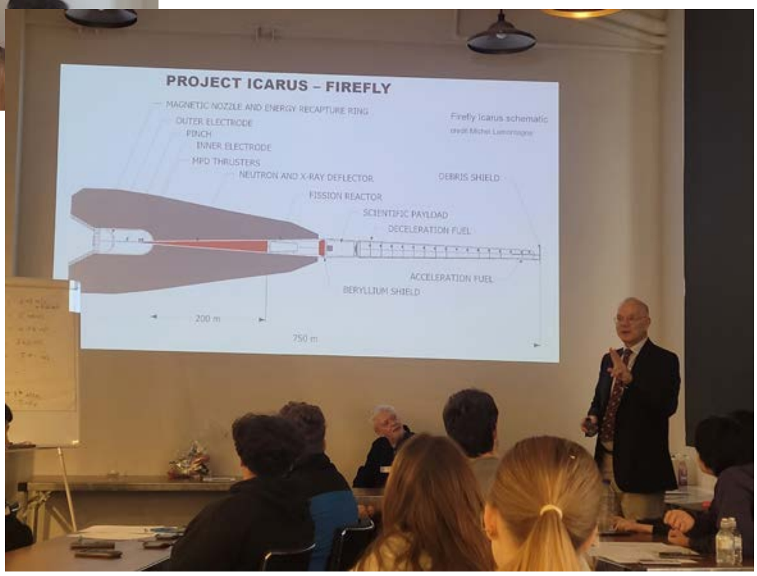


John explains the rocket engineers rule of thumb with Rob in support. Credit: Arya Gonullu



Rob explains the hard way to solve the Voyager to AlphaCent problem, John to the left. Credit: Arya Gonullu

John - it's a long long way to Alpha Centauri Credit: Satinder Shergill



Rob describes the Icarus Firefly configuration Credit: Satinder Shergill

Biological intelligence vs AI - and the Fermi Paradox

Is artificial intelligence the great filter that makes advanced technical civilisations rare in the universe?

In this recent paper Professor Michael Garrett of the Jodrell Bank Centre for Astrophysics at the University of Manchester, examines the hypothesis that the rapid development of Artificial Intelligence (AI), culminating in the emergence of Artificial Superintelligence (ASI), could act as a "Great Filter" that is responsible for the scarcity of visible advanced technological civilisations in the universe.

John I Davies

Professor Garrett is an astrophysicist with a long and strong interest in the search for extraterrestrial intelligence. In a recent preprint of paper for Acta Astronautica, *Is artificial intelligence the great filter that makes advanced technical civilisations rare in the universe?* [1]. The Great Filter [2] is the idea that there is some insuperable obstacle to the development or longevity of communicating civilisations. This is highly dependent upon the final factor L in the Drake equation [3], the length of time for which intelligent life, and thus civilizations, release detectable signals into space. He cites papers by Bailey (see Principium 41, *Interstellar News: Two answers to - Where is everybody?*) and Bennett (*Compression, The Fermi Paradox and Artificial Super-Intelligence*, arxiv.org/abs/2110.01835) as proposers of this idea.

His suggestion is that the Great Filter may be the result of a relatively short time between the emergence of civilizations which develop a technology that releases detectable signs of their existence into space and them being superseded by and overwhelmed by the ASIs they have created.

It's striking that Professor Garrett does not use the term Artificial General Intelligence (AGI) but uses the term Artificial Superintelligence (ASI). AGI is now looking old-fashioned since it takes humanity as the benchmark and thus tends to imply consciousness and intention. Notably Garrett cites Yuval Harari "nothing in history has prepared us for the impact of introducing non-conscious super intelligent entities on the planet" (www.vox.com/2017/3/27/14780114/yuval-harari-ai-vr-consciousness-sapiens-homo-deus-podcast). Clearly the direction taken by Large Language Models (LLMs) in recent years seems to be towards ASI, skipping the previously assumed intermediate step of AGI.

[1] Volume 219, June 2024, Pages 731-735 - www.sciencedirect.com/science/article/pii/S0094576524001772
[2] *The Great Filter - Are We Almost Past It?* philpapers.org/rec/HANTGF-2, Robin Hanson mason.gmu.edu/~rhanson/home.html), September 1998
[3] The Drake equation (en.wikipedia.org/wiki/Drake_equation) suggests that the number of communicating civilisations, N, is given by multiplying together the terms - R* = the average rate of star formation in our Galaxy, f_p = the fraction of those stars that have planets, n_e = the average number of planets that can potentially support life per star that has planets, f_l = the fraction of planets that could support life that actually develop life at some point, f_i = the fraction of planets with life that go on to develop intelligent life and civilizations, f_c = the fraction of civilizations that develop a technology that releases detectable signs of their existence into space and L = the length of time for which such civilizations release detectable signals into space.

◀ It-s noticeable that the influential book *Superintelligence: Paths, Dangers, Strategies*, by Nick Bostrom (2016) also does not mention AGI (as far as I can determine, not having a searchable copy) [1].
He suggests that the final factor L in the Drake equation, the length of time for which intelligent life, and thus civilizations, release detectable signals into space, may be as short as 100-200 years.
It's hard to be sure both that ASI, if achieved, will surpass us and will succeed in overwhelming us in any reasonably predictable interval but Professor Garrett suggests that since this is possible, and would be an extinction event, we should take precautions now.
Having pointed out the weakness of any international regulation he suggests that "multiplanetary civilization could distribute its risk across several widely separated celestial bodies" thus distributing the risk. This would require a rigorous quarantine along the lines of the Butlerian Jihad in Frank Herbert's *Dune* [2] "Thou shalt not make a machine in the likeness of a human mind".
In the short term he suggests regulation of AI but notes several obstacles to this -

> Ensuring compliance and accountability in AI development and deployment also poses significant challenges. The decentralised nature of AI development, the enormous size of the global AI research community spread across almost every research domain will further complicate the oversight and enforcement of regulations. In short, regulation of this new technology is going to be very difficult, if not impossible to achieve. Without practical regulation, there is every reason to believe that AI could represent a major threat to the future course of not only our technical civilisation but all technical civilisations.

- and -

> If ASI limits the communicative lifespan of advanced civilizations to a few hundred years, then only a handful of communicating civilisations are likely to be concurrently present in the Milky Way. This is not inconsistent with the null results obtained from current SETI surveys and other efforts to detect technosignatures across the electromagnetic spectrum.

If Professor Garrett's suggestions are likely to be fulfilled then perhaps we should devote our energies to transmitting warnings to our fellow sentient biological species and hoping that our ASI masters will be happy to keep us as amusing pets.

One final thought occurs to me, will ASIs become separate intelligences with differing objectives or will they form a "hive mind", since they communicate at light speed or close to it? In the former case we have to hope that any hostility between them is contained and we do not become "collateral damage".
The hive mind thesis is discussed in the *The Black Cloud*, by Fred Hoyle (1957) where the conclusion is that individuals communicating at light speed would merge their identities. The key here is the latency of the communication. Hoyle imagines a cloud big enough to surround the Sun, like a very close Dyson sphere, and assumed delays of a minute. At the speeds of computation available in 1957 this delay might be irksome but tolerable. At current speeds of computation it would be more likely to result in separate intelligences. Perhaps this reinforces Professor Garrett's suggestion that -

> A multiplanetary civilization could distribute its risk across several widely separated celestial bodies, reducing the likelihood of simultaneous destruction across all platforms. ... If one planet or outpost in space falls to a misalignment of AI's goals with biological interests, others may survive and immediately learn from these failures.

Professor Garrett even suggests that widely separated bodies could be used as test environments "where the effects of advanced AI can be studied without the immediate risk of global annihilation" in the manner of a "sandbox" as used to test potentially dangerous software.

In his paper Professor Garrett has reviewed both current AI and current SETI and brought them together to a largely pessimistic conclusion.

[1] More about this in *Sending ourselves to the stars?* in Principium 13, May 2016 - with further material in its predecessor of the same title in Principium 12, February 2016.
[2] en.wikipedia.org/wiki/Dune_(franchise)#The_Butlerian_Jihad

■

The Journals

John I Davies

Here we list recent interstellar-related papers in the **Journal of the British Interplanetary Society (JBIS)**, which has been published since the 1930s and in **Acta Astronautica (ActaA)**, the commercial journal published by Elsevier, with the endorsement of the International Academy of Astronautics.

JBIS

Two issues of JBIS online, September and October 2023, have appeared since the report in our last issue. P44. Later issues are in print but not yet online. The October issue was an Interstellar Issue.

Title	**Author**	**Affiliation**
Abstract/Précis/Highlights		

JBIS VOLUME 76 **2023 NO 10 OCTOBER 2023 Interstellar Issue**		
Population Demographics and Other Issues for the Massive Ra World Ship Model – Part 1	**Kelvin F Long**	**Interstellar Research Centre, Stellar Engines Ltd**
A world ship is a massive spacecraft carrying a human crew on a trip to the stars over many generations that may take millennia to complete the crossing. It is completely independent of any resource supply chains from back home and is the initial foundations upon which an interstellar settlement may grow into a fully-matured civilisation. Strategies for sending humans around other stars depend on the ability to construct large World Ships which are of order 10^{11} tons in mass, 100 km in length and host large populations of millions of people over many generations of lifetime. A mission architecture is constructed for a 1 million population carrying capacity growing to 10 million, based on an original 1984 published model which achieves a cruise speed of 1,500 km/s or 0.5% the speed of light (c) for a 1,000 year trip time. This is for a concept called Ra, named after a god who drove his sun chariot across the sky. We discuss how the world ship population is divided into categories. We also discuss the critical issue of population demographic and economics. Power supply and habitat spin rate are also discussed. It is concluded that the design of a society within a world ship presents challenges for social-cultural philosophers and the adoption of a free market economy. This paper is the first part to a follow up which will describe a world ship driven by an inertial confinement fusion engine.		

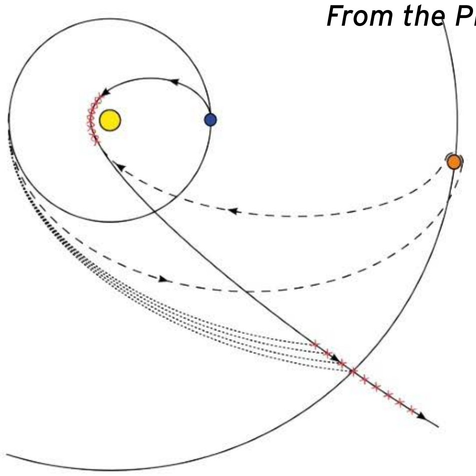
From the Kelvin F Long paper-

TABLE 2: Habitat Size for the Cylindrical World Ship with a Radius of 7.24 km

Habitat Length (km)	Internal Volume (m^3)	Surface Area (m^2)	Area/Person (m^2 /p) p = 200,000	Area/Person (m^2 /p) p = 2 million
5	8.234×10^{11}	5.568×10^8	2,784	278
10	1.647×10^{12}	7.843×10^8	3,921	392
15	2.470×10^{12}	1.012×10^9	5,058	506
20	3.293×10^{12}	1.239×10^9	6,196	620
25	4.117×10^{12}	1.467×10^9	7,333	733
30	4.940×10^{12}	1.694×10^9	8,470	847

The Temporal Contact Equation: An Estimate for the Time of First Contact with ETI	Kelvin F Long	Interstellar Research Centre, Stellar Engines Ltd
First contact between humanity and ExtraTerrestrial Intelligence (ETI) has been a subject for interesting debate particularly over the last century. It is now possible to estimate the likely time-scales for when this may occur due to the significant development of two separate disciplines of knowledge; interstellar propulsion theory and the discovery of exoplanets. This paper demonstrates such a calculation with the aim of provoking discussion and preparations where appropriate. It is estimated on the speculative assumption that if intelligent (advanced technological) life existing within ~200 light years (ly) of Sol first contact may occur as early as in the next ~1-2 centuries depending on the velocity maturation level and technological growth model assumptions. This calculation has been made purely on the basis of our arrival out there and does not take into account the possibility of them arriving here which may be much earlier or could have occurred already.		
Impact Initiated Nuclear Pulse Propulsion and Applications	**Philip Baldock**	-
A new iteration of nuclear pulse propulsion (NPP) is investigated in which propulsive nuclear explosions are initiated via hypervelocity impacts. Working entirely without a fission first stage and requiring precise planning of orbits often years in advance, this new iteration, being intrinsically difficult to weaponise, is suited only to peaceful and commercial purposes and so sidesteps the political issues regarding weapons proliferation that have so far prevented use of NPP as originally envisioned (in the form of Project Orion) despite high potential utility and technological maturity demonstrated. Use of Jovian gravity assist/Oberth effect burn to invert a Hohmann transfer orbit into a retrograde ellipse is investigated and suggests that collision velocities with a waiting spacecraft propulsion system could be attained upwards of 70 km/s. Potential schemes for fusion chain reaction initiation are suggested: 1) Inversion of impactor plate by collision with conical annulus into a collapsing cylindrical tamper, 2) Plasma Z-pinch powered by induction of fast moving permanent magnet through a conducting coil, 3) Impact induced x-ray flash powering spherical tamper collapse by ablation as in conventional Teller-Ulam systems, as well as how these may be used in combination. Further avenues for research are suggested.		

From the Philip Baldock paper-



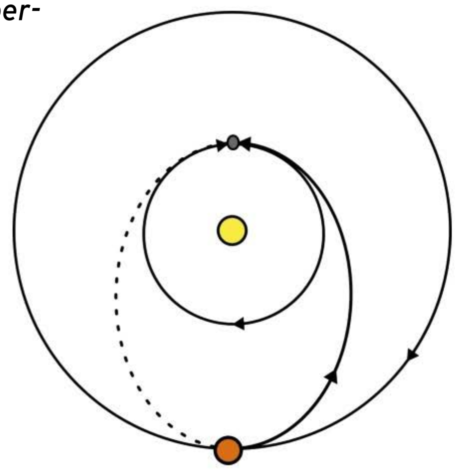


Fig.2 Dashed lines represent initial impactor path (thick dashes) around Jupiter into retrograde ellipses and outbound impactor paths (thin dashes) out of the Solar System to await the passage of the incoming spacecraft.	Fig.3 Hohmann transfer to Jupiter is followed by Oberth effect rocket delta v sufficient to reverse impactor orbit into retrograde ellipse: a ~15 km/s orbital delta v may be achieved with only 3.3 km/s rocket delta v.

Introducing the Exoplanet Escape Factor and the Fishbowl Worlds (two conceptual tools for the search of extra terrestrial civilizations)	Elio Quiroga Rodríguez	Universidad del Atlántico Medio, Islas Canarias, España
The search for extraterrestrial intelligence on exoplanets is a rich field of conceptual exploration. Author introduces two definitions that could help to narrow down the possibilities that an extraterrestrial civilization may or may not have initiated exploration of its own star system and beyond. It is concluded that in some cases certain extraterrestrial civilizations may not be able to leave their home worlds before their biological extinction, purely because of physical limitations.		

Acta Astronautica

Acta Astronautica papers are published online before print. These issues with relevant papers have appeared since our last issue, Principium P44.

Title	Number+date	Author
Abstract or Summary		

A light sail astrobiology precursor mission to Enceladus and Europa	**Volume 218, May 2024**	**Adam Hibberd, Andreas M Hein, Manasvi Lingam**

Icy moons with subsurface oceans of liquid water rank among the most promising astrobiological targets in our Solar System. In this work, we assess the feasibility of deploying laser sail technology in precursor life-detection missions. We investigate such laser sail missions to Enceladus and Europa, as these two moons emit plumes that seem accessible to in situ sampling. Our study suggests that GigaWatt laser technology could accelerate a 100 kg probe to a speed of ~30 km/sec, thereupon reaching Europa on timescales of 1–4 years and Enceladus with flight times of 3–6 years. Although the ideal latitudes for the laser array vary, placing the requisite infrastructure close to either the Antarctic or Arctic Circles might represent technically viable options for an Enceladus mission. Crucially, we determine that the minimum encounter velocities with these moons (about 6 km/sec) may be near-optimal for detecting biomolecular building blocks (eg amino acids) in the plumes by means of a mass spectrometer akin to the Surface Dust Analyzer onboard the Europa Clipper mission. In summary, icy moons in the Solar System are potentially well-suited for exploration via the laser sail architecture approach, especially where low encounter speeds and/or multiple missions are desirable.
Open access version: arxiv.org/abs/2402.18691

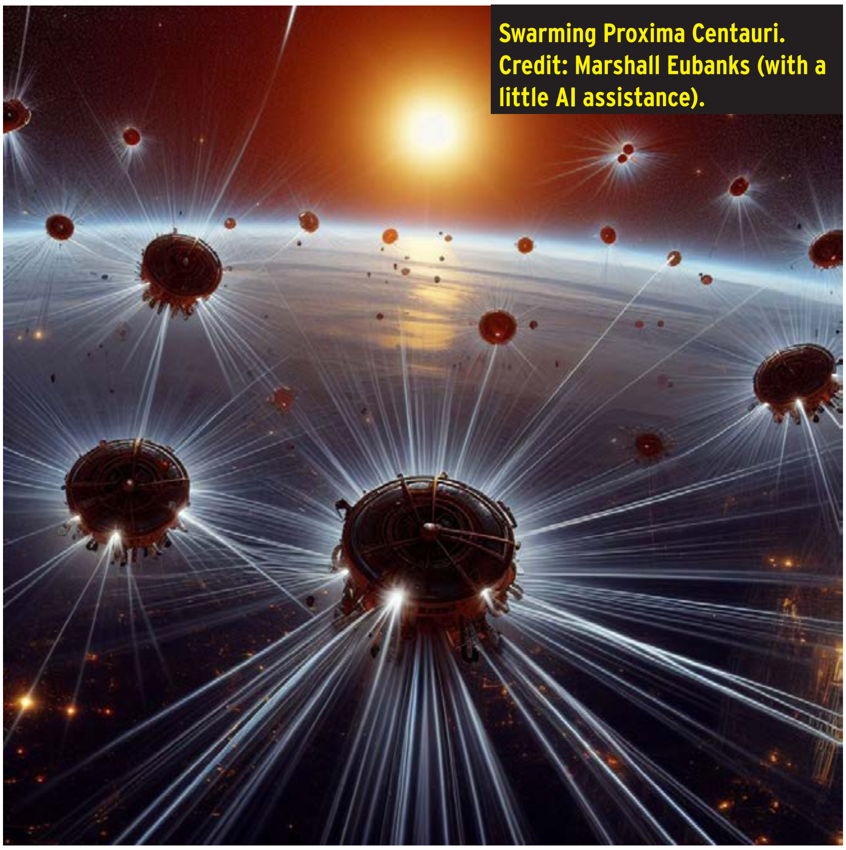
Direct fusion drive based on centrifugal mirror confinement	**Volume 219 June 2024**	**Jerry Carson, Raymond Sedwick**

A concept for direct fusion drive based on centrifugal mirror (CM) confinement of thermonuclear plasmas (DFD-CM) is described. In centrifugal mirrors, electric and magnetic fields are combined to confine the plasma within a rapidly rotating annulus of burning plasma fixed between two mirror magnets. High energy fusion products leave the reactor core at a rate determined by the velocity of plasma rotation and the strength of the mirrors. Those departing through the jet-side mirror deposit their energy in a "warm" plasma that then expands through a magnetic nozzle to deliver jet power in the 100–1,000 kW range. Fusion products departing through the power-side mirror are converted to electricity to power the reactor. Moderate thrusts at attractive specific impulses (10,000+ seconds) are possible. Findings are presented on CM reactor dynamics in propulsion applications, to include new insights into the relationship between mirror and centrifugal components of plasma confinement. Additionally, analysis will be presented on reactor operability limits and characterization of viable configurations based on power density, technology constraints, and the ability to self-power. Ongoing research into the physics of the warm plasma will be discussed, to include description of improved fidelity estimates for fusion energy deposition. Finally, considerations for Alfvén's frozen-in theorem relative to fusion plasmas and magnetic nozzle performance will be outlined.
Viable space commerce and future space exploration will require advanced power and propulsion technologies capable of multi-MW power generation with high specific impulse, moderate thrust levels, and low system specific mass. DFD could make a round trip to Mars in three months, and to Saturn, in less than three years. A DFD-CM powered mission could deliver an orbiter and four atmospheric probes to Neptune in four years. A second-generation Interstellar Probe powered by DFD-CM could reach the edge of the heliosphere (1,000 astronomical units) in 25 years.

BECOME AN i4is MEMBER

Are you intrigued by what lies beyond our solar system?
Would you like to support research towards interstellar space missions?
Does interstellar research fascinate you?
If so....
BECOME AN i4is MEMBER!

John I Davies



Swarming Proxima Centauri. Credit: Marshall Eubanks (with a little AI assistance).

The Initiative for Interstellar Studies (i4is) has a membership scheme intended to build an active community of space enthusiasts whose sights are set firmly on the stars. You can directly support interstellar programmes and even get involved with our projects! We are an interstellar advocacy organization that conducts theoretical and experimental research and development projects and supports interstellar education and research in schools and universities.

By becoming a member, you are not just supporting our cause, but will also gain:

- early access to select Principium articles before publicly released;
- member exclusive email newsletters featuring significant interstellar news;
- access to our growing catalogue of videos;
- the opportunity to participate in livestreams of i4is events and activities;
- access to download and read our annual report.

Reach for the stars with us by becoming a member today at i4is.org/membership/
Students are eligible for a 90% discount!

THE i4iS MEMBERS' PAGE

John I Davies

The i4is membership scheme exists for anyone who wants to help us achieve an interstellar future. By joining i4is, you help to fund our technical research and educational outreach projects. Members can access the members-only area of the website including our video talks, members newsletter and preprints.

Meet the team - and the world

i4is team members will be at three in-person events later this year.

In August we will be at the annual **World Science Fiction Convention, Worldcon24**, in Glasgow, Scotland. Team members from the USA, UK and the rest of Europe will be there. More about this elsewhere in this issue and in P41 and P43. The full details about how to join us, and thousands of others there, are at glasgow2024.org.

In October we will be at the **International Astronautical Congress**, the big astronautics event of the year, in Milan, Italy - 14-18 October. Details at www.iac2024.org.

In December we will be at the **First European Interstellar Symposium** 2-5 December. Hosted by the University of Luxembourg with the major participation of i4is, the Interstellar Research Group (formerly TVIW), Breakthrough Initiatives and the Luxembourg Space Agency. Details at irg.space/first-european-interstellar-symposium.

As soon as you decide to be at any of these then email Principium@i4is.org and let us know when you will be there.

And even if you aren't travelling then you can meet us online at our SF Book Club. To join the club, email bookclub@i4is.org.

Interstellar Blogs

Keep up with our star astrodynamicist, Adam Hibberd, through the i4is *Starship Blog* (i4is.org/category/starship-blog) and his personal site, *Adam's Music and Space Research* (adamhibberd.com/blog). He's a busy man and a key member of the i4is core team.

Recent member newsletters

There has been one member newsletter since the February 2024 issue of Principium. The March issue came out on 28 March. All member newsletters are available from the members-only area on the website.

A use for a Hollow Asteroid?

In *Project Hyperion: The Hollow Asteroid Starship – Dissemination of an Idea*, Andreas Hein. our Executive Director, reminds us of an early idea for a worldship (i4is.org/project-hyperion-the-hollow-asteroid-starship-dissemination-of-an-idea). Andreas is sceptical about using an asteroid directly but we certainly might find structural materials in such a convenient location outside planetary gravity wells.

The idea dates back to the sixties at least and, arguably, back to Goddard, Tsiolkovsky and J D Bernal. See Robert Goddard ("The Last Migration," 1918) [1], Konstantin Tsiolkovsky ("The Future of Earth and Mankind," 1928) - and J D Bernal (The World, the Flesh & the Devil: An Enquiry into the Future of the Three Enemies of the Rational Soul, 1929. [2]

Project Hyperion is building on this and more recent work we supported at the International Space University, AdAstra, soon after our foundation. Together with our major programme item, Worldships, at the Glasgow World Science Convention in August, this makes 2024 our year of the worldship.

Cover of the AdAstra worldship final report. Credit: International Space University

Getting more actively involved

There is lots to do whether your skills are technical, educational, administrative or financial. The more volunteers we have, the more we can achieve! Please get in touch at info@i4is.org.

[1] web.archive.org/web/20191102205336/https://www.bis-space.com/2012/03/23/4110/the-ultimate-migration

[2] www.quarkweb.com/foyle/WorldFleshDevil.pdf

NEXT ISSUE

Host of the First European Interstellar Symposium: Professor Andreas Hein, Space Systems Engineering (SpaSys) group at the University of Luxembourg and Executive Director of i4is.
Credit: University of Luxembourg

- **IAC 24 Preview**: Anticipating the International Astronautautical Congress 2024 in Milan in October - see poster on next page.
- **IRG/i4is Interstellar Symposium Preview**: Explaining what we expect at the First European Interstellar Symposium in December at the University of Luxembourg.
- **Aerographene and Aerographite - the metamaterials for an interstellar probe?**: Andreas Hein explains how a material mostly made of voids can be strong enough to withstand both massive acceleration and the stresses of interstellar transit at 0.2c.

- and a couple of postponed articles -

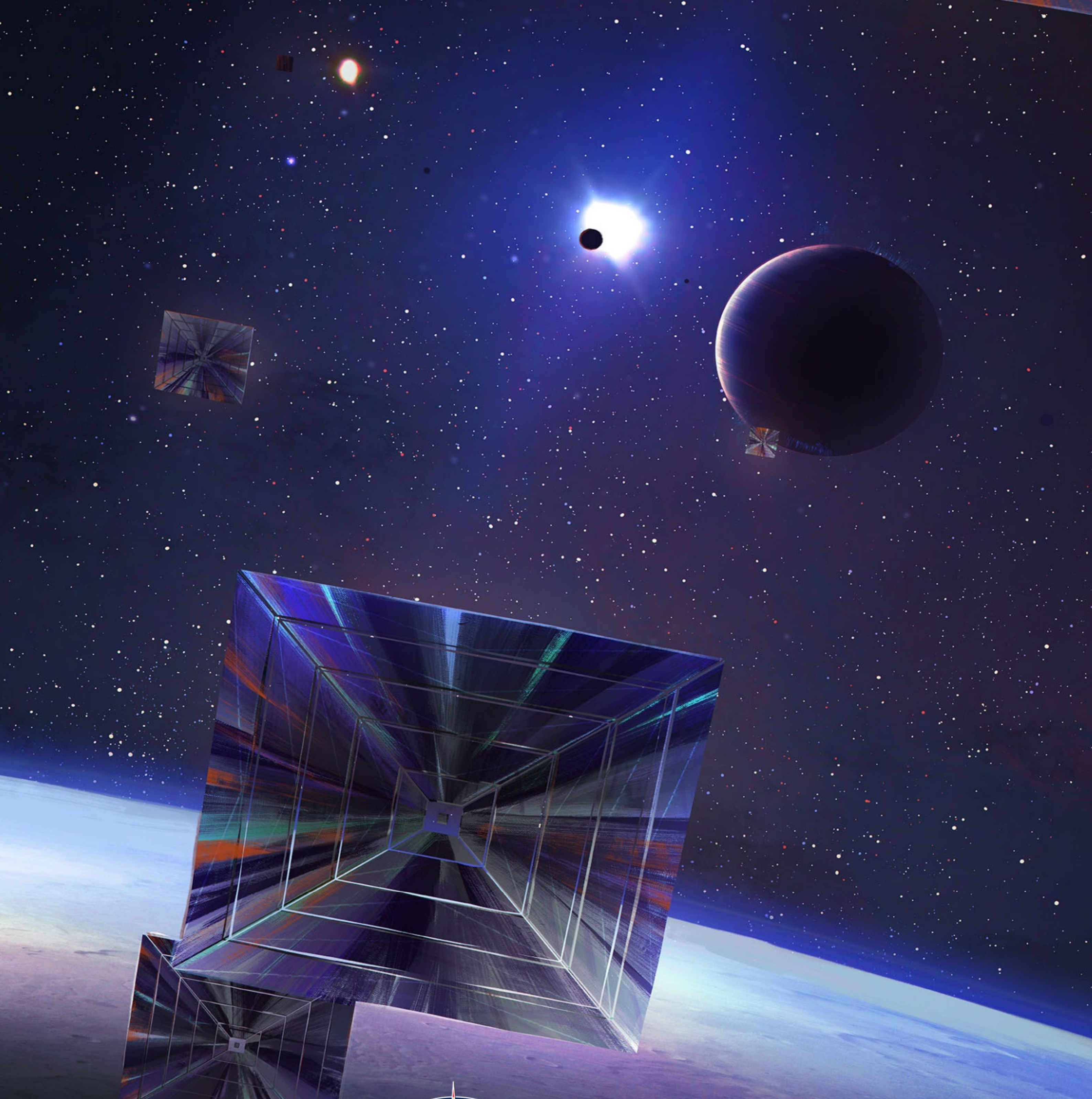
- **Current FTL thinking**: Faster than light (FTL) travel has been the subject of much serious thinking and it still engages the brains of some of the brightest on the planet but are we any nearer to achieving it other than in fiction? Dr Dan Fries, Deputy Head of the i4is Technical Team, will review where things stand.
- **Doubling Human Lifespan - implications for the interstellar enterprise**: Many of the social and moral issues arising from the possibility of worldships might look different for longer-lived humans.

Plus **Interstellar News** and interstellar papers in **The Journals**.

Solar noon in Milan Cathedral.
Credit: INAF-Osservatorio Astronomico di Brera

First European Interstellar Symposium

2-5 December 2024, Luxembourg



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IRG

INITIATIVE FOR INTERSTELLAR STUDIES

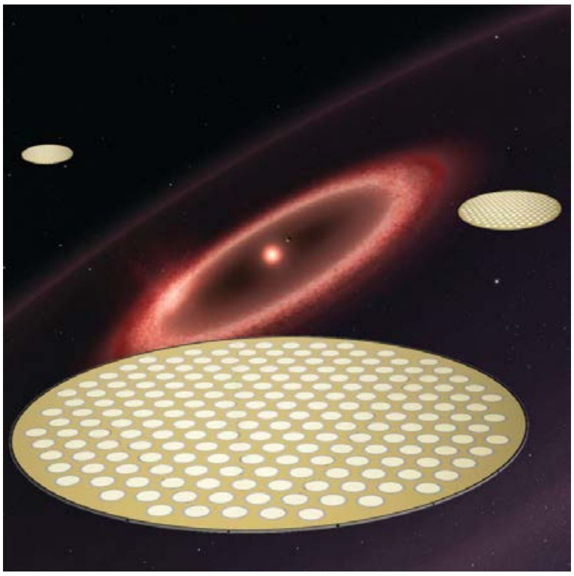
BREAKTHROUGH INITIATIVES
BREAKTHROUGH PRIZE FOUNDATION

LSA LUXEMBOURG SPACE AGENCY

COVER IMAGES

Our cover images for this issue show a swarm of laser-propelled probes based on recent Space Initiatives/i4is proposals and a prophetic 1920s design for a rotating space station.

FRONT COVER



Oblique view of a metamaterial probe

W Paul Blase (Space Initiatives Inc), one of the Space Initiatives/i4is team who won the NASA NIAC grant to further their study of interstellar swarming missions, produced this image of probes nearing Proxima Centauri. The dust ring around the star was detected by ALMA (the Atacama Large Millimetre/submillimetre Array) Observatory in Chile.

Paul's oblique view of such a metamaterial probe shows infrared laser ports along the rim for probe-to-probe communications and flat optical wells on the upper surface for visible-light laser communications to Earth (blue 432 nm output which is red-shifted by the probe's 0.2c speed to green 539nm at reception).

BACK COVER

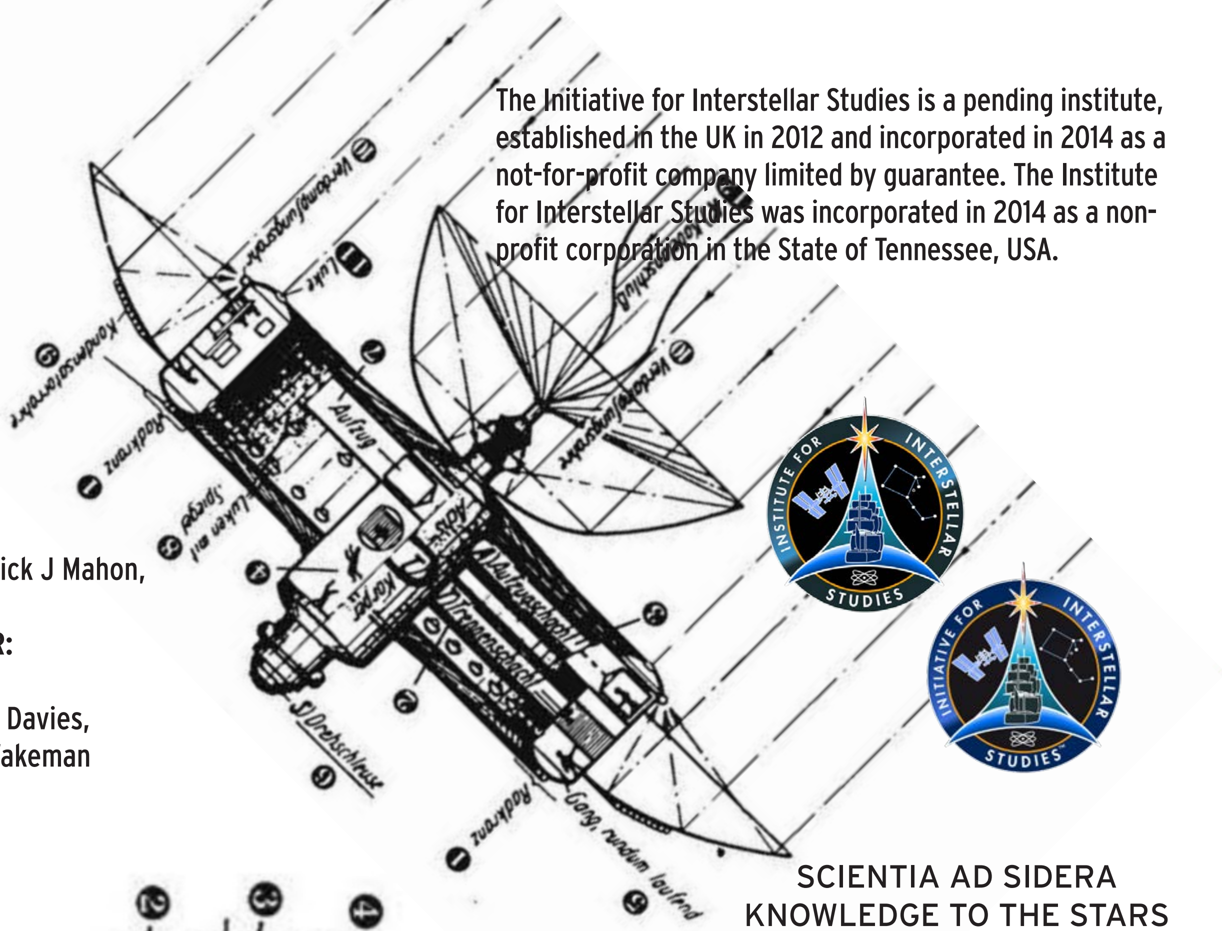
The Problem of Space Travel: The Habitat Wheel

The plan and elevation of a space station "Habitat Wheel" are extracted from a NASA translation of "Das Problem der Befahrung des Weltraums, Der Raketen-Motor" a visionary book published in 1929 by Herman Potočnik (aka Hermann Noordung see en.wikipedia.org/wiki/Herman_Poto%C4%8Dnik#The_Problem_of_Space_Travel).

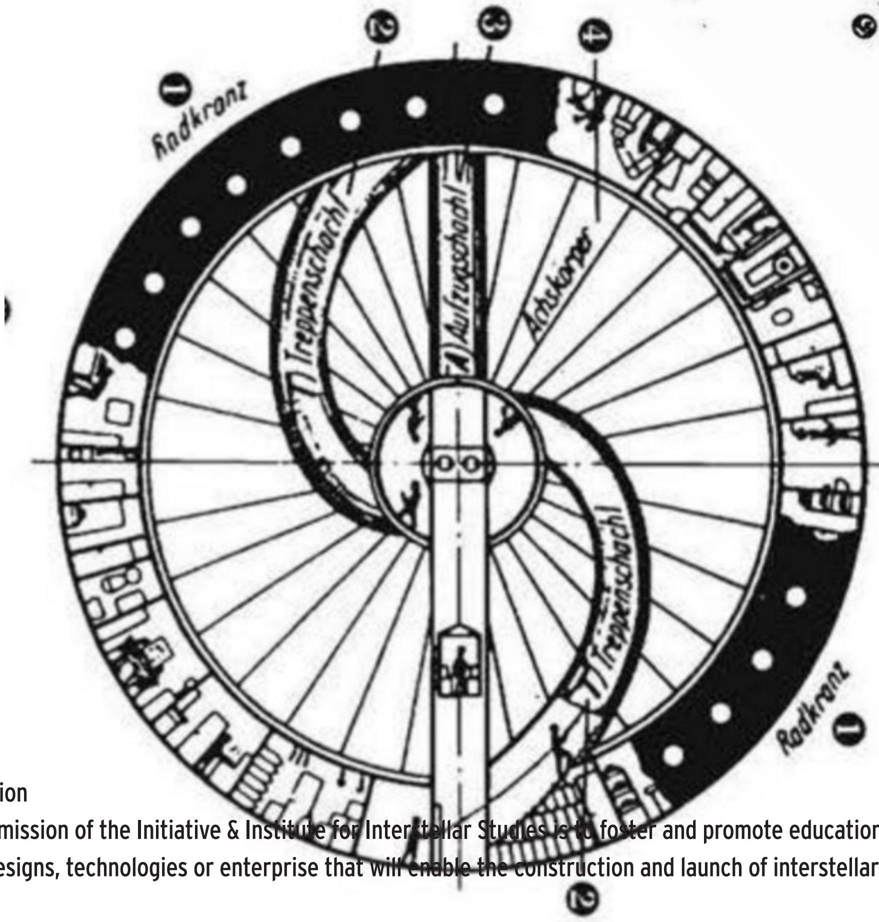
The whole text is available at www.nasa.gov/wp-content/uploads/2023/03/sp-4026.pdf.

The image to the left is an isometric view of the same concept from the book.

The Initiative for Interstellar Studies is a pending institute, established in the UK in 2012 and incorporated in 2014 as a not-for-profit company limited by guarantee. The Institute for Interstellar Studies was incorporated in 2014 as a non-profit corporation in the State of Tennessee, USA.



SCIENTIA AD SIDERA
KNOWLEDGE TO THE STARS



Front cover: Probes nearing Proxima
Credit: Paul Blase

Back cover: The Problem of Space Travel: The Habitat Wheel
Credit: From NASA translation of "Das Problem der Befahrung des Weltraums, Der Raketen-Motor"

Mission
The mission of the Initiative & Institute for Interstellar Studies is to foster and promote education, knowledge and technical capabilities which lead to designs, technologies or enterprise that will enable the construction and launch of interstellar spacecraft.

Vision
We look to a positive future for humans on Earth and in space. Our vision is to be an organisation catalysing the conditions in society supporting a sustainable space-based economy. Over the next century and beyond we aim to enable robotic and human exploration of space beyond our Solar System and to other stars. Ultimately we envisage our species as the basis for an interstellar civilisation.

Values
To demonstrate inspiring leadership and ethical governance, to initiate visionary and bold programmes co-operating with partners inclusively, to be objective in our assessments yet keeping an open mind to alternative solutions, acting with honesty, integrity and scientific rigour.