PRINCIPIUM

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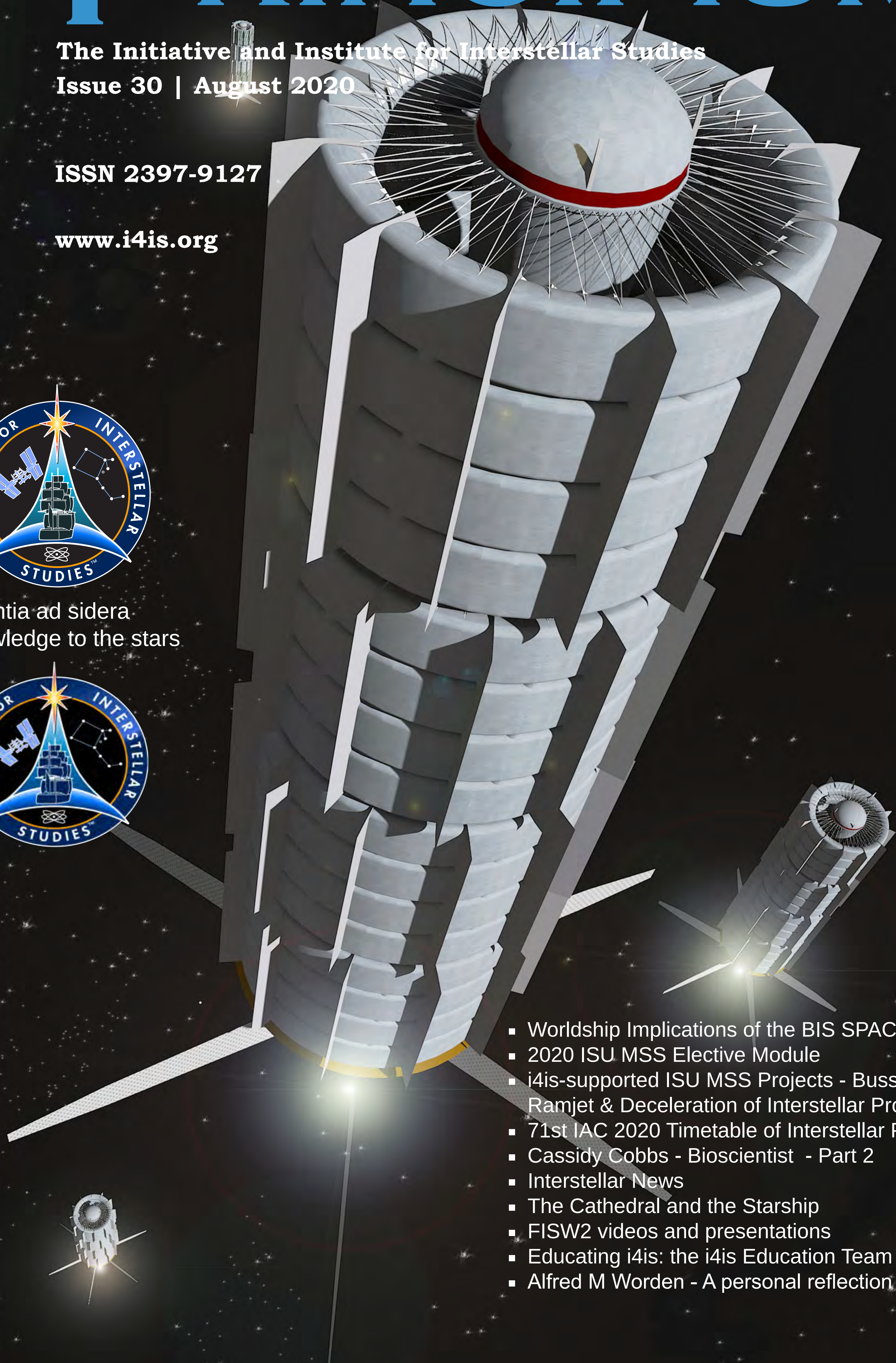
Scientia ad sidera
Knowledge to the stars



- Worldship Implications of the BIS SPACE Project
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Editorial

Welcome to issue 30 of Principium, the quarterly about all things interstellar from i4is, the Initiative and Institute for Interstellar Studies. This is our biggest ever issue, 96 pages. We hope you'll forgive the omission of some items promised last time!

Our lead feature this time is *Implications for an Interstellar Worldship in findings from the BIS SPACE Project* by one of the BIS project team Richard Soilleux.

Our front cover image is a worldship fleet envisaged by Michel Lamontagne and the back cover image is an earth-rise from the NASA Lunar Reconnaissance Orbiter. Much more about both inside the back cover.

We have reports of i4is-supported activities at the International Space University :

- The two-week elective module, Interstellar Studies (with video access for our members) - there will be more in our next issue.
- Two MSS Projects - Bussard Ramjet & Deceleration of Interstellar Probes.

We have a summary of the Interstellar Papers announced for the 71st International Astronautical Congress in October. It's a "Cyberspace Edition" open to all and this is a unique opportunity to see and hear the leading figures in the field at no cost. We have part two of our interview with one of our activists, *Cassidy Cobbs - Bioscientist*. We introduce an intriguing new paper by our Executive Director, Dr Andreas Hein, *The Cathedral and the Starship* and announce the videos and presentations from the second Foundations of Interstellar Studies (FISW2) - also available to our members. Rob Swinney, our Education Director introduces *Educating i4is: the i4is Education Team*. We have eight pages of Interstellar News.

Arising from a conversation at the ISU Elective, we have a letter to the editor, *India in Space*, from ISU student, Pranjal Samarth, which tells us about the rising space endeavour in his country and his suggestion that it may be best-placed to design and build the first interstellar probe.

And, as promised last time, we celebrate the life of a great American, *Alfred M Worden (1932-2020) A personal reflection by John Davies*. As the Scots sing "When will we see your like again?"

The full list is in the Contents page following this editorial.

In our next issue, P31 November 2020, we will have a review of *Extraterrestrial Languages* by Daniel Oberhaus postponed from this issue and more from our ISU elective. We'll have a report on i4is participation in the Starshot Communications Workshop and an introductory piece on the tough job of getting data and pictures back from light years away, *The Interstellar Downlink*.

If you have any comments on Principium, i4is or interstellar topics more generally, we'd love to hear from you!

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More in *The i4is Members Page* - page 60

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Back issues of Principium, from number one, can be found at www.i4is.org/Principium.

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

Contents

Alfred M Worden (1932-2020)

A personal reflection by John Davies

In 2020 we marked the passing of Al Worden, Apollo 15 command module pilot. Principium Editor John Davies met him just twice and only briefly on both occasions but he left a strong impression. Here he presents a personal reflection on Colonel Alfred Merrill Worden, US Air Force retired, 1932-2020.

I missed the first Moon landing. The date was announced after I and three friends had agreed a holiday in Yugoslavia. We had arranged to borrow a VW camper van from a mutual friend, booked a ferry and arranged two weeks off with our bosses. We had seen the "flyby" of Apollo 8 and the almost "touch and go" of Apollo 10 so we talked about cancelling for the Moon landing but decided to go. Three of us were spacecraft engineers at Hawker Siddeley Dynamics in Stevenage, UK, and, frankly, we were rather immature and a little blasé about the whole thing.

As a result we were camping in our reserve tent by the Adriatic, having blown the engine of the VW on the Grossglockner pass over the Alps. All we saw was the flickering of a black and white portable television outside the palatial caravan of some fellow campers. We came home by train and the VW came back on the annual autumn "wreck train" months later. I think the owner forgave us.

So when i4is co-founders, Kelvin Long and Rob Swinney, told us that the i4is HQ would be opened by Al Worden the name rang a bell but I had to look him up. His presence was organised by Vix Southgate (who space advocates in the UK and beyond will know well) and, on the appointed day, 8 October 2017, she drove him to our rather remote HQ where he gave us an account of his mission and his vision for the future in space. I exchanged just a few words with him but I was left with a strong impression. This was a man both proud of what he had done and modest in his manner. There is a full account of the occasion in Principium, Issue 19, November 2017 - *'The Interstellar Space' Opening of i4is HQ, 8 October 2017*.

I met him again and had five minutes conversation with him at the New Scientist Live exhibition a week or two later. Again I felt I had met a man who was a gentleman in the broad sense - civilised, modest but having done something he was very proud of. He chatted to a couple of us, smoking a cigarette outside the restaurant where he was having dinner with the rest of the BIS team. He joked "My doctor tells me these things are killing me but at my age I don't see what difference it makes". As it turned out he had a "good innings" by any standards and "died in harness", more or less, not fading away.

Al emphasises billions of stars to the audience in the historic Faraday Theatre.

I last saw him, again courtesy of the BIS, at the Royal Institution, where he was a speaker in a debate, reported in Principium *News Feature - Debate: Moon, Mars and Beyond at the Royal Institution* (P22, August 2018). Al made the case for *"Beyond"* reaching out past Mars and ultimately to the stars. He made a strong case, although the "*Moon"* was winner, advocated by Professor Chris Welch of the International Space University.

This memoir seems to have been as much about me as about Al Worden and perhaps that's because I acquired a strong sense of the best of the USA via the US Air Force in early childhood. Our neighbours at that time were a US Air Force Master Sergeant, JB Morton, and his family. Living off-base in a small northern English town they were the first non-Brits I had met and JB was an impressive figure, legendarily half-Apache and, I was told, with an occasional temper his colleagues jokingly attributed to his ancestry. JB was a good friend of my father, two engineers who liked discussing the world over a beer or two.

Al Worden had done far more famous things but I saw a strong parallel between them from a personal point of view. Colonel Worden was, I believe, a lesson to all of us of both pride in his achievements, continuing enthusiasm for his subject, space, and modesty in manner. We need more humans like him.

Implications for an Interstellar World-ship in findings from the BIS SPACE Project

Richard Soilleux

LEAD FEATURE

The British Interplanetary Society (BIS) has delivered advanced thinking in space technology since the 1930s. The BIS SPACE Project follows on from the space habitat studies of Gerard O'Neill and others in the 1970s to re-examine the possibilities in the light of subsequent advances (www.bis-space.com/what-we-do/projects/project-space). In this article one of the principal architects of the project gives us a summary of the works and some observations on its lessons for interstellar worldships.

Images are credit: Richard Soilleux except where otherwise stated.

1. Introduction

The concept of the worldship has a long history in science fiction, so much so that it is the way that many people expect we shall eventually travel to the stars. It is now generally accepted that a flourishing and wealthy space-borne civilisation, capable and experienced in building orbital megastructures, is a pre-requisite for undertaking the enormous political, financial, scientific, and engineering challenges of such a venture.

Orbital development is expected to evolve from the ISS into tourist hotels then 1st generation orbital manufacturing with spacecraft refuelling, repair, and assembly in LEO [1]. Eventually, crippling launch costs will make 2nd generation facilities utilizing extra-terrestrial materials economically attractive*. Economic, power and safety demands point clearly to a location for such an orbital materials processing and manufacturing complex (OMPMC) in HEO beyond the protection of Earth's magnetic field and drives orbital settlement beyond LEO. Further study confirmed O'Neill's choice of either the Earth/Moon L4/L5 libration points or an unspecified HEO [2]. Utilising extra-terrestrial resources, initially from near Earth asteroids (NEAs), semi-autonomous factories could build large space-borne structures at little cost to Earth but with great benefit to an orbital economy. A 3rd generation OMPMC co-located with its source NEA eliminates shipping costs for raw materials and, by restricting traffic to Earth encounters, minimizes transport time/cost for finished products and people. Many NEAs approach Mars orbit so a redundant accompanying habitat could become a Mars / Earth cycler for transporting many passengers between the planets in comfort and safety. Similarly, deep space capable nuclear-powered habitats, or interplanetary worldships, could open the solar system to human exploration, exploitation, and habitation.

To date, most of the thinking about interstellar worldships has focused, not unreasonably, on the still unsolved problems of developing suitably large and powerful propulsion systems. In contrast, far less effort has been given to the equally essential life support systems which are often assumed to be relatively straightforward to construct. In reality, the seductive assumption that it is possible to build an artificial ecosystem capable of sustaining a significant population for generations is beset with formidable obstacles.

This is illustrated by a recent large and complex study (the BIS SPACE Project), which revisited Gerard K O'Neill's vision for large orbital habitats with a safe, comfortable, Earth-like environment. The study concentrated on the smallest of O'Neill's habitats, Island 1, for 10,000 inhabitants and culminated in a new design called Avalon [4]. Modelling work for the environmental control and life support system (ECLSS), including the heat and chemical balance during recycling, enabled a much more detailed design than has previously been attempted.

* In-Situ Resource Utilisation (ISRU) is already the subject of active study from very near-term, pre-commercial, investment to relatively far-future exploitation for worldships. Principium has featured this in several past issues - see Shergill (Principium 21 page 15, Principium 23 page 32, Principium 26 page 40), Vermeulen (Principium 23 page 24), Daniels (Principium 24 page 25).

In a talk at the Second Foundations of Interstellar Studies Workshop in 2019* and further elaborated in a paper published in JBIS [3], Mark Hempsell pointed out that the perceived parallels between the requirements of a solar system wide economy and those of an interstellar worldship were not necessarily valid. Most importantly, an interplanetary civilisation has enormous amounts of power and human and material resources at its disposal and will be sustained, as it is on Earth, by an extensive trade network. In stark contrast, an interstellar worldship suffers extreme isolation and must depend solely on its own limited resources. Nevertheless, many parallels remain and much of what is learned in designing and constructing orbital habitats and spaceships will be applicable to the interstellar scenario.

Avalon is intended as the first large habitat to be constructed as a Company Town [8] to support the first OMPMC. It is therefore relatively self-sufficient and closer to an interstellar worldship than habitats in the mature orbital civilization envisaged by Hempsell except that Avalon has access to ample supplies of raw materials. Furthermore, the importance and complexity of any biological ECLSS should not be underestimated, not only for food production and air and water purification but also for heat transport. It may well be, that all future space habitats will require such systems with large numbers of plants being an integral part of the ECLSS. Once the technology is proven and well established there will be little incentive to change, even if newer technologies become available. If plants must be grown anyway many of them might as well produce food, especially fresh produce. This might result in inter-settlement trade being limited to fewer and non-perishable foodstuffs capable of surviving the many months likely to be required for orbital transport.

2. Design Principles for long stay orbital habitats

The main engineering constraints for large orbital habitats are atmospheric pressure containment, sufficient radiation shielding and rotation to impart about 1 g of pseudo-gravity. The review of O'Neill's Island 1 [4] identified significant problems with the design, concerned mainly with the lack of rotational stability and insufficient radiation protection. Indeed, most earlier designs gloss over such important issues, deficiencies that have now been addressed by extensive and detailed study.

Settlements for permanent occupation over several generations must be robust and reliable. Regular maintenance and repair, with major re-fits to replace damaged or worn components and obsolete equipment, will enable the main structures to endure.

Safety of settlers and visitors is of paramount importance and requires:

- A safe comfortable living and working environment,
- Safe means of access and egress,
- Full emergency response capability. A means of evacuating the entire population to onboard "safe havens", other habitats and, if necessary, to Earth.
- Full modern medical support.

Main structural components designed for reliability during a long working life (1,000 years) require:

- Strong, main structures with large engineering safety factors,
- Multiple (at least 2, better 3) redundancy of critical components and life support sub-systems,
- All critical components to be fail-safe,
- Minimal moving parts for critical main structures,
- Materials and structures easily repaired not replaced,
- Regular preventative maintenance, inspection, and repair.

Economy of construction requires:

- Maximum utilization of materials already in orbit even if they have sub-optimum properties,
- Simple methods suitable for automated manufacturing and construction.

* Reported in Principium | Issue 26 | August 2019 pages 4-17.

3. The Avalon orbital settlement [4]

The following brief overview of the Avalon orbital settlement (Figure 1) is not intended to be comprehensive but instead focuses on the features most relevant to interstellar worldship design. Full details are of course available in the references.

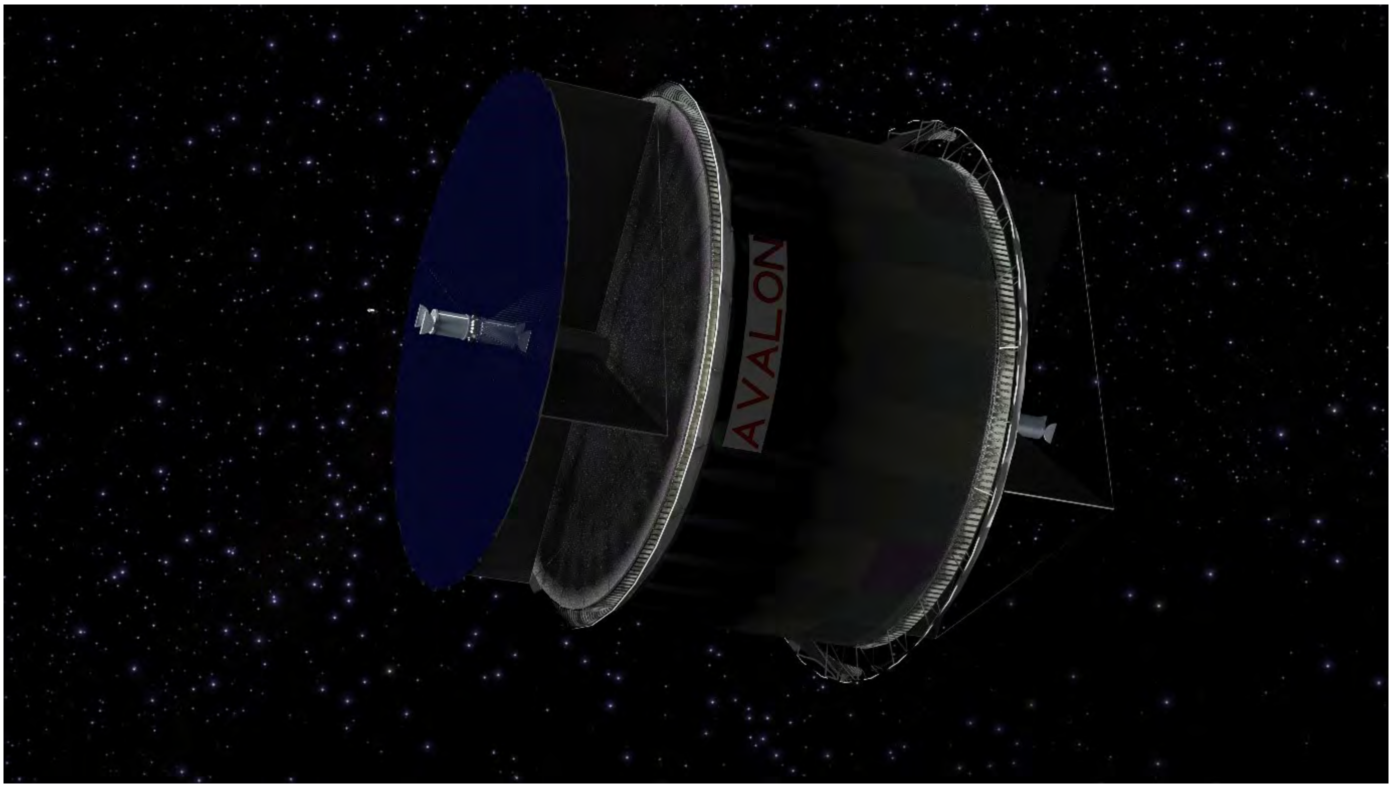


Figure 1. Artist's impression of Avalon. (Image credit Mark Hempsell.)

3.1 General

A conservative approach is adopted for Avalon to provide a safe comfortable environment for workers and their families. It therefore has Earth-like conditions of air composition and pressure, gravity, and ionizing radiation with comfortable levels of temperature, humidity, and lighting.

A key feature of the design is counter rotating concentric double hulls with a massive shield hull protecting the inner pressure hull, not only from radiation, including thermal radiation, but also against abrasion by micrometeorites (Figure 2). Also, the gap between the hulls prevents the propagation of shock waves to the underlying structure mitigating the effects from even quite severe impacts. This arrangement has no net angular momentum; a great benefit when orientating the habitat and during station keeping manoeuvres by avoiding external precession effects. The design also aids in the initial spin-up as the electric drive slowly counter-spins the hulls to the right velocities, balancing angular momentum throughout. However, counter-rotating hulls must be constructed very accurately and kept apart under all circumstances.

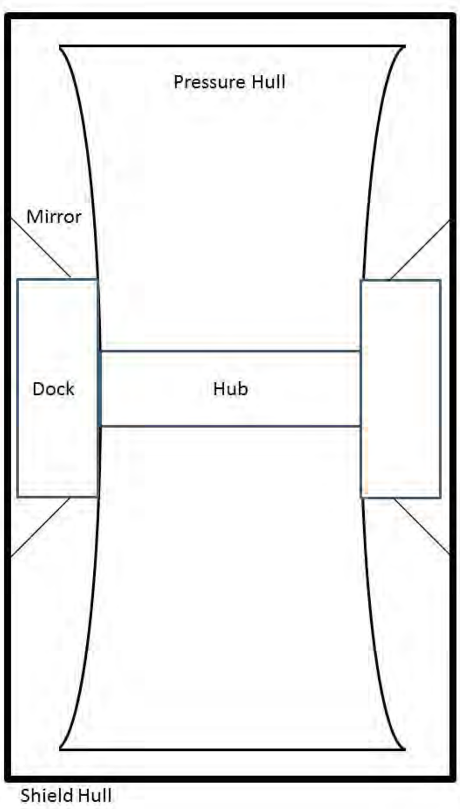


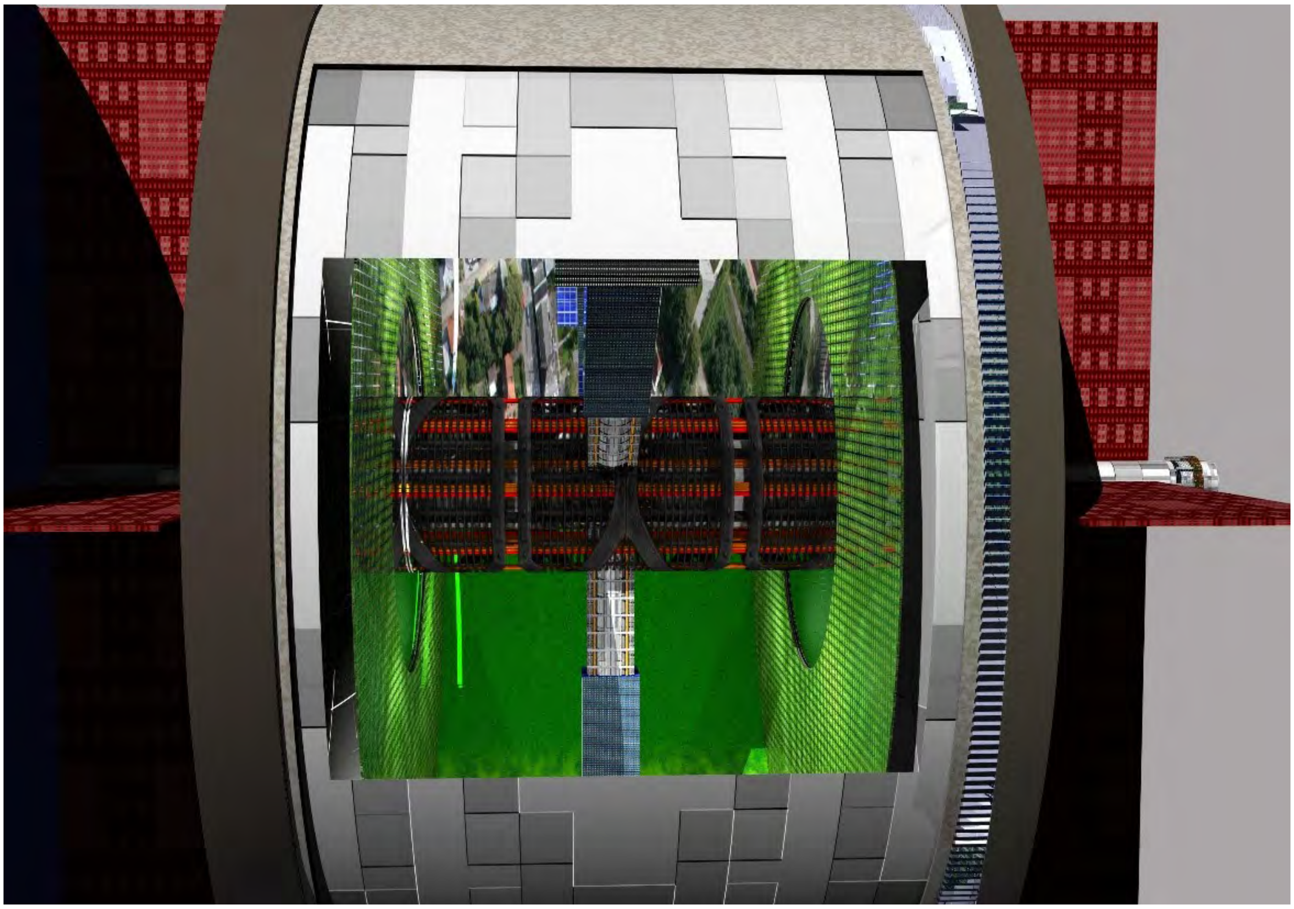
Figure 2. Double hull cross sectional diagram.
(Image credit Stephen Gunn.)

The design uses a cylinder rather than a sphere to maximize the habitable surface at constant gravity and provide shielded space for agriculture (Figure 3). Rock, left over from processing asteroid regolith for volatiles and metals, is vitrified and reinforced with steel to make a strong one-piece shield hull. It is unpressurised so it can have flat endcaps to save mass, but the pressure hull must have curved ends for strength. A concave shape is chosen to leave room inside the shield hull for spacecraft docks protected from radiation and abrasion from micrometeorites (Figure 2).

The long cylinders often portrayed in both habitat and spaceship designs are rotationally unstable and will eventually start spinning end-over-end. To prevent toppling the radius to length ratio must be less than 1.3 resulting in the shape of Avalon which resembles a tuna can.

Although people can probably adapt to higher rotation rates, 1 -2 rpm is likely to be unnoticeable and minimize any disconcerting phenomena arising from the Coriolis effect. Conveniently, the desired 1 g of internal gravity at 500 m radius requires a rotation rate of 1.3 rpm for the pressure hull – the more massive shield hull rotates more slowly while maintaining net zero angular momentum.

Figure 3. A general cutaway view of Avalon through both hulls into the interior.
(Image credit Stephen Gunn.)



It is vitally important that both hulls are manufactured accurately to avoid any unsymmetrical distribution of mass and a built-in tendency to wobble. High accuracy is also necessary to provide sufficient clearance between the contra-rotating cylinders. Both hulls are therefore constructed by 3d printing in a jig-factory to ensure the “print heads” rotate very accurately to lay down the hull matrix to very fine tolerances.

Also, mass must be distributed evenly around the circumference of both hulls when building both internal and external structures to minimize wobble on spin-up. Temporary changes in mass distribution are inevitable in an occupied habitat, however, as vehicles, equipment, goods, and people move around. These cause small changes in hull spacing; measured accurately with lasers and countered by automatically pumping water between ‘trim’ tanks round the inner hull.

The counter-rotating hulls risk catastrophic failure [4] should they make contact, so management of this critical risk is discussed in some detail. Of utmost importance is the maglev system used to keep the inner and outer hulls apart.

3.2 The maglev system

The various forces acting on an orbiting habitat that must be resisted by the maglev system can be summarized as follows -

(1) Internal forces imposed by station-keeping.
(2) Collisions with spacecraft or meteorites.
(3) Internal forces imposed by the habitat's precession to maintain sun-facing orientation for the solar cells.
(4) Perturbations from internal displacements of mass, including large movements of people.

To manage these internal forces, it is estimated that an internal maglev system capable of delivering forces >100 kN (equivalent to 10.2 t at 1 g) is required, similar to the axle load of the driving wheels (>10 t) of a typical articulated lorry. This should be sufficient to absorb collisions by spacecraft as massive as the shuttle orbiter up to relative velocities of 40 m sec^{-1} or impacts from meteorites <400 kg. It should also be able to cope with a rapid redistribution of mass, up to (for example) a catastrophic collapse of internal decking spanning about 40 m or mass evacuation of the population.

Of the various options, electrodynamic suspension (EDS) systems* are attractive because they are dynamically stable. Changes in distance between the track and the magnets create strong restoring forces so no active control is needed. EDS systems levitate but do not propel so require separate linear motors for propulsion.

The system chosen is a recent development called magnetodynamic suspension (MDS), which uses the attractive magnetic force of a Halbach array of permanent magnets near an aluminium or stainless-steel clad steel track for lift and stability [5]. The self-regulating MDS system provides levitation while propulsion and guidance come from a permanent magnet linear synchronous motor (LSM). This method provides failsafe suspension because no power is required to activate levitation magnets. It also avoids the need for the complex cooling systems used by superconducting magnets reducing risks and minimizing maintenance requirements.

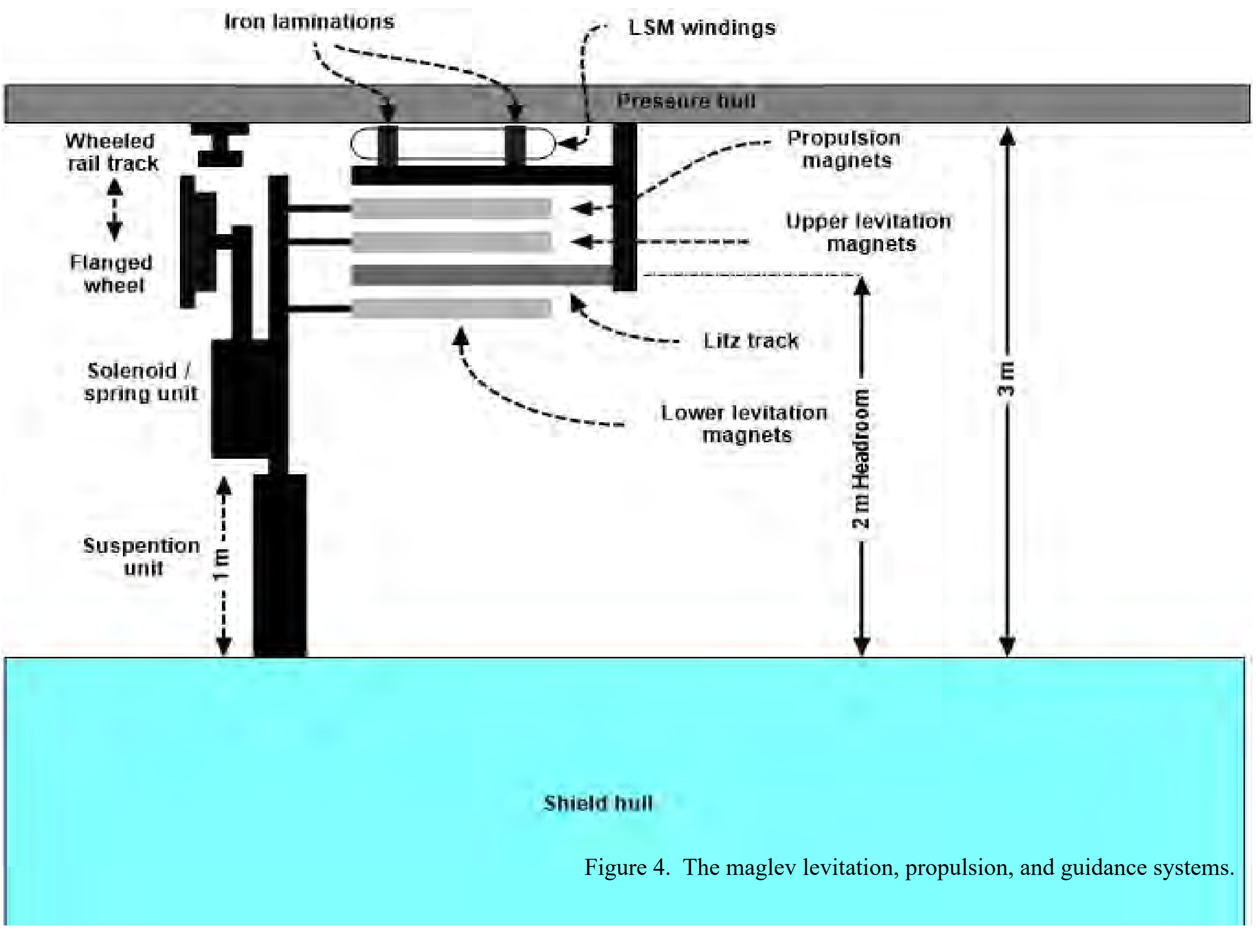


Figure 4. The maglev levitation, propulsion, and guidance systems.

* en.wikipedia.org/wiki/Electrodynamic_suspension

Double levitation arrays with propulsion, and guidance systems for Avalon are seen in Figure 4. It shows the 1 m wide, 4 m long, arrays of levitation magnets in relation to the cantilevered ladder track. The propulsion permanent magnets also provide guidance by interacting with the LSM iron lamination rails.

A power cut would cause the entire system to slow and eventually stop with a complete loss of pseudogravity, guarded against with two separate back-up power supplies. In the unlikely event that this should also fail, a wheeled secondary bearing system, also shown in Figure 4, ensures that it would fail-safe.

3.3 Avalon's part closed ECLSS [6]

The main outputs from an environmental control and life support system (ECLSS) are clean air (mainly by CO^2 removal and O^2 regeneration), clean water and nutritious food.

A basic closed ECLSS, or artificial ecosystem was modelled first, combining biological and mechanical components, capable of providing a varied, though limited, balanced diet and recycling nutrients. The simple spreadsheet model showed that mass balance is achievable provided all waste biomass is fully oxidized by supercritical water oxidation (SCWO)* to recycle nutrients, especially carbon and oxygen. This key equipment operates at high temperature and pressure, so is vulnerable to failure with severe consequences for the functioning of the ECLSS. The basic system is also inefficient with much edible biomass being recycled. The spreadsheet model was therefore extended (shown schematically in Figure 5) with additional processes using animals, fungi, and microorganisms to decrease risk while increasing efficiency by maximizing value extracted from crop biomass and increasing the range of foodstuffs.

Supercritical water oxidation (SCWO) is the only recycling process for the basic ECLSS whereas it is largely, but not completely, replaced by biological methods in the extended version thereby reducing the risk of failure of the high-tech equipment. If composted biomass is used to make soil, SCWO becomes redundant for recycling eliminating entirely the failure risk. This approach is adopted for Avalon although SCWO is retained as emergency backup to the biological recycling systems and to dispose of toxins in wastewater (including excreted drugs).

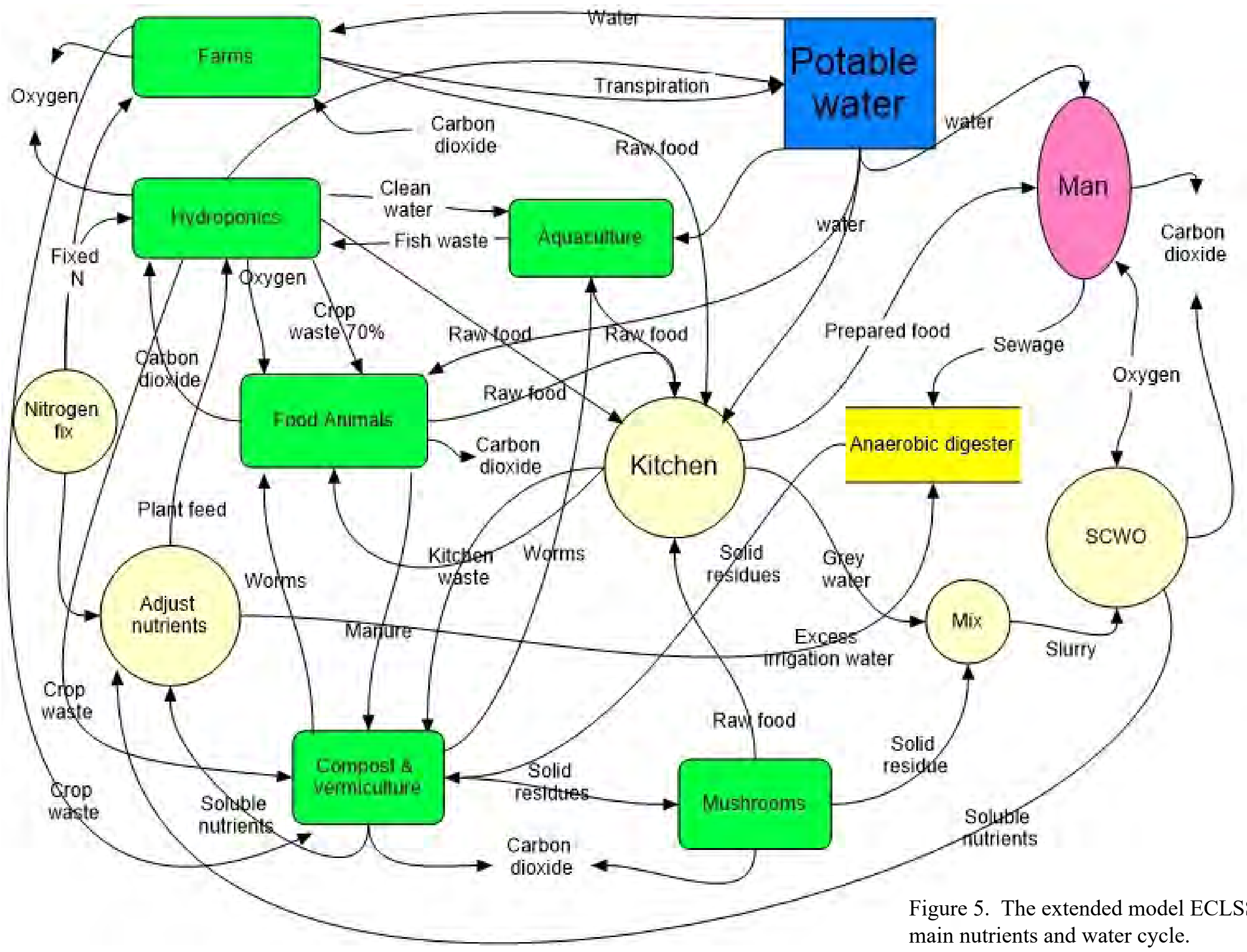


Figure 5. The extended model ECLSS main nutrients and water cycle.

* en.wikipedia.org/wiki/Supercritical_water_oxidation

A fully closed ECLSS is probably impossible. At a minimum, hydrogen, oxygen, nitrogen, and carbon lost from airlocks must be replaced as will any nutrients lost to the ecosystem as products (eg soil, wood, fibres, chemicals). This presents a resource-management challenge for any fully autonomous spacecraft and an economic challenge even if only partially autonomous.

Recycling does not provide a primary source of fixed nitrogen for new plant growth and significant quantities are lost to the air as N_2 because of uncontrollable denitrification processes. The total loss per day for Avalon has been estimated at 43 kg to be replaced from the atmosphere.

3.4 Growing conditions

Avalon emulates ideal growing conditions on Earth with air of almost standard composition, ample water and plant nutrients and illumination from sunlight (or artificial equivalent). Temperature is 25 °C, and RH 50%, chosen as comfortable for people and good for food producing plants and animals including fish.

3.5 Lighting

Day length is important, affecting plant growth as well as human sleep patterns. Modern cities operate continuously using artificial lighting and an orbital habitat need be no different facilitating interaction with all Earth time zones. Also, support staff are on different shifts making an arbitrary light/dark cycle counterproductive.

Continuous illumination is therefore selected with blinds or windowless bedrooms enabling dark sleeping periods to promote a healthy work/sleep pattern. It also means that neither sunshades for artificial night nor street and interior lighting are needed. A further important benefit is that heat flow is no longer cyclic, and a steady state more readily achieved.

Avalon uses cold-light mirrors, which reflect visible light inside but transmit UV and IR. This means that all the energy brought inside Avalon from sunlight is in the visible range so light production is 100% efficient. In contrast, the best white light LEDs are just 50% efficient, so double the heat burden should they be used.

Light levels inside Avalon are determined by the minimum requirements of people at 10,000 lux, equivalent to shade illuminated by a bright midday sky in Summer. Light at 10,000 lux is sufficient for propagation and growing leafy vegetables but fruiting crops need supplementary lighting by narrow-band red and blue LEDs in the hydroponics units to ensure maximum yield. These may or may not be used continuously depending on the requirements of individual crops while dark periods, needed by some plants, are provided with blinds.

Although comfortable for people but marginal for crops this level of lighting reduces waste heat by a factor of 10 compared to full sunlight.

3.6 Heat balance [7]

The shield hull is warmed by waste heat, mainly from the maglev system, but also from other hull-mounted facilities that use power. The power for these external facilities comes from a separate electrical supply mounted on the shield hull, amounts are sufficiently small that it is not necessary to use dedicated external radiators.

Heat Source	Power MW	Radiating surface area km²	Radiator area km²
Sunlight	125.56	0.44	0.22
Electric external end cap	264.00	0.93	0.46
Total	389.56	1.37	0.69

Table 1. Overall heat input and disposal.

Internally however, the waste heat generated from solar radiation and electricity consumption from external photovoltaic panels (Table 1) must be removed and dumped to avoid overheating. A spreadsheet model was used to calculate heat flow taking large amounts of waste heat from throughout the habitat to the external radiators (Figure 2) accessed through the counterrotating shield hull via the hub. The only viable transport mechanism was to use the ventilation system to carry it as latent heat absorbed during evapotranspiration in the food growing areas and recovered when water vapour was condensed for recycling in air conditioners mounted at the hub. Even so, heat transport proved to be such a problem that it became necessary to reduce the main source and minimize the amount of internal lighting by the measures outlined above.

3.7 Space required for the ECLSS

Calculations of the area required yield a minimum of 130 m^2 per person for hydroponics, plus aquaculture, animal, and fungi units to extract added value from waste. Together these provide for food and water, air, carbon, and nutrient recycling. The system for Avalon combines the aquaculture and hydroponics units as aquaponics for improved efficiency (Figure 8). This space estimate does not depend on biological nitrogen fixation (BNF)* using plants, for which the area required would almost double. Fixed nitrogen must therefore be supplied as fertilizer from either chemical or biological synthesis from the air or imported together with carbon and water. For a population of 10,000, the total growing area without nitrogen fixation becomes 1,300,000 m^2 (130 ha).

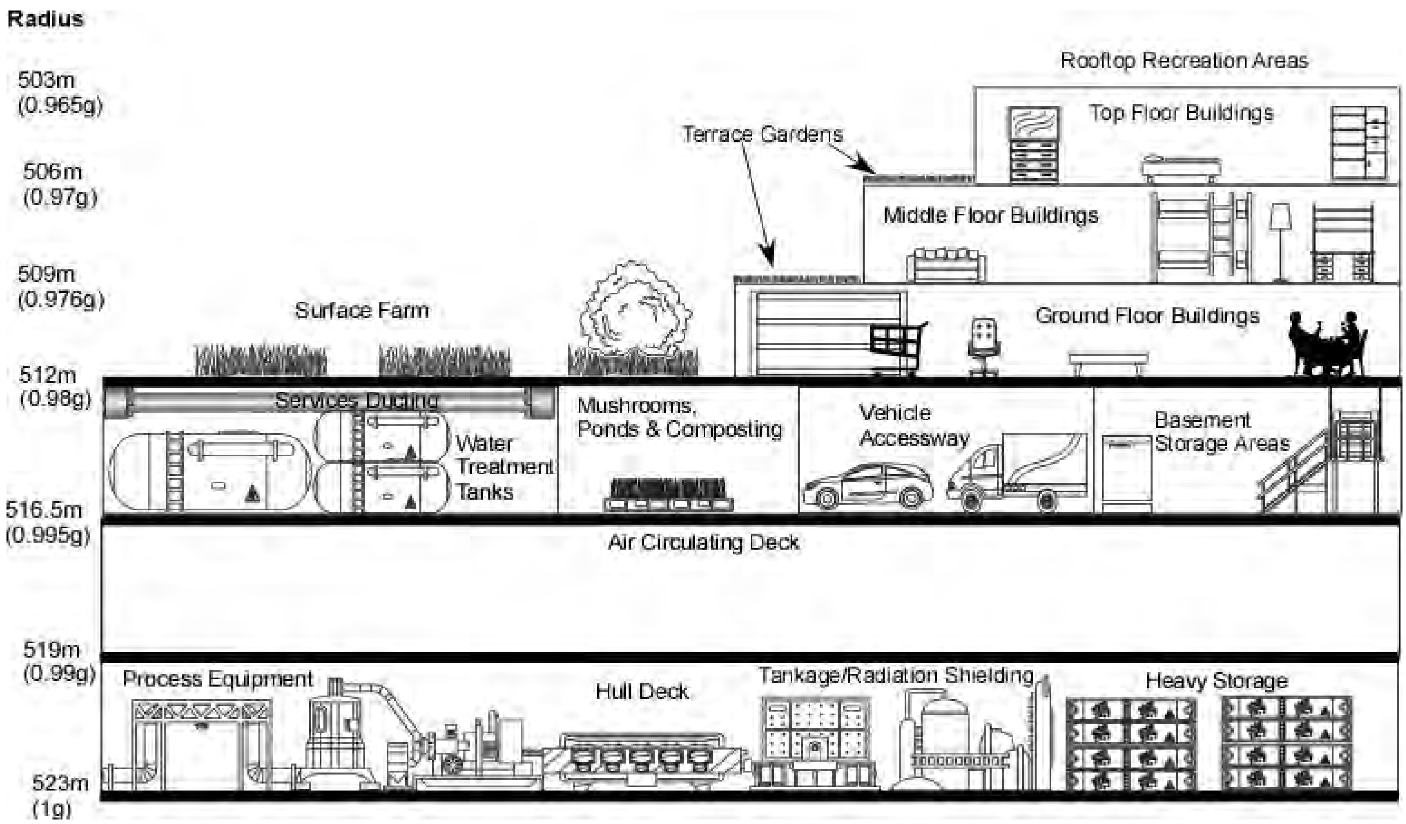


Figure 5. Shows the habitat deck layout; detailed in the text. (Image credit Stephen Gunn.)

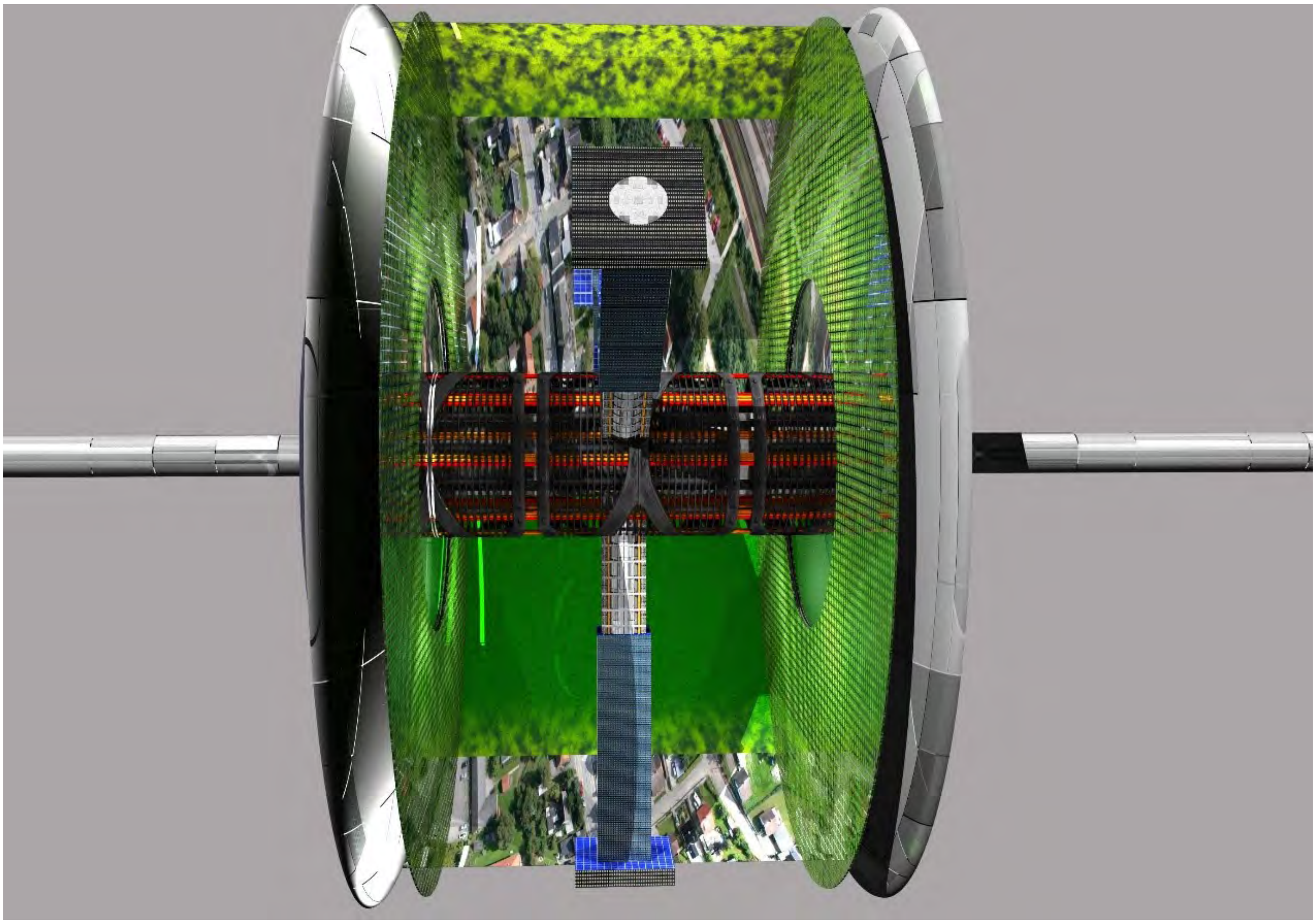
Avalon has four decks, three of which are below “ground” level, while the top (4th) deck provides additional growing space in three farms separated by villages (Figure 5).

The 3rd deck accommodates drainage sumps including clean and dirty water storage and processing tanks. These are linked to the anaerobic sewage and food producing aerobic spirulina bioreactors and vermiculture /composting and mushroom production units. The 3rd deck also provides space below the villages for transport routes, storage and, possibly, “underground” windowless bedrooms.

The 2nd deck contains the fans and ducting used to draw clean, cooled, dry air from the bottom of the airshafts and distribute it throughout the other decks before being vented into the interior. Finally, the 1st (hull) deck is used for heavy machinery.

* en.wikipedia.org/wiki/Nitrogen_fixation#Biological

Figure 6. Interior view showing end-cap greenhouses and distant farmland. Also shown are the central hub and transfer shafts. (Image credit Stephen Gunn.)



3.8 Endcap aquaponics/greenhouses

The endcaps are ideal for growing plants as they are illuminated as much as, if not more strongly than, the surface of the top deck. Most food is produced in factory style aquaponics units built into vertical greenhouses 300 m high (Figure 6) to give the necessary 130 ha of growing space.

There are 60 greenhouse floors attached to each endcap, 4.9 m apart with gravity decreasing from 1 g at ground level to 0.41 g at the top. The concave elliptical shape of the endcaps means the available floor space behind the inward facing glass walls also decreases with height. This effect is most noticeable for the lowest 21 floors as shown in Figure 7. Nevertheless, there is room for aquaponics units on all 60 floors while the large unused areas to the rear on the lower levels provide storage space. Also, in this backspace are lift shafts, stairs and vehicle ramps attached to the support webs (not shown in Figure 7).

The greenhouses face the sunlit interior and plants are grown close to the glass with a silvered back wall just 3 m away helping with the required high level of illumination. Even so, heat load constraints mean the imported sunlight is barely adequate for growing plants and some supplementary lighting is necessary using red and blue LED grow-lights to promote flowering and fruiting.

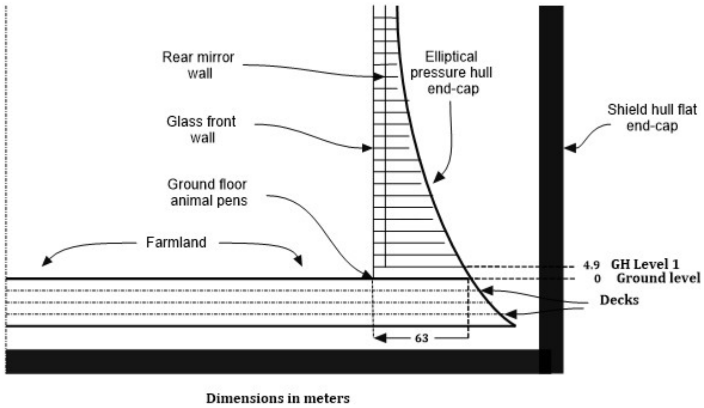


Figure 7. Shows how each greenhouse (bottom 21 levels) attaches to the concave pressure hull endcap above the four decks.

The LEDs are mounted in front of the mirror wall, so they illuminate the more shaded side of the leaves. Blackout blinds to simulate night, or netting for shading, are fitted to the greenhouse windows as necessary to provide the right growing conditions for individual crops.

The nitrogen cycle is a critical part of ECLSS recycling, and the lost fixed nitrogen must be replaced. Avalon uses single cell algae (spirulina) in fermenters to provide high protein fish food for the aquaponics units with the added fixed nitrogen passed directly to plants in the associated hydroponics compartment (Figure 8).

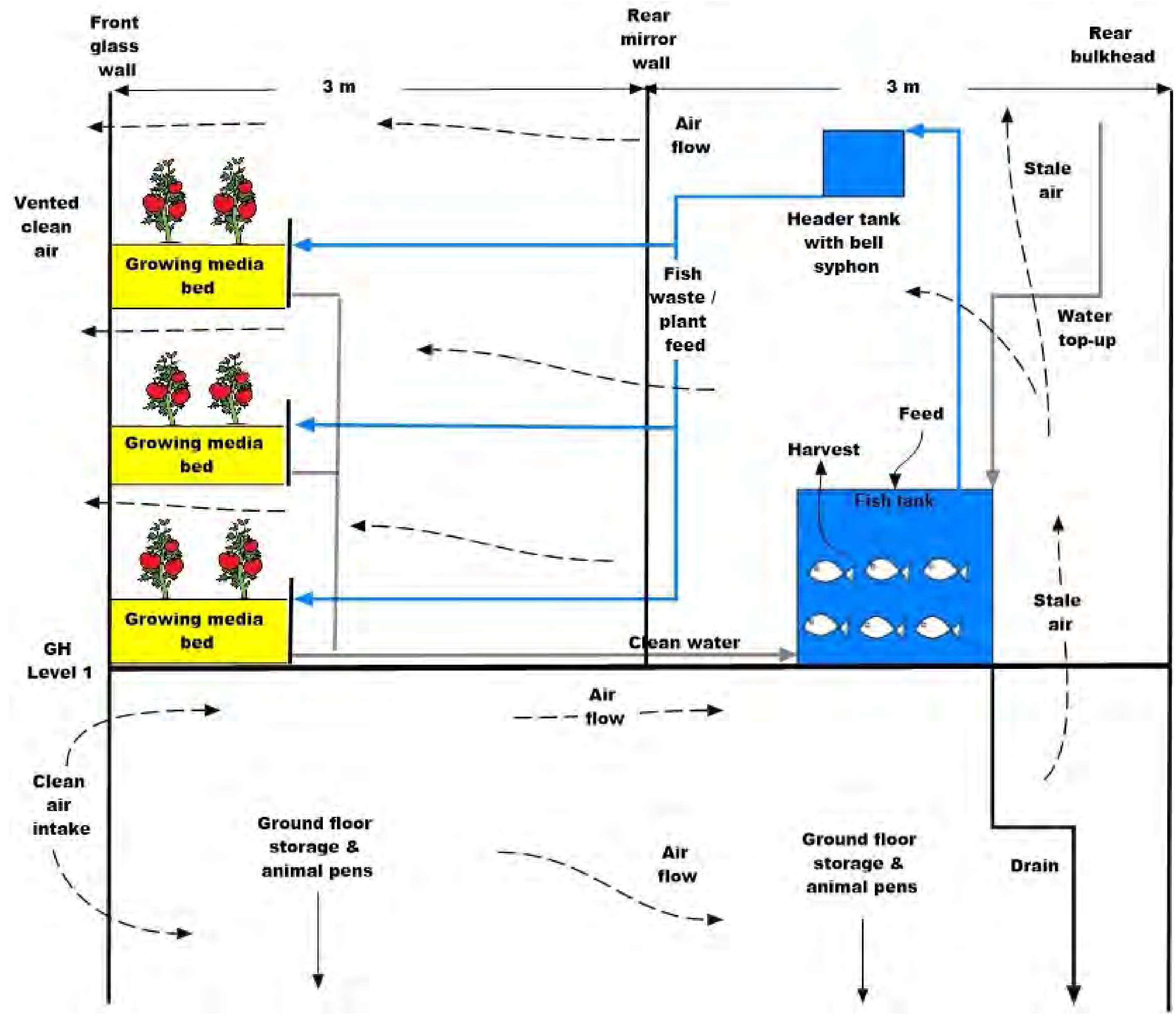


Figure 8. Shows the lowest level of the endcap greenhouse detailing the hydroponics/aquaculture units situated above the ground floor storage and animal pens. (Not to scale.)

The fish culture water provides the plants with the necessary nitrogen, potassium, phosphorus, and micronutrients without any supplementary dosing. The plant roots act as bio-filters for the toxic fish metabolites and so clean the water before it is recirculated back to the rearing tank. Most importantly, nitrifying bacteria live within the support medium and metabolize ammonia produced by the fish oxidizing it to nitrate to improve water quality and provide a more available source of nitrogen for the plants.

Fish tanks occupy a quarter of the floor space required by the 30 cm deep growing beds. Fish are reared in cohorts and moved to ever-larger tanks as they grow until they reach maximum size and are harvested along with the associated batch of plants to maintain a suitable balance. Although the water is recirculated, some is lost to evapotranspiration and is made-up with condensate from the hub dehumidifiers piped down to the fish/header tanks on each floor (Figure 8).

The food production units are sized to match the population so the output from the aquaponics, animal and mushroom units are just sufficient (Table 2).

Source	**Mass kg/pp/ day**	**Proportion of requirement %**
Vegetables	0.32	52
Milk	0.06	9.7
Eggs	0.06	9.7
Meat	0.06	9.7
Fish	0.02	3.2
Mushrooms	0.04	6.5
Remaining solids	0.06	9.7
Total	0.62	100

Table 2. Human food supplied from the various production units. (The farms cannot grow food until soil is made so their anticipated output is omitted.)

3.9 Disease control

The most important step in preventing plant disease in a space habitat is to avoid importing plant pathogens. All imported seed and plant material must therefore be tightly controlled and come only from certified stock. The most likely source of imported pathogens comes from the need to bring in decayed plant material (compost) to start soil formation. Precautions must therefore be taken within Avalon to minimise the impact of plant disease should it occur.

The three farms and two endcap aquaponics units are physically isolated from each other and are operated as independent sub-systems. Also, each of the five, food producing sub-systems has its own dedicated set of spirulina bioreactors and recycling units to help maintain their isolation from each other. Consequently, plant material, compost and animal feed are never shared but recycled within each sub-unit; measures that help prevent the spread of disease and/or manage other problems with output.

The complete agricultural system uses large amounts of water, mostly (70%) in the soil, and far in excess of that required elsewhere (Table 3).

Medium	**Mass t**	**Proportion %**	**Total Water t**	**Water pp t**
Air	352,200	1	3,500	0.35
Soil	1,132,000	25	283,000	28.3
Hydroponics	82,500	30	27,500	2.75
Fish tanks	41,300	100	41,300	4.00
Crops	2,500	90	2,270	0.23
People	700	90	630	0.06
Fruit trees	200	200	400	0.04
Timber	11,500	200	23,000	2.3
Ponds, pools	20,000	100	20,000	1.00
Pipes etc	1,000	100	1,000	0.1
Total water			402,600	40

Table 3. Distribution of water in the various sub-systems. (Soil is included because of its importance although it has not yet been made.)

3.10 Nutrient imports and Oxygen for export

The following estimates of losses to the system assume a mature ECLSS with the nutrients locked up in biomass mainly being recycled. During the time that the ECLSS is being established, nutrients will need to be imported in ever increasing quantities until the rate of increase in biomass becomes stabilized.

In Avalon, waste biomass is composted and used to make soil. Most of the compost within the soil is broken down by microorganisms releasing plant nutrients in the process. This process does not go to completion, however, and some recalcitrant carbon compounds remain to make humus, the organic part of fertile soil. For every 1 t of C sequestered 2.66 t of O_2 remain in the atmosphere and, since it is not then used for recycling, it will accumulate. The excess oxygen must be removed to maintain the required partial pressure and the lost carbon replaced as CO2 required by growing plants.

Instead of making soil, however, waste biomass can be reformed using hydrothermal methods to make useful chemical products [7].

Products (t/yr)		**Ex-ECLSS (t/yr)**	**Imported nutrients (t/yr)**		
		Biomass	C	H_2O	N
LOX	10,073	7,555	3,778	11,332	
LH_2	108				15.7
CH_4 sewage	44				
CH_4 biomass	4,282				
Or glucose	8,300				
Or ethanol	2,145				
Or acetic acid	1,492				
Or lactic acid	3,820				

Table 4. Products from biomass following food production and replacement nutrients required.

Significantly, the glucose could be fermented to yield 3,820 t/yr of lactic acid for conversion to poly lactic acid which can be used in 3d printers to make a wide range of plastic items that are completely biodegradable.

Avalon is therefore not a closed system and nutrients locked up as soil, and other products such as wood and fibres for clothing, must be imported and the excess oxygen exported.

Products and replacement nutrients to be imported are shown in Table 4. They depend on waste biomass from food production and not especially grown for industrial feedstock, so quantities are necessarily limited.

3.11 Governance and control

Avalon is expected to operate in a system of space law that allows its inhabitants and controlling entities legally to acquire resources and to trade and which will enshrine their rights and responsibilities [8].

Avalon follows the example of the ISS and uses a tiered system of computer control [4]. The Tier 1 (top tier) control system directs the operations of other subservient lower tier systems. Data or telemetry rises from the lower tiers back to the top where it is radioed to Ground Control or sent to the crew's portable computer system. Tier 2 (local tier) is where major functions such as guidance or thermal control are performed. All the sensors, fans, pumps, valves, etc are controlled at Tier 3 (user tier).

Recent rapid advances in artificial intelligence (AI) should provide significantly more on-board capability than the ISS and enable Tier 1 to be under local instead of Ground Control. However, although current (and probably near future) AIs can outperform humans in specific well-defined areas they are not really intelligent and do not understand the consequences of their actions. Avalon's Management System (AMS) therefore consists of a master AI overseen by and working under the control of a human management team, a very powerful combination. The AMS consisting of both human and AI components remains subservient to the Council and operates according to overarching policy guidelines provided by, and periodically reviewed and up-dated as necessary by the Council.

3.12 Emergency response

If a major incident should render Avalon uninhabitable, the entire population could be evacuated to an onboard "safe haven" and, if necessary, from there to Earth.

4 Implications for interstellar worldships

Avalon must provide a safe comfortable environment for workers and their families, so a conservative approach is adopted. It therefore has Earth-like conditions of air composition and sea level pressure, gravity, and ionizing radiation with comfortable levels of temperature, humidity, and lighting. It is possible, however, that some of these conditions might be relaxed because of experience gained in lunar, Martian or orbital settlements. In particular, air pressure could almost certainly be reduced safely to the levels found in certain high-altitude cities, such as Denver Colorado, with populations in the millions. The consequent reduction in mass being helpful for a worldship. Unfortunately, the huge mass of radiation shielding has already been cut to the minimum and could probably not be reduced further because it is not adequate for pregnant women who might need to take additional precautions. The levels of lighting, temperature, humidity and pseudogravity have little if any impact on mass so are less critical for a worldship and the values chosen will depend on other factors. Although the appropriate level of pseudogravity is not known for certain, we do know that full Earth gravity has a major influence on the development and maintenance of the human body while extended exposure to microgravity has a large negative impact. We also know the importance of exercise and that long periods of inactivity or bedrest have a negative impact on human health. It may well be that humans will be able to live relatively healthy lives at reduced gravity levels on Mars but perhaps not on the Moon. It would be unethical, however, to raise children under conditions that had a negative impact on their development so that they were unable to ever return to live on Earth. This issue takes a different form, of course, for interstellar worldships where a return to Earth is not anticipated and the gravity at the destination may differ from that of Earth.

Orbital settlements for permanent occupation over many generations must be robust and reliable. Regular maintenance and repair, with major re-fits to replace damaged or worn components and obsolete equipment, will enable the main structures to endure with design lifetimes of perhaps 1,000 years.

These principles apply directly to interstellar worldships as recognised by Patrick Mohan [9] who, amongst other things, recommends a circular economy – an industrial system that is restorative by design. Used items are not simply replaced but regularly inspected and maintained. If necessary, they are repaired and reused or repurposed but recycled only when beyond repair. Furthermore, he shows that a recycling rate better than 90% is necessary for a significant proportion (>36.6%) of a material to remain useable after 100 y. Recycling must therefore be managed carefully, and a detailed inventory maintained of all materials and nutrients wherever they are in the system. Lost materials cannot leave the ship, of course, so will accumulate, in the case of heavy metals and plastics, perhaps to toxic levels.

4.1 Construction

The infrastructure for a mature orbital civilization may well be built by largely autonomous jig-factories controlled by AIs, powered by solar energy and utilizing asteroid regolith. Using 3d printers gives the flexibility to build a wide variety of megastructures for use in space including large habitats and interplanetary spacecraft. This pre-existing capability could build worldships at a cost comparable to large orbital habitats so building and launching them would be unexceptional and certainly not the heroic endeavour often assumed.

4.1.1. Rotating hull sections and magnetic bearings

An interstellar worldship will almost certainly require a rotating habitat attached to non-rotating hull sections. Counter-rotating double hulls are a key feature of Avalon, the absence of net angular momentum simplifying orientation and manoeuvring. A worldship design could utilize counter rotating twin habitats to achieve the same effect.

There is a clear risk of catastrophic failure should the bearings fail. Management of this critical risk is key, and the chosen type and design of maglev system should, with regular maintenance and repair, provide a robust long-term solution.

4.2 ECLSS.

Although the modelling results are self-consistent, and no fundamental showstoppers were identified, this theoretical study leaves much practical detail to be resolved for the ECLSS for which a working system has yet to be demonstrated. Nevertheless, there is sufficient confidence in the results for them to be used to predict requirements for an interstellar worldship.

An important finding was that a fully closed ECLSS is probably impossible. At the very least, nutrients removed from the ecosystem as wood, fibres, and chemicals, or otherwise rendered biologically unavailable, must be replaced. Also, the oxygen released by photosynthesis and not immediately used to recycle products must be removed from the atmosphere and stored until they are recycled at the end of their useful life. A sensitive issue is the treatment of dead bodies which will almost certainly have to be recycled in a worldship.

If a flourishing orbital economy is a prerequisite for building worldships, it follows that there will be decades, perhaps centuries, of experience of building and maintaining artificial environments and ecosystems before such an enterprise is attempted. Although orbital habitats will not have the same imperative as worldships to be closed systems, their operation must still be tightly controlled for economic reasons. Biological recycling is more efficient than the technological methods used for manufactured items but cannot be perfect and the inevitable losses must be replaced in both an orbital habitat and worldship, from imports and stores, respectively.

All the energy brought inside Avalon from sunlight is in the visible range so light production is 100% efficient. In contrast, the best white light LEDs are just 50% efficient, so double the heat burden. Since artificial lighting is the only option for a worldship ventilation and waste heat management will be even more challenging than it proved for Avalon.

The area required for the ECLSS is estimated at a minimum of 130 m^2 per person for hydroponics, plus aquaculture, animal, and fungi units to extract added value from waste. Together these provide for food and water, air, carbon, and nutrient recycling as well as heat management. For a population of 10,000, the total growing area without nitrogen fixation becomes 1,300,000 m^2. The water inventory shows just how much water is required for intensive agricultural systems where demand is many times that required for light industrial and personal use. Most water (70%) is absorbed into the soil which when wet has a mass of ~1.4 Mt. Consequently, a worldship should avoid using soil because the added mass would be unaffordable in energy terms.

These requirements of the ECLSS illustrates just how much space, and therefore mass, is necessary to feed everybody, even using highly intensive agriculture, and has clear implications for a worldship.

Avalon adopts measures to keep different parts of the food production system isolated from each other to help prevent the spread of disease and/or manage other problems with output. A modular approach for food production, perhaps between counterrotating twin habitats, would be similarly beneficial in a worldship.

A surprising finding was that the plant growing areas of the ECLSS are fundamental to the cooling system of the habitat and demonstrates the complexity and interconnectedness of the artificial ecosystem. It also became clear that it is necessary to seek to optimise the whole system even if the operation of some sub-systems is then less than optimum.

4.3 Governance

Avalon is expected to operate in a system of space law that allows the legal acquisition of resources and trade and which guarantees rights and responsibilities. An Interstellar ship will be constructed within the extant legal framework and, initially at least, Earth law can be expected to control the actions of the crew in flight.

Whatever system of governance is used for a worldship the ruling entity (probably a captain and officers) will be constrained by international law and Company Policy. Executive orders will be carried out by officers and crew aided by autonomous sub-systems to manage the complex functions of the ship.

4.4 Emergency response

Safe havens are a key feature of the emergency response for Avalon. During an interstellar journey with nowhere to evacuate to, it is essential that a modular design be used for the habitation compartments, each capable of housing the entire population in an emergency. A fleet of worldships is a natural response to the most extreme threats.

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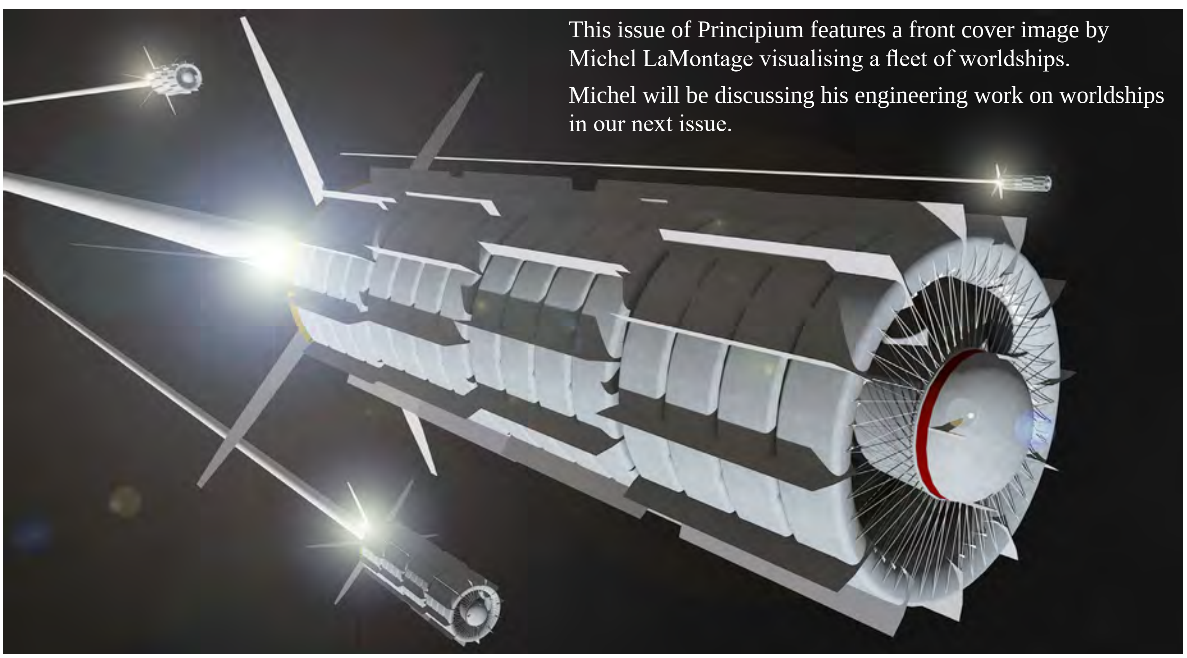
About the Author

Dr Richard James Soilleux is a member of the project team developing the BIS SPACE project (Study Project Advancing Colony Engineering). He is the author of the Foreword to the special edition of the Journal of the British Interplanetary Society (JBIS) incorporating the core papers arising from the BIS SPACE Project and several of the papers emanating from the SPACE project. His career has been with the UK Ministry of Defence (MoD) in Chemical Defence specializing in methods for the safe destruction of chemical weapons. He was one of the UN's weapons inspectors in Iraq and led the UK chemical weapons disposal team in Libya. He was also a technical advisor to the Japanese Government for the disposal of legacy weapons in China. Dr Soilleux holds degrees from Portsmouth University and his PhD was in reaction kinetics.



This issue of Principium features a front cover image by Michel LaMontage visualising a fleet of worldships.

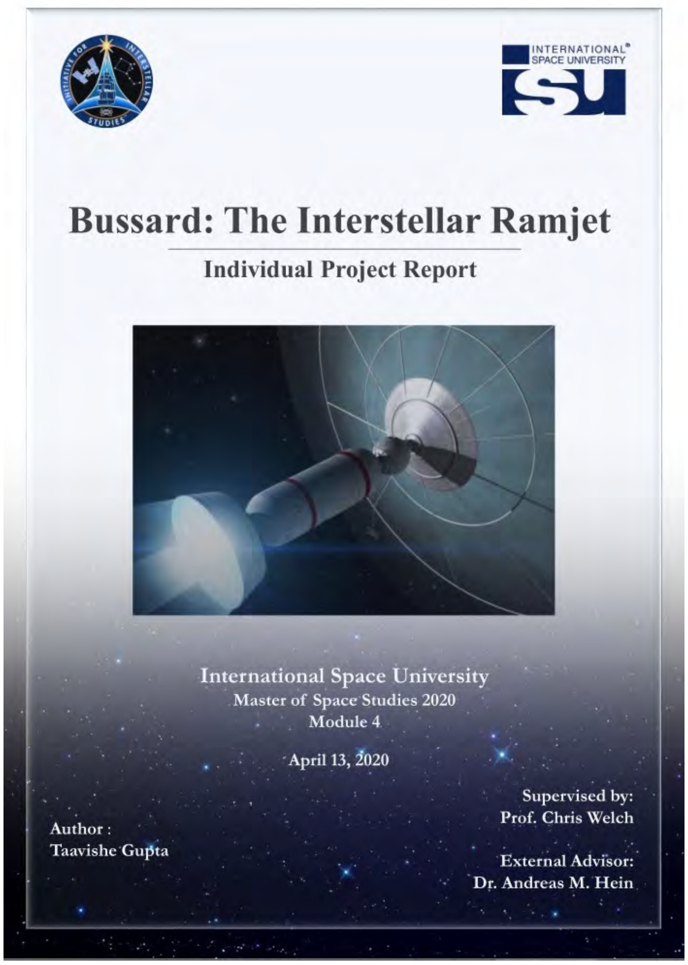
Michel will be discussing his engineering work on worldships in our next issue.

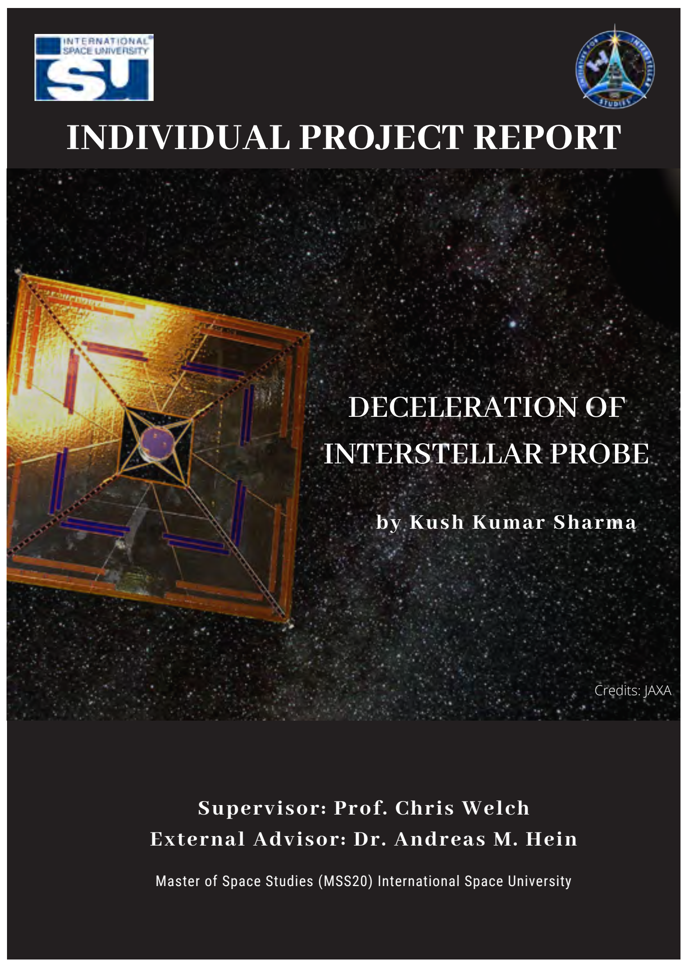
News Feature: i4is-supported ISU MSS Projects - Bussard Ramjet and Deceleration of Interstellar Probes

Patrick Mahon

ISU Master of Space Studies students explore the Bussard Ramjet and the deceleration of interstellar probes in their Master's dissertations. Patrick Mahon reports on two recent project reports from ISU students supported by i4is, which investigate a couple of interesting interstellar research topics.

i4is has worked with the International Space University for several years now. One of the ways we do this is by offering the time and guidance of our experts to ISU students on their Master of Space Studies course [1] when they are undertaking their final project. Over the last year, two ISU students asked to work with i4is on interstellar-themed projects: Taavishe Gupta on the Bussard Interstellar Ramjet, and Kush Kumar Sharma on the Options for Decelerating an Interstellar Probe. Both benefited from having our Executive Director, Dr Andreas Hein, as their External Advisor, working closely with their supervisor, Professor Chris Welch. This article summarises their project reports.



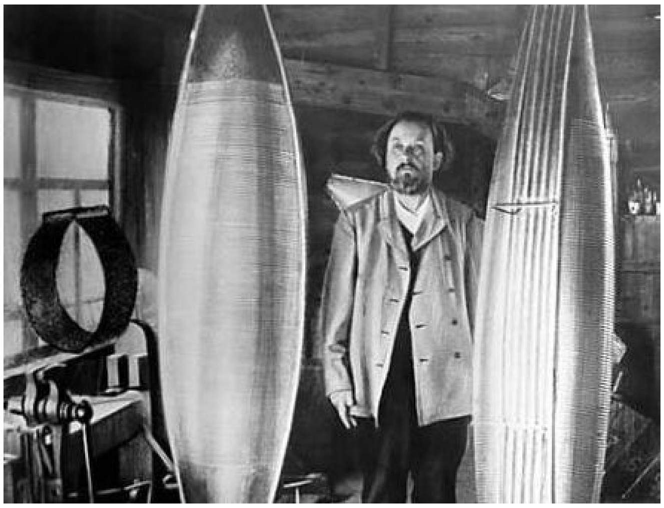


Taavishe Gupta, Bussard: The Interstellar Ramjet

Taavishe Gupta's report [2] considers the feasibility of the Bussard Interstellar Ramjet. As many readers of Principium will be aware, Bussard developed his ramjet concept in 1960 as a solution to the challenges imposed on interstellar missions by the Tsiolkovsky rocket equation:

$\Delta V = V_e \ln (m_i/m_f)$

The equation tells us that the change in velocity (ΔV) produced by a rocket of initial mass m_i (including propellant) and final mass m_f (once all the propellant has been used) is given by the product of the rocket's exhaust velocity V_e and the logarithm of the ratio of initial to final mass. It's the appearance of the logarithm that causes problems for interstellar travel. For any realistic mass ratio, delta-V will never be more than a few multiples (three is a good rule of thumb) of your exhaust velocity. And for the propulsion technologies that are feasible now or in the near future, that generally leads to interstellar journey times of hundreds to thousands of years.



Konstantin Eduardovich Tsiolkovsky (1857-1935) in his workshop.
Credit: BBC / rambler.ru

BBC *Great Lives* -
www.bbc.co.uk/programmes/m000ltfm

Tsiolkovsky governs the maximum performance of any rocket that carries its own propellant (comprising fuel and oxidiser) on board. Bussard's revolutionary idea was to consider whether it might be possible instead to pick up your propellant as you go along, just as an aircraft takes its oxidiser from the surrounding air as it travels along, adding it to the fuel carried on board. Although we think of space as a vacuum, it's not completely empty. The interstellar medium contains a low density of material, roughly 99% of which is gas, with the rest being dust. The gas is mostly hydrogen or helium. Bussard's idea was to collect that interstellar gas, and use it as fuel.

To do so, Bussard placed a large diameter electromagnetic ram scoop at the front of his spacecraft, facing forwards. This is intended to collect and compress the interstellar hydrogen encountered by the vehicle as it moves, this material then providing the input to a fusion engine. See Figure 1.

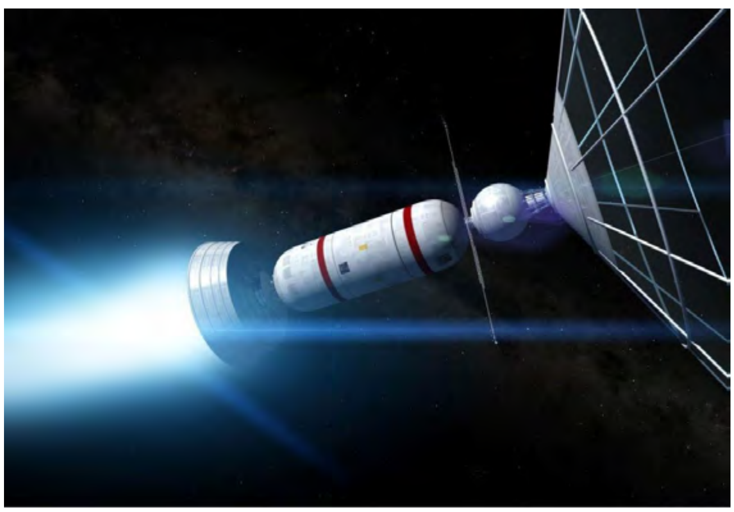


Figure 1. A visualisation of the Bussard Ramjet.
Credit: Adrian Mann

In the six decades since Bussard proposed the original design, there has been much commentary on it*. Many authors have pointed to significant technical challenges to the successful operation of a Bussard Ramjet.

Three of the most significant are:

- that the ram scoop has to be huge to collect enough fuel;
- such a huge scoop then potentially creates more drag on the spacecraft than the thrust generated by the fusion engine; and
- the use of interstellar hydrogen as the fuel is problematic, as the reaction is slow and suffers high radiative losses.

Other researchers have, however, sought to modify the original design so as to overcome these various problems.

Some of the most important proposals (each of which are discussed in detail in an interesting 2019 paper by i4is's friend Al Jackson [3]) are:

- the laser-propelled ramjet – where the ramjet still collects the fuel, but this is accelerated out the back of the spacecraft by a linear ion accelerator powered by energy received by the spacecraft from a laser on or near to Earth, thus avoiding the problem of using hydrogen as the propellant for a fusion engine;
- the ram-augmented ramjet – which works by burning the interstellar hydrogen alongside an onboard source of reaction mass, such as antimatter, in order to overcome some of the problems with the proton-proton nuclear reaction; and
- the catalytic nuclear ramjet – where a catalyst is used to speed up the nuclear reaction rate. For example, a normal carbon atom can be used as the catalyst, with fusion converting the carbon, through a series of six fusion reaction, to nitrogen, oxygen and eventually back to carbon again, but in the process creating helium from four protons much faster than if the catalyst was not present.

Having reviewed this background material on the Bussard Ramjet, Gupta maps the potential and level of uncertainty of the various solutions proposed in the literature, and highlights the two she sees as most promising for near-term research. These are the ram-augmented ramjet mentioned briefly above, and the use of graphene as the structural material for the ramscoop, which could help to deal with some of the engineering challenges faced by Bussard's original design. Finally, she creates a 'roadmap' for future research on these two issues, concluding with seven recommendations for future research. See Figure 2.

If you are interested in the concept of the Bussard Ramjet, but have not previously had time to find out more about it, this project report provides a valuable review of the key issues, including two appendices full of equations, for those who want to get right into the theory.

Taavishe Gupta will be presenting *A Feasibility Analysis of Interstellar Ramjet Concept*s (IAC-20,D4,4,11,x58592) at IAC 2020 see *71st International Astronautical Congress 2020 - Timetable of Interstellar Papers* elsewhere in this issue.

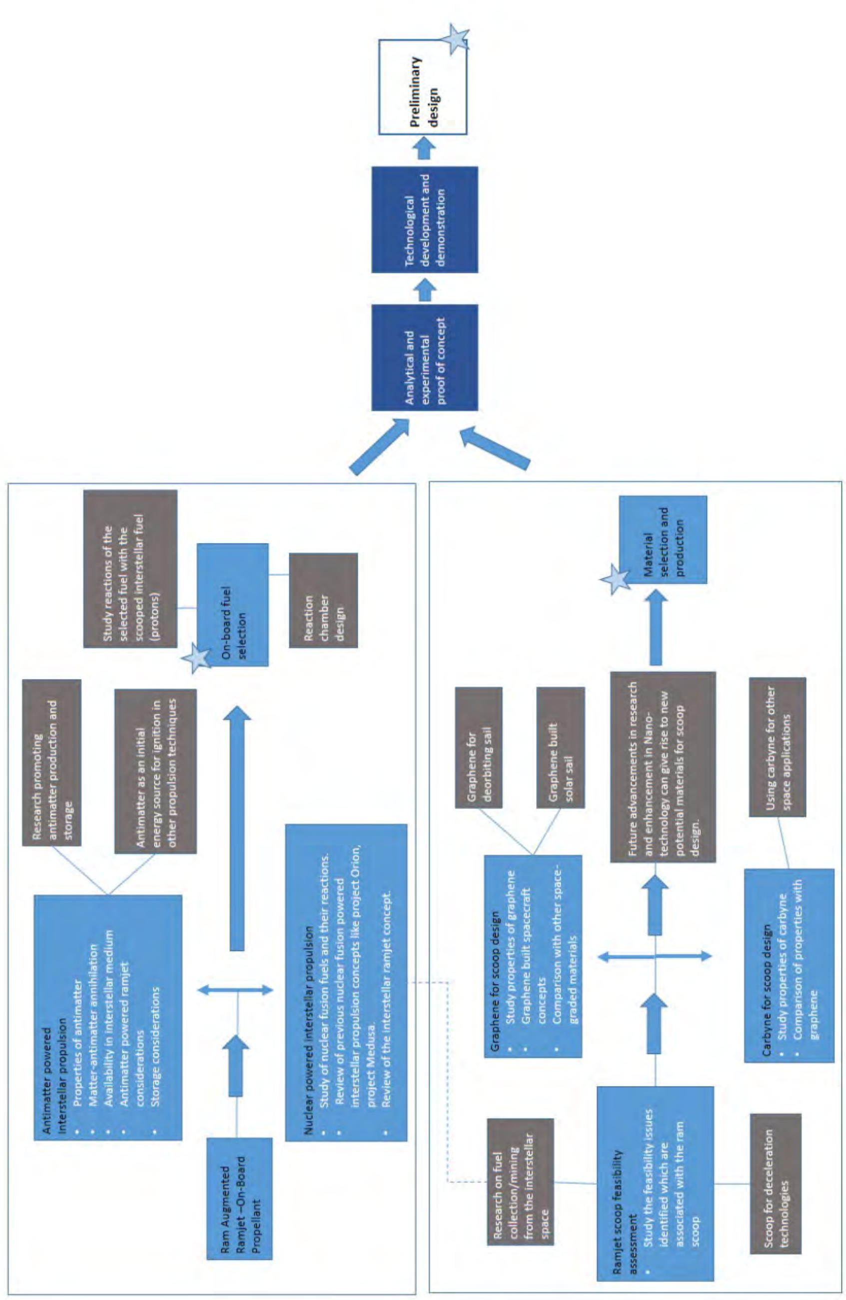


Figure 2. Recommended Roadmap for future research on Ram – Augmented Interstellar Ramjet.

Credit: Gupta

* Most recently in Principium, see *The Interstellar Ram Jet at 60* A A Jackson in Principium | Issue 29 | May 2020 page 42.

Kush Kumar Sharma, Deceleration of Interstellar Probe

Sharma's project report [4] nicely complements the concept that lies at the heart of Gupta's report. The Bussard Ramjet is, at its heart, an attempt to find a solution to the central problem of interstellar travel: even the nearest stars to our solar system are an extraordinarily long distance away. Getting to them within a reasonable timeframe therefore requires extraordinarily high velocities.

Now suppose we solve that problem, whether via a variant of the Bussard Ramjet or otherwise, and send a probe to, say, Proxima Centauri b to see if the potentially habitable exoplanet actually harbours life of any kind. Clearly, the value of any such mission will lie in the scientific return we obtain (eg stellar and planetary physics, and astrobiology). To justify the massive investment of resources, effort and time that will no doubt be required, we should be aiming to maximise that scientific return. But how?

One key way to do this is by slowing the probe down when it reaches its destination, so that it can spend longer taking scientific measurements. However, that's really hard to do, so the default mission plan is for an undecelerated flyby of the target. How big a problem is this?

Well, if we were to launch a probe at 5% of the speed of light to Proxima b, which is 4.3 light years away, it would take somewhere over 86 years to reach its destination. However, because Proxima Centauri is a red dwarf star, its habitable zone, within which Proxima b orbits, is much closer to the star than it would be if it were as bright as our Sun. Proxima b orbits its star at a radius of 0.0485 AU, just under one-twentieth the distance between the Earth and the Sun. And travelling at 5% of the speed of light, our probe would take about three hours to go from 10 times further out than this orbit (when the exoplanet will be relatively difficult to see in the glare of its parent star), past the planet and out to the same distance on the other side of the star (when the exoplanet will once again be hard to see or measure against the light of Proxima Centauri).

I'll repeat that. After waiting for an entire human lifetime for the probe to arrive, it will have just three hours to record meaningful scientific data on the exoplanet Proxima b, to find out whether there's life there (and if so, what sort). At that point, the main scientific objective of the mission will be over, as the probe exits the star system and heads towards nowhere in particular.

That's the motivation behind Sharma's project: what can we do to slow an interstellar probe down when it reaches its destination (ideally to a velocity at which it can be captured by the object's gravity and enter into orbit), so we can maximise the scientific return?

Sharma classifies the options for decelerating an interstellar probe into two main types:

- active – the spacecraft carries a rocket or ramjet which fires opposite to the direction of travel as the destination is approached, slowing the spacecraft down; and
- passive – the spacecraft transfers some of its momentum to the surrounding interstellar medium, reducing its velocity without the use of fuel.

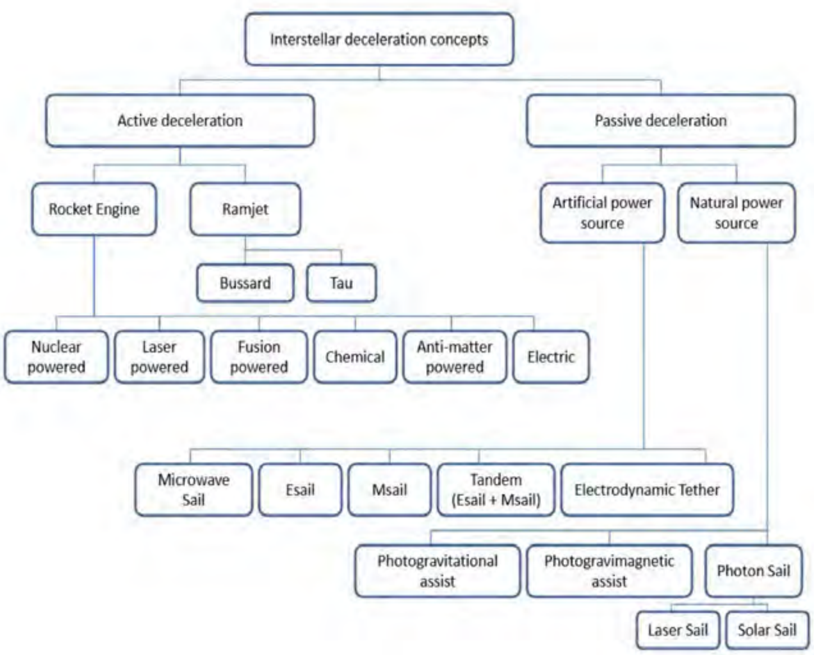


Figure 3: Conceptual overview diagram of interstellar deceleration concepts.

Credit: Sharma

Given the problem which Gupta's project report considers – how to travel fast enough to arrive at an interstellar destination in a reasonable time – active deceleration options are deeply problematic, since it takes just as much propellant to slow down from any velocity V to zero as it does to accelerate from zero to V in the first place. So given a propulsion system and a propellant budget, most mission planners are going to use up all the fuel to accelerate to the highest possible cruise velocity. Taking your deceleration propellant with you, so you can slow down when you get there, carries a very substantial weight penalty and, other things being equal, means the mission will take an awful lot longer. It's therefore unsurprising that Sharma focuses almost all his attention on passive deceleration options.

These are themselves divided into two kinds, depending on what powers the process:

- an artificial power source – the options here are an electric sail, a magnetic sail, a hybrid of the two, a microwave sail, or an electrodynamic tether. Each of these requires an onboard power source to enable the transfer of momentum to the interstellar medium; or
- a natural power source – a photon sail (ie a solar or laser sail), a photogravitational assist (where solar radiation and gravity is used to reduce the spacecraft's momentum), and a photogravimagnetic assist (where solar radiation, gravity and magnetic fields are all used). These options require no onboard power source, but their effectiveness will depend on the strength of the relevant electromagnetic or gravitational fields in the vicinity of the target, or alternately they will require a lengthy deceleration phase prior to arriving at the target.

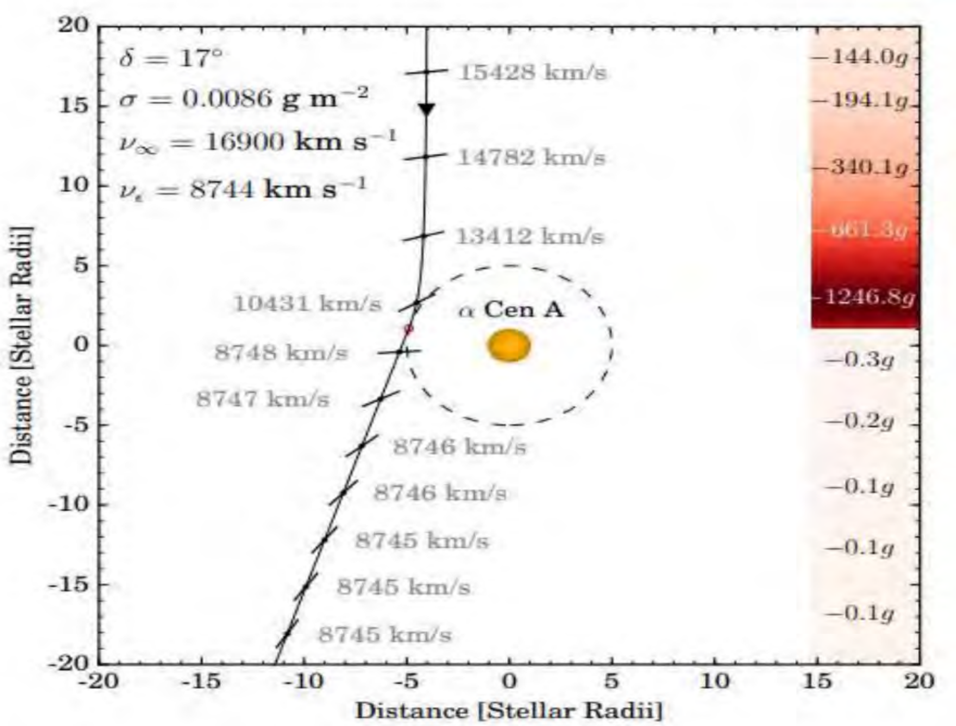


Figure 4: Performance example -
Trajectory of lightsail during during photogravitational assist (from Heller and Hippke, 2017 [5]).

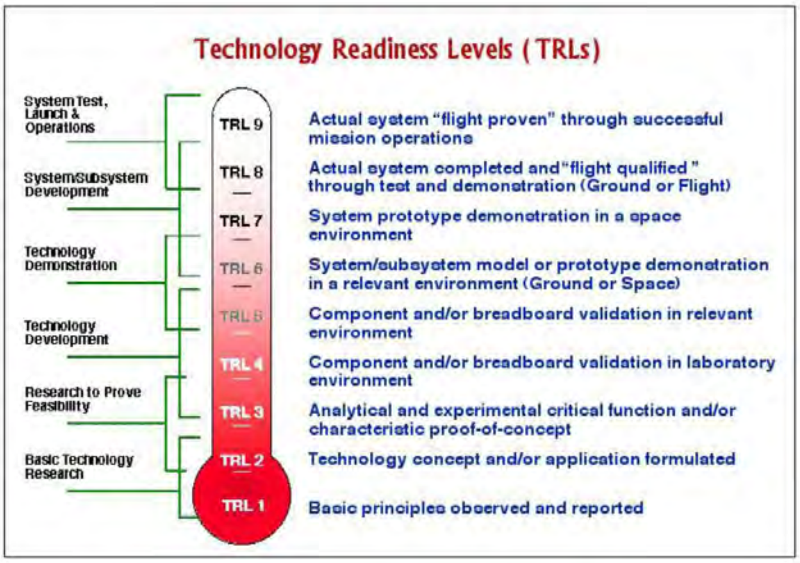
The heart of this project is a performance analysis of the main passive deceleration options, comparing their design characteristics, engineering feasibility, and Technology Readiness Levels (TRLs). The challenge to this promising approach is that the different options are so varied that it is difficult to find a consistent way of comparing them. Nonetheless, my reading of Sharma's results is that a combined electric plus magnetic sail appears to show the greatest promise, as the strengths and weaknesses of the two sail technologies complement each other well.

The report concludes with six recommendations for further research, providing an excellent starting point for anyone who would like to take the topic further.

Technology Readiness Level assessment (credit: Sharmar)	
Deceleration Concept	TRL
Electric sail	3 - 4
Magnetic sail	2 - 3
Tandem (Esail + Msail)	2
Solar sail	4 - 5
Photogravitational assist	2
Photogravimagnetic assist	2
Electrodynamic Tether	4

Technology Readiness Levels – Thermometer Diagram

Credit: ESA (Technology Readiness Levels Handbook for Space Applications - reference TEC-SHS/5551/MG/ap [artes.esa.int/sites/default/files/TRL_Handbook.pdf)](artes.esa.int/sites/default/files/TRL_Handbook.pdf)



Any Principium readers who would like to find out more about either or both of these excellent Master's projects may be interested to know that both authors will be presenting summaries of their work in session D4.4 at the 71st International Astronautical Congress, which will be free to join online between 12 and 14 October [6].

Kush Kumar Sharma will be presenting *Feasibility assessment of deceleration technologies for interstellar probes* (IAC-20,D4,4,6,x61030) at IAC 2020 see *71st International Astronautical Congress 2020 - Timetable of Interstellar Papers* elsewhere in this issue.

References:

[1] Details of the International Space University's Master of Space Studies course are available on their website at www.isunet.edu/mss/.

[2] T Gupta, Bussard: The Interstellar Ramjet (MSS Project Report), International Space University, April 2020.

[3] A Jackson, Three Interstellar Ramjets, Jan 2019. Available online at www.researchgate.net/publication/330508853_Three_Interstellar_Ram_Jets [Last accessed 19 August 2020.]

[4] K K Sharma, Deceleration of Interstellar Probe (MSS Project Report), International Space University, April 2020.

[5] Heller, R and Hippke, M, 2017. Deceleration of High-velocity Interstellar Photon Sails into Bound Orbits at α Centauri. Astrophysical Journal Letters, Vol. 835, No. 2 iopscience.iop.org/article/10.3847/2041-8213/835/2/L32/meta

[6] Full details of IAC 2020 are available online at www.iafastro.org/events/iac/iac-2020/ .

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Do you think humanity should aim for the stars?

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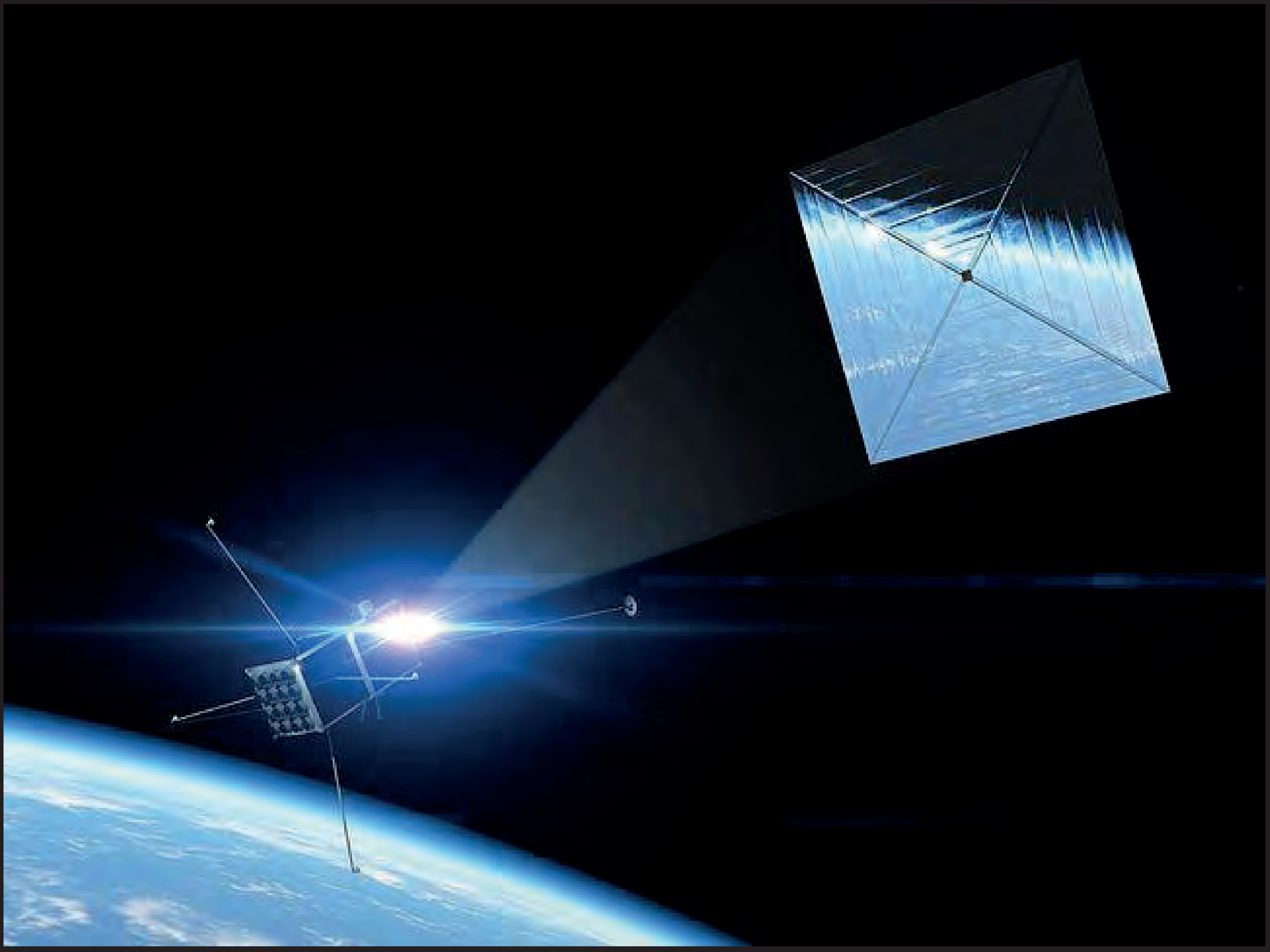

The Initiative for Interstellar Studies (i4is) has launched a membership scheme intended to build an active community of space enthusiasts whose sights are set firmly on the stars. We are an interstellar advocacy organisation which:

- conducts theoretical and experimental research and development projects; and
- supports interstellar education and research in schools and universities.

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71st International Astronautical Congress 2020

Timetable of Interstellar Papers

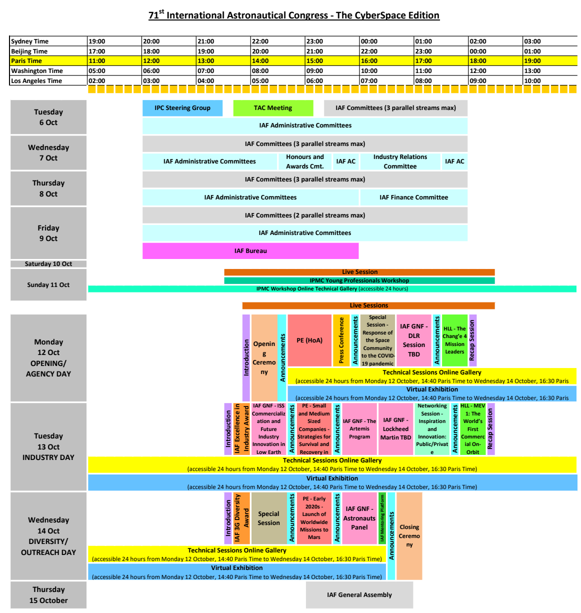
This year's Congress is a ***Cyberspace Edition*** and is offered without registration fee, free of charge for a global community (www.iafastro.org/events/iac/iac-2020). Principium readers, and especially i4is members can therefore access the whole programme. This is a possibly unique opportunity to engage with this global event without the substantial entry fee normally charged and, of course, without travel expenses.

We will keep i4is members up to date via Members Newsletters - and, as always, keep an eye on our FB (InterstellarInstitute), Twitter (@i4interstellar) and LinkedIn (www.linkedin.com/groups/4640147).

IAC technical sessions this year are not timetabled but will be continuously accessible in an Online Gallery for the three days of the Congress.

Time	START Monday 12 October	FINISH Wednesday 14 October
Sydney	22:40	00:30 (next day)
Beijing	20:40	22:30
Paris	14:40	16:30
Washington	08:40	10:30
Los Angeles	05:40	07:30

The catalogue of all technical sessions is at - iafastro.directory/iac/browse/IAC-20/catalog-technical-programme



They are grouped into themed sessions but some sessions are not fully detailed at the time of this publication.

The rest of the Congress, including awards, commercial and space agency sessions is live as detailed at - www.iafastro.org/wp-content/uploads/2020/07/IAC2020Glance.pdf

In this report we attempt to list all the items likely to be of special interest to Principium readers. Many are explicitly interstellar in topic but others are important in contributing to our interstellar goal including innovations in propulsion, exploitation of resources in space, deep space communication and control, enhanced and more economical access to space, etc.

You will find -

- Code & link - the unique IAC code and a link to the Abstract
- Paper title, Speaker, institutional Affiliation and Country
- A brief summary based on the Abstract

Please contact john.davies@i4is.org if you have comments, find discrepancies or have additional items to suggest.

SESSION Strategies for Rapid Implementation of Interstellar Missions: Precursors and Beyond

Web address - iafastro.directory/iac/browse/IAC-20/D4/4/

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,D4,4,1,x57895	Interstellar Probe: Science Discoveries at the Boundary to Interstellar Space and Beyond	Dr. Pontus Brandt [1]	Johns Hopkins University Applied Physics Laboratory (JHU APL)	USA

JHU-APL "Interstellar Probe" study for NASA - a 50 year "super Voyager" reaching 1,000 AU (1.5% of a light year) using SLS Block2 and a powered Jupiter Gravity Assist for asymptotic speeds (Vinf [2]) of up to 8.5 AU/year starting around 2030 (note Pluto distance about 40 AU).

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,D4,4,2,x60132	Rapid Access to the Interstellar Medium: A Feasibility Study	Dr. Leon Alkalai	NASA/JPL	USA

JPL feasibility study, options included using Nuclear (fission) Electric Propulsion (NEP), very large Solid Rocket Motor (SRM) and a solar perihelion burn (Oberth manoeuvre [3]), Solar Thermal Propulsion (STP) with a solar perihelion burn, and solar electric propulsion. SRM up to 16 AU/y Vinf but other options, with development may achieve 19.5 AU/yr.

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,D4,4,3,x56295	A Pragmatic Interstellar Probe Mission: Progress and Status	Dr Ralph L McNutt, Jr	JHU-APL	USA

NASA funded JHU-APL study of near-term,"pragmatic" Interstellar Probe mission. Launch before 1 January 2030, 50 year mission with 400 watt declining to 200 watt power, 1,000 AU downlink and solar Oberth manoeuvre option (11 authors including NASA MSFC, University of Kiel, Germany, and University of Southern California (USC)

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,D4,4,4,x59255	System Engineering a Solar Thermal Propulsion Mission Concept for Rapid Interstellar Medium Access	Dr Jonathan Sauder	JPL-Caltech	USA

Examining a solar thermal propulsion (STP) system for rapid access to the local interstellar medium (ISM) via a solar perihelion burn (Oberth manoeuvre). Vinf 9 AU/yr with current technology, up to 16 AU/yr with technological advances (heat exchanger lining materials, turbo pumps, and advanced heat exchanger geometries) may enable STP to provide higher escape velocities than SRM (12 authors all Caltech apart from Dr Leon Alkalai, NASA).

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,D4,4,5,x58922	Vaporization of interplanetary dust during the acceleration phase of a laser-driven lightsail	Ms Monika Azmanska	McGill University	Canada

During the acceleration phase of a laser-driven lightsail, the impact of dust grains on the lightsail could compromise the low laser absorptivity of the sail, causing significant deposition of laser energy into the sail, resulting in its total destruction. The drive laser may be used to deplete the number of dust grains in the volume to be swept by the passage of the sail, possibly by laser light diffracted around and transmitted through the sail. (Two other authors, Mr John Kokkalis and Prof Andrew Higgins, both McGill.)

[1] See also JBIS 72 NO 6 JUNE 2019 General interstellar issue, HUMANITY'S FIRST EXPLICIT STEP IN REACHING ANOTHER STAR: The Interstellar Probe Mission - also Principium | 27 Nov 2019 page 12.

[2] Vinf = Velocity at Infinity - the velocity away or towards the Sun of an object on an interstellar trajectory.

[3] See News item *2I/Borisov - the second interstellar object* in Principium 27 Nov 2019 page 10 and citations from there.

Code & link	Paper title	Speaker	Affiliation	Country
[IAC-20,D4,4,6,x61030]()	Feasibility assessment of deceleration technologies for interstellar probes [1]	Mr Kush Kumar Sharma	International Space University (ISU)	France
Sending a probe to another star will be costly, scientific value will be increased by ability to decelerate at the target system allowing data collection for a longer duration. This paper compares and assesses the feasibility of deceleration concepts - the most feasible near-term approach is identified, with a roadmap for its development (two other authors, Prof Chris Welch, ISU, and Dr Andreas Makoto Hein, Ecole Centrale de Paris & Technical Director, i4is).				

Code & link	Paper title	Speaker	Affiliation	Country
[IAC-20,D4,4,8,x59724]()	Case Study of an Interstellar Mission to Altair: Foundations for Interstellar Travel with Advanced 21st Century Technology	Dr Ugur Guven	UN CSSTEAP	USA
A case study of interstellar travel to Altair using advanced 21st century technology by various methods (thermal nuclear propulsion, fusion propulsion, advanced warp propulsion) with different velocity and acceleration levels taking relativistic effects into account.				

Code & link	Paper title	Speaker	Affiliation	Country
[IAC-20,D4,4,10,x60816]()	Comprehensive Case Study of an Interstellar Travel to Barnard's Star via Electric Ion Propulsion employing Semi-Relativistic flight Parameter	Ms Kirti Vishwakarma	University of Petroleum and Energy Studies	India
This paper discusses the possibility of an interstellar mission to Barnard's Star, the sixth closest star to our Solar system, potentially with two planets, arriving in a reasonable amount of time (with Dr Ugur Guven, University of Petroleum and Energy Studies). A case study evaluating different modes of propulsion and specifically an Electric Ion Propulsion system.				

Code & link	Paper title	Speaker	Affiliation	Country
[IAC-20,D4,4,11,x58592]()	A Feasibility Analysis of Interstellar Ramjet Concepts [2]	Ms Taavishe Gupta	International Space University (ISU)	France
The original Bussard interstellar ramjet was proposed to attain high velocities and short flight times for interstellar travel fuelled by fusion energy of interstellar gas (hydrogen). However, several problems were identified and several ramjet variants have been proposed. This paper presents a literature review of the interstellar ramjet concept, a feasibility analysis of the variants and underlying assumptions made by past researchers and a range of resulting fundamental and technical gaps. It identifies credible potential solutions and a roadmap for further research to improve the interstellar ramjet concept (two other authors, Prof Chris Welch, ISU, and Dr Andreas Makoto Hein, Ecole Centrale de Paris & Technical Director, i4is).				

[1,2] See also *News Feature: ISU student projects Bussard Ramjet and Interstellar Deceleration* in this issue.

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,D4,4,14,x56451	Sustainable Design for Extended Space Travel, Apprised	Mr Antoine Faddoul	Tony Sky Designs Group	USA

The conventional aspects of design reach idiosyncratic levels when considering extended space journeys. How does a design team approach the scheme for crewed interstellar journeys? How to manage sustainable designs for longer durability, minimal maintenance, energy self-sufficiency, self-maintenance and improvements? Over a hundred design items related to three main areas (Structure, Environment, and Human needs) were evaluated providing a comprehensive set of futuristic scenarios.

SESSION Innovative Concepts and Technologies

Web address - iafastro.directory/iac/browse/IAC-20/D4/1/

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,D4,1,3,x59908	ChipSats - New Opportunities	Mr Frederic Schoutetens	International Space University (ISU)	France

ChipSats (mass <10 grams) offer design modularity, low development costs and low entry barrier for technology allowing extraordinary potential for new applications, despite low functionality, short orbital lifetimes and the lack of regulation. This paper includes an extensive literature study and delivers a roadmap for the ISU to become the global leader in space education, developing and launching ChipSats within three to five years - in addition to two potential missions and applications.

(20 other authors, all ISU)

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,D4,1,5,x57348	A LEU Approach to the Particle Bed Nuclear Thermal Rocket Engine	Ms Danika Lenard	Little Prairie Services (LPS)	USA

A Particle Bed Reactor (PBR) Nuclear Thermal Rocket Engine (NTRE) was investigated by the US Strategic Defense Initiative Organization (SDIO) 1987-1993 in program Timberwind including a full-scale critical reactor facility that is still in use today. However it employed Highly Enriched Uranium (HEU) and the Defense Threat Reduction Initiative (DTRI) produced a desired migration away from HEU to High Assay Low Enriched Uranium (HALEU) - enrichment typically<20% - with consequent technical challenges. This paper describes a new approach by LPS with three different Tristructural-isotropic (TRISO [1]) fuel particle concepts - to be dispersed through the fuel element to produce a uniform quantity of thermalized neutrons leading to a flatter, more uniform reactor power spectrum.

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,D4,1,6,x57113	NASA Interstellar Propulsion Assessment	Mr Les Johnson	NASA	USA

A NASA Workshop on Interstellar Propulsion was held at the 6th Interstellar Symposium in the fall of 2019 in Wichita, Kansas, to assess the viability of selected advanced propulsion technologies for potential to meet the goal of launching a true interstellar probe achieving 0.1c transit velocity. This paper will describe the requirements, ground rules, and assumptions for each candidate technology's technology readiness assessment, the fundamental physics and engineering requirements of each, and a high-level technology maturation approach to enable a true interstellar mission within the next 50 years.

[1] en.wikipedia.org/wiki/Nuclear_fuel

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,D4,1,10,x61142	A concept for space colonization process based on asteroid minery	Mr Salvador Daniel Escobedo Casillas	University of Guadalajara	Mexico
The habitability zone of a sun-like star (120 to 24 percent of sunlight received by Earth) can be extended for the colonization of its solar system even when solar radiation rates are smaller than those of the natural habitability zone. This paper develops a concept of propagation of the human species within this habitable zone in three phases - implementation of a mining system that allows the production of basic materials for the construction of a space habitat, assembly of a habitable workstation with the capacity of sustaining human life temporarily with some dependence on earth resources and finally the construction of a self-sustaining space base having the necessary resources to maintain human life for indefinite periods of time. Concepts include a swarm of mining nano and microsatellites and a workshop ship destined to transform raw materials, (second author Prof Paloma Gonzalez, Tecnologico de Monterrey, Mexico).				

SESSION New Missions Enabled by New Propulsion Technology and Systems

Web address - iafastro.directory/iac/browse/IAC-20/C4/9/

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,C4,9,1,x60833	Development and analysis of novel mission scenarios based on atmosphere-breathing electric propulsion (abep)	Ms Shreepali Sanjay Vaidya	University of Pisa	Italy
Atmosphere-Breathing Electric Propulsion (ABEP) collects atmospheric residual gases as propellant to an electric thruster potentially supporting Very Low Earth Orbits (VLEO), space-tug between Earth and Moon and any celestial body with atmosphere - introducing ISRU to electric propulsion. This paper presents development and investigation of various mission scenarios using ABEP with parameters intake efficiency, available power, thruster efficiency, system lifetime, etc using MATLAB and commercially available ASTOS simulation software. (Three other authors, all from Institute of Space Systems, University of Stuttgart, Germany.)				

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,C4,9,2,x59647	Integrated optimization of trajectories and layout parameters of spacecraft with air-breathing electric propulsion	Mr Alexander Golikov	Central AeroHydrodynamic Institute (TsAGI)	Russian Federation
Small spacecraft in ultra-low Earth orbits (150-250 km) using ABEP are an alternative to heavier conventional spacecraft. Issues include changing external environment, momentum of acquired propellant / atmosphere drag versus thrust provided and electric power source. This paper provides integrated optimisation yielding requirements for ABEP characteristics, power supply system and spacecraft layout. (co-author Prof Alexander S Filatyev, same Institute)				

Code & link	Paper title	Speaker	Affiliation	Country
[IAC-20,C4,9,3,x60528]	Sitael's activities on the development of air breathing technology	Dr Tommaso Andreussi	Sitael Spa	Italy
Since 2016 Sitael has developed an Air-Breathing Electric Propulsion (RAM-EP) system to generate thrust in the upper atmosphere of either the Earth or other suitable celestial bodies without needing on-board propellant. Technological challenges include design of an air breathing electric thruster compatible with atmospheric gas operation and testing the full system on-ground in an environment reproducing flight conditions. Sitael is working on RAM-EP in a framework of two development programmes, European Commission AETHER and national funded CLOSE (four other authors from Sitael Spa and Politecnico di Torino).				

Code & link	Paper title	Speaker	Affiliation	Country
[IAC-20,C4,9,7,x56172]	Exploration of trans-Neptunian objects using the Direct Fusion Drive	Mr Paolo Aime	Politecnico di Torino	Italy
The Direct Fusion Drive (DFD) is a compact engine, based on the D-^{3}He aneutronic fusion reaction that uses the Princeton field reversed configuration for the plasma confinement and an odd parity rotating magnetic field as heating method. This work presents possibilities to study the outer border of the solar system using DFD propulsion to reach targets such as the dwarf planets Makemake, Eris and Haumea in less than 10 years with a payload mass of at least of 1,000kg. Mission profiles are the simplest possible, using a thrust-coast-thrust profile with each mission is divided into 3 phases: spiral trajectory to escape Earth gravity, interplanetary travel and manoeuvres to rendezvous with the dwarf planet. Propellant mass consumption, initial and final masses,velocities and ΔV for each manoeuvre are presented showing that a DFD propelled spacecraft will open unprecedented possibilities to explore the border of the solar system in a limited amount of time and with a very high payload to propellant ratio.				

Code & link	Paper title	Speaker	Affiliation	Country
[IAC-20,C4,9,13,x60403]	Comparitive Study on Various Advanced Propulsion Techniques for Interplanetary Missions	Mr Pushkar Chaudhary	R V College of Engineering, Bengaluru	India
This paper compares various advanced propulsion systems that are in development and can be used for interplanetary missions. The propulsion systems considered are (i) Antimatter propulsion (ii) Plasma propulsion: VASIMR technology (iii) Nuclear-Thermal propulsion and (iv) Laser propulsion. This paper also proposes combinations of propulsion systems which could theoretically overcome the disadvantages of single advanced propulsion systems.				

SESSION Space Resources, the Enabler of the Earth-Moon Econosphere

Web address - iafastro.directory/iac/browse/IAC-20/D4/5/#paper.57710

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,D4,5,1,x55660	Major Results of the Second Mining Space Summit	Mr Joseph Mousel	Luxembourg Space Agency	Luxembourg
In October 2019, the Luxembourg Space Agency (LSA) organized the second Mining Space Summit. More than 180 participants from 24 countries working in different industries (eg oil gas, terrestrial mining, space, finance, and government) joined the one-day workshop. This paper highlights a 'best practice' on how the forward looking space resources community can learn from the existing successful terrestrial resources community, and vice versa.				

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,D4,5,7,x60941	Analysis of technology, economic and legislation readiness levels of asteroid mining industry: a base for the future space resource utilization missions	Ms Smiriti Srivastava	Space Generation Advisory Council (SGAC)	Singapore
This paper contextualizes prospects for the development of asteroid mining building on the success of previous space resource exploration and predicting the future of resource utilization in development of space habitats and highlights the importance of sustainable investments in asteroid mining projects, strategies in vogue and mission feasibility factors. It aims to support the International Asteroid Warning Network, Impact Disaster Planning Advisory Group, Space Mission Planning Advisory Group, Space agencies, educational institutions and interested stakeholders by providing a critical analysis of the state of the art for optimal future development of the space mining industry. (Five other authors from SGAC, ISAE - Institut Superieur de l'Aeronautique et de l'Espace, France, and Nepal Astronomical Society.)				

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,D4,5,11,x59550	Resource Modelling and Simulation of Asteroid Ore bodies for Off-Earth Mining	Dr Scott Dorrington	UNSW	Australia
Observational data of near-Earth objects suggests that most asteroids are rubble piles – aggregates of boulders, rocks and regolith held together by weak gravitational and surface forces. This paper details the development of a software package containing tools for generating 3D resource models of asteroid ore bodies for the use in the planning and simulation of operations involved in off-Earth mining and mineral extraction. Orbital operations are modelled using a constant density polyhedral mode and surface operations make use of detailed discrete element methods (DEM) simulations in a restricted area of operation surrounding the spacecraft. This approach provides a balance between numerical accuracy and computation time to allow rapid simulation of spacecraft operations and off-Earth mining processes without the need for large-scale computational facilities or long run times. (Two other authors both Commonwealth Scientific & Industrial Research Organisation (CSIRO), Australia.)				

SESSION Space Transportation Solutions for Deep Space Missions

Web address - iafastro.directory/iac/browse/IAC-20/D2/8-A5.4/

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A5,4-D2.8,2,x57589	NASA's Space Launch System: Transformative Launch Capability for Human and Robotic Deep Space Missions	Ms Beverly Perry	NASA Marshall Space Flight Center (MSFC)	USA

NASA's new super heavy-lift vehicle, the Space Launch System (SLS), presents mission planners with an unrivalled new launch option with plans for landing the first woman and next man on the moon and support for a proposed probe to the interstellar medium (see papers by Akalai, McNutt and Brandt elsewhere in this article). The ultimate variant, Block 2 with an additional upper stage and/or a solid rocket motor kick stage to enable missions with a C_3 (Earth departure energy [1]) as high as 300 km^2/sec^2. At IAC, the SLS Program will present information on the capabilities of SLS and its utilization for transformative human and science deep space missions.

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A5,4-D2.8,3,x59291	Assessment of On-Orbit Cryogenic Refueling: Optimal Deport Orbits, Launch Vehicle Mass Savings, and Deep Space Mission Opportunities	Mr Justin Clark	Ohio State University College of Engineering	USA

Cryogenic fuels offer higher energy densities than their storable counterparts, increasing the performances of spacecraft propulsion systems and reducing system masses. The exponential relationship of payload mass and launch vehicle size [2] suggests a potential solution - on-orbit cryogenic refuelling depots, so a spacecraft can be launched with a smaller launch vehicle, refuelled in orbit, and continue its mission [3]. In this paper, the ESA's PyKEP orbital mechanics library is utilized with Python to determine where cryogenic fuel depots might be best positioned yielding outputs including porkchop plots, estimates of optimal orbits for depots around the Earth and the Moon and trajectories into such orbits. Required fuel masses for a spacecraft from a depot to a destination are computed, resulting launch vehicle masses calculated with possible mass savings as compared with traditional launch vehicle/architectures. The idea of sustainable on-orbit cryogenic refuelling infrastructures is discussed with long-term effects on human exploration of the solar system. (Two other authors, both Ohio State U.)

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A5,4-D2.8,4,x58230	Optimal Spacecraft Trajectories under Uncertainties	Mr Deepak Gaur	Amity School of Engineering	India

Economic space transport requires minimum energy transfer trajectories typically derived using the Circular-Restricted Three-Body Problem (CRTBP). Chaotic dynamics in some situations is a challenge. In this work, a new technique allows better understanding and visualization of the 3-dimensional capture problem; Reduced CRTBP order condenses information into a 2-dimensional image.

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A5,4-D2.8,5,x60670	In-situ Resource Utilization of Asteroid Mining: Endeavour to Explore	Ms Vanshika Arora	University of Petroleum and Energy Studies	India

This paper explores the possibility of asteroid mining operations as part of the Artemis (lunar) mission. Water from asteroids yield liquid oxygen and liquid hydrogen as rocket fuel. Potentially costing less than fuel from Earth due to the high cost of escaping Earth's gravity [3].

[1] Earth departure energy (km^2/sec^2), equal to the square of the departure hyperbolic excess velocity - see NASA/TM—2010-216764 *Interplanetary Mission Design Handbook:Earth-to-Mars Mission Opportunities 2026 to 2045* Glenn Research Center 2010.

https://strives-uploads-prod.s3.us-gov-west-1.amazonaws.com/20100037210/20100037210.pdf?AWSAccessKeyId=AKIASEVSKC45ZTTM42XZ&Expires=1597418729&Signature=LulsXOFMytTgeio0Qvuy4yx06jQ%3D

[2] A direct result of the Tsiolkovsky rocket equation and thus of Newton's second law. See also *The Tyranny of the Rocket Equation*, Don Pettit, www.nasa.gov/mission_pages/station/expeditions/expedition30/tryanny.html.

[3] See also Interstellar News item *Asteroid mining with small spacecraft - a "filling station" beyond our gravity well* in this issue.

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A5,4-D2.8,6,x60658	Knowledge and Technology Building Blocks for Space Access Architectures	Mr Arun Subramanian Venkataraman		India
Gateway Earth Development Group (GEDG) proposes a technically and economically viable architecture for interplanetary space exploration and on-orbit satellite servicing manufacturing, and space tourism as enablers for the development of a space station (GatewayEarth) in Earth's geostationary orbit (GEO). At this station, interplanetary spacecraft could be built and serviced to take astronauts on missions across the Solar System. This paper, part of an existing draft architecture design, analyses the available knowledge and technology, mapping all available papers and patents on component modules of the station to provide the stakeholders in space access with a broad overview of ownership of IP in their domain. Helping them strategise research efforts - identifying white spaces and areas where substantial work is needed, helping to identify partners to collaborate and minimize duplication of effort. This paper will utilize WIPO's (World Intellectual Property Organization) International Patent Classification system to classify the technologies. (Second author Mr Matjaz Vidmar, University of Edinburgh.)				

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A5,4-D2.8,9,x59363	Nuclear Thermal Propulsion (NTP) Post-Burn Transient: Cool-Down Propellant Consumption and its Effect on Total Delta-v	Mr Jack Plank	The Ohio State University College of Engineering	USA
Nuclear Thermal Propulsion (NTP) is an enabling technology for missions to deep space destinations because of its unique combination of high thrust and high specific impulse. NTP also produces decay heat, since the products of nuclear fission continue to release heat through radioactive decay for a period of time after the engine is shut down and extra propellant must be fed through the reactor and exhausted after shutdown until the energy being generated has diminished enough to be removed by less wasteful means. This paper quantifies the extent to which the impulse from the engine cool-down phase affects an NTP vehicle's mission profile showing that reducing the proportion of hydrogen spent during the engine cool-down phase can benefit mission performance, yielding more delta-v.				

SESSION Small Bodies Missions and Technologies (Part 1)

Web address - iafastro.directory/iac/browse/IAC-20/A3/4A/

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A3,4A,8,x59688	Trajectory analysis and design for an European Fast Kinetic Deflection Mission	Mr Pablo Hermosin	Deimos Space SLU	Spain
The European Space Agency has promoted a study to analyse the current capability to achieve the deflection of a real target asteroid of around 50 m in the shortest possible time using a kinetic impactor. Challenges include - short warning time (only few years) from the Potentially Hazardous Asteroids (PHA) discovery to its close approach with Earth. Complex guidance, navigation and control (GNC) system required to impact the target at very high speed. Deimos has an Airbus contract in charge of trajectory design (search and optimization of thousands of trajectories to hundreds of asteroids). This paper gives the methodology followed with the main results reporting deflection capabilities depending on asteroid, craft design and the mission characteristics (two other authors, Deimos and Airbus).				

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A3,4A,9,x58609	Spacecraft Trajectory Simulation for Autonomous Landing on Small Planetary Bodies	Ms Larissa Balestrero Machado	Universität der Bundeswehr München	Germany
Exploration of small planetary bodies (asteroids, comets and moons) requires in-situ measurements for identification of resources. Landing is challenging due to irregular gravitational field and other disturbances but remotely controlling a spacecraft landing is often not possible. This paper presents hardware-oriented development, validation and testing of methods, algorithms and sensors for autonomous landing. Model simulation uses a multicopter to simulate landing.				

SESSION Small Bodies Missions and Technologies (Part 2)

Web address -iafastro.directory/iac/browse/IAC-20/A3/4B/

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A3,4B,3,x56468	Comet Interceptor: An ESA mission to a Dynamically New Solar System Object	Dr Joan Pau Sanchez Cuartielles	Cranfield University	UK
The European Space Agency (ESA) selected the Comet Interceptor (Comet-I) in 2019 as its first fast (F) class mission. Comet-I aims to explore a dynamically new comet (DNC), or a serendipitous interstellar object (ISO) before solar approach with three spacecraft elements - main spacecraft A (ESA-provided) for remote observations (>1,000 km) avoiding the dust environment, smaller spacecraft B1 (JAXA[1]) and B2 (ESA) separate from spacecraft A several days before the encounter flying closer to the comet (<500 km). Launching to Sun-Earth L2 [2] in 2028 with the ESA M4 ARIEL Mission on an Ariane 6.2 launcher. Near term telescopes such as LSST [3] will find a target object and it is likely (ie >50% chance) that the target may be known before Comet-I's launch.				

SESSION Finance and Investment: The Practitioners' Perspectives

Web address -iafastro.directory/iac/browse/IAC-20/E6/2/

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,E6,2,7,x61046	Astrodynamics vs mining industry financing – modeling viable investment structures for asteroid resources	Mr Sebastian M Ernst		Germany
The past decade has seen an advent and subsequent decline of the topic of asteroid resources. A lack of known good investment strategies as well as gaps in international agreements on mineral rights in space are the dominant show-stoppers. Financial and related logistical aspects of terrestrial mining are well understood by mining companies, governments and the financial industry but a key aspect, astrodynamics, has not yet reached the minds of the mentioned actors. A new model is presented that evaluates technological and financial strategies against the entire known population of approximately one million asteroids. Mr Ernst suggests it is costly but viable to hide a target asteroid's location as a means of protecting one's investment.				

[1] JAXA is the Japan Aerospace Exploration Agency www.jaxa.jp.

[2] Sun-Earth L2 is a the gravitationally neutral point on the Sun-Earth line beyond Earth. A good launch point to reach incoming comets or intersteller objects (ISOs) like 1I/'Oumuamua.

[3] LSST is the Large Synoptic Survey Telescope (now known as the Vera C Rubin Observatory) will scan the entire sky available to it every few nights.

SESSION SETI 1: SETI Science and Technology

Web address -iafastro.directory/iac/browse/IAC-20/A4/1/

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A4,1,1,x60743	The Breakthrough Listen Search for Extraterrestrial Intelligence: Overview	Dr Steve Croft	University California Berkeley	USA
Breakthrough Listen (BL), the most comprehensive, intensive, and sensitive search for technosignatures to date, has deployed equipment at telescopes around the world. As of 2020 March, BL has generated over 10 PB of archival data products. Two PB are currently available in a publicly accessible archive and the open data strategy includes a software suite which enables data to be ingested into Python programs. There is also a growing pilot program with the open-source GNU Radio collaboration. The paper will describe the current status of the BL observing program, its data products, analysis pipeline, progress in deep learning, growing international collaborations, and planned next steps. (12 other authors, two Breakthrough Initiatives, one MIT, others UC Berkeley.)				

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A4,1,3,x60842	On the search for artificially dispersed signals towards the Galactic center and nearby stars with the Breakthrough Listen program	Dr Vishal Gajjar	University of California Berkeley	USA
So far, most of the SETI has been focused on searching for narrow-band signals around 1420 MHz [1]. The Breakthrough Listen (BL) program aims to search the entire terrestrial radio window and includes a detailed survey of the Galactic Centre (GC). The paper will discuss the detailed search strategy towards the GC, contiguously spanning from UHF (700 MHz) to W-band (93 GHz). Following a conjecture by Andrew Siemion, specialised hardware aids a search for artificially dispersed transient signals. (The paper has 13 other authors, one Columbia University, two Breakthrough, others UC Berkeley.)				

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A4,1,4,x61207	Commensal SETI Survey Strategies for MeerKAT	Dr Daniel Czech	University of California Berkeley	USA
Breakthrough Listen will shortly begin conducting a commensal SETI survey with the MeerKAT radiotelescope in South Africa. One of the strategies to achieve this goal will be to "beamform" on sources of interest present in the primary field of view of the telescope for each pointing (dependent on their proximity to the pointings planned by the Large Survey Projects (LSPs) [2]). The paper examines strategies to maximise the number of targets that can be observed in a specific amount of primary observing time. (The paper has 13 other authors - two Breakthrough, others UC Berkeley.)				

[1] 1420 MHz is the "Hydrogen line" in the radio spectrum en.wikipedia.org/wiki/Hydrogen_line. falling into a band sometimes called the waterhole since it has been assumed to be a possible meeting place for interstellar communicators en.wikipedia.org/wiki/Water_hole_(radio).

[2] MeerKAT en.wikipedia.org/wiki/MeerKAT

Code & link	Paper title	Speaker	Affiliation	Country
[IAC-20,A4,1,11,x56555](IAC-20,A4,1,11,x56555)	Cosmological KLT for Einstein-De Sitter universe with SETI applications	Dr Nicolò Antonietti	INAF - IRA	Italy

The relativistic KLT [1] was firstly considered by one of the authors as early as the 1990's, but that was confined to special relativity only. During the SETI 1 Session of the IAC 2019 held in Washington DC, these authors presented a paper attempting, for the first time, to extend their KLT calculations to the Friedmann-Lemaitre-Robertson-Walker (FLRW) metric of the expanding universe. It was claimed that their new results could be of interest for SETI applications regarding incoming signals from receding galaxies. In this new paper the previous paper's calculations are applied to the Einstein-De Sitter model of the expanding universe, thus paving the way for further cosmological applications of the KLT (note this is the whole abstract).

(Second author Dr Claudio Maccone, International Academy of Astronautics (IAA) and Istituto Nazionale di Astrofisica (INAF), Italy.)

SESSION SETI 2: SETI and Society

Web address -iafastro.directory/iac/browse/IAC-20/A4/2/

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A4,2,3,x57073	Astropolitics and the Implications of Belonging to an Extraterrestrial Polity	Mr Mclee Kerolle	Space Generation Advisory Council (SGAC)	USA

Under the premise that advanced technological extraterrestrial civilizations have been discovered, this paper will address the political implications regarding further discovery that Earth belongs to an extraterrestrial polity with several hundred extraterrestrial civilizations. Presenting two presumptions -

- dealing with the anthropocentric nature of politics of outer space functions in an extraterrestrial community;
- that extraterrestrial civilizations more technologically advanced than humanity are likely to be more culturally and ethically advanced, and as a result would not harm human civilization.

Are the five main space treaties of the United Nations consistent with what is the most famous post detection policy, the First SETI protocol of 1989? What would be the impact on space law of the discovery of belonging to an interstellar polity?

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A4,2,5,x55449	Legal issues regarding extraterrestrial life and intelligence	Mr Raphael Costa	Institut du Droit de l'Espace et des Telecommunications - IDEST	France

Two legal issues: the protection of alien lifeforms (its environment and the lifeform itself) and the protection of humanity from those lifeforms. What are the legal tools which can protect alien lifeforms? Perhaps human rights could apply in some conditions? Perhaps laws regarding protection of oceans could be used to protect water lifeforms, for instance under the ice of Europa? The contamination of Earth by extraterrestrial matter, including living substances, is covered by the Outer Space Treaty, signed and ratified by more than a hundred countries, including all spacefaring nations. Whatever the United Nations committee procedures are, the risk of unilateralism is huge.

[1] Karhunen–Loève theorem en.wikipedia.org/wiki/Karhunen–Loève_theorem.

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A4,2,6,x60955	A Comprehensive View of SETI: Technical, Legal, and Outreach Considerations	Ms Mirandah Ackley	International Space University (ISU)	France

This work is a comprehensive approach to the search for extraterrestrial intelligence, based on three core questions: (1) How can we detect signals from other intelligent life forms? (2) What should humanity do after a positive detection? (3) How can societal awareness of SETI be raised to normalize detection initiatives? An analysis of current research in the field highlighted that there are several gaps, including those in science, technology, legal implications, and outreach endeavours that hinder its progression. An outreach plan is presented as a response to the third question to normalize the search for extraterrestrial intelligence to the public, in the context of scientific advancement and space exploration.

(20 other authors, all ISU)

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A4,2,7,x58825	The InCosmiCon Research Center and its activities in the field of SETI, Big History and interculturality	Dr Paolo Musso	University of Insubria	Italy

As announced at the IAC 2019 held in Washington, at the beginning of 2020 the University of Insubria (Italy), in collaboration with the UCSS of Lima (Peru), has created a new research center called InCosmiCon (Intelligence in the Cosmic Context), based at the Department of Human Sciences, Innovation and Territory (DISUIT). Its goal is to investigate the nature of intelligence in an interdisciplinary way. In the present paper some of the InCosmiCon members are going to present its structure, its first results, and its projects for the near future, while a separate paper will be specifically devoted to a Peruvian project about Astrobiology and Optical SETI.

(a large author list - institutions in Italy and Peru including Dr Claudio Maccone, much cited in this subject)

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A4,2,11,x56994	Science Fiction to Science: KLT to communicate with Starshot and Tau Zero	Dr Claudio Maccone	International Academy of Astronautics (IAA) and Istituto Nazionale di Astrofisica (INAF)	Italy

See also IAC-20,A4,1,11,x56555 *Cosmological KLT for Einstein-De Sitter universe with SETI applications* elsewhere in this report. In the present paper the previous calculations are applied to the hyperbolic motion of a spaceship ie the uniformly accelerated motion in the spaceship's reference frame. That is precisely the KLT for telecommunications between the Earth and a relativistic spaceship moving in the expanding universe from one stellar system to another one. This being the case, the mathematics of the KLT for Starshot is described in detail in the present paper. Dr Maccone also offers a tribute to SF author Poul Anderson, whose "Tau Zero" described the motion of such a relativistic interstellar spaceship in 1970.

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A4,2,12,x59772	SETI Search: Plausibility of a SETI Probe and Search Parameters for an Interstellar SETI Search	Dr Ugur Guven	UN CSSTEAP	USA

This paper presents the novel concept of SETI search probe using advanced nuclear technology with helium cooled modular reactors or gaseous core reactors with Uranium Hexafluoride to reach very high speeds in a spiral search pattern beyond the Heliopause with illustrations and simulations to provide the scientific community with a plausible method that is attainable with early 21st century technology.

SESSION Tools and Technology in Support of Integrated Applications

Web address -iafastro.directory/iac/browse/IAC-20/B5/1/#paper.59095

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,B5,1,7,x59095	Edge computing and its applications in satellites	Mr Archit Latkar	Ramaiah Institute of Technology	India

iafastro.directory/iac/paper/id/59095/abstract-pdf/IAC-20,B5,1,7,x59095.brief.pdf

Edge computing moves computing power from cloud based platforms to edge devices. Traditionally edge devices collect data and simply transfer it to the cloud servers, reducing data transfer demands and thus improving speed and efficiency. Example applications of edge computing in satellites include - encryption to protect data, distributing artificial intelligence, data-centres in a constellation of satellites, improved remote area communication, intelligent systems for interplanetary missions and beyond. This paper explores how edge computing can be applied on satellites, what new computer architecture technologies can be implemented and what can be achieved.

SESSION Space Exploration Overview

Web address -iafastro.directory/iac/browse/IAC-20/A3/1/

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,A3,1,9,x57930	Advancing Space Exploration through Crowdfunding Space Projects	Dr Bruce Betts	The Planetary Society	USA

The Planetary Society’s LightSail 2 solar sail spacecraft, currently in orbit, was entirely crowdfunded (49,426 people from 109 countries contributed more than 7 million US dollars). The Planetary Society is very interested in seeing crowdfunding for space projects develop and grow. Dr Betts will discuss the Planetary Society call for proposals and provide details with the hope the space industry can work together to unlock the potential of crowdfunded space projects – and thereby enable additional science and technology while directly engaging more people than ever in space exploration (see also Interstellar News item *LightSail 2 continues* in this issue).

Code & link	Paper title	Speaker	Affiliation	Country
IAC-20,E1,6,8,x56502	How online influencers help tell the world the story of space	Mr Remco Timmermans	International Space University (ISU)	UK

The latest example of a space organisation seeking social media influencers is the IAFExplorers campaign of the International Astronautical Federation (IAF) which is seeking young super-influencers (those who have over 100,000 social media followers) to attend the Global SpaceExploration Conference GLEX 2020. This paper will describe how influencer marketing works in different industry sectors, analyse the increasing interest from industries including high tech, NGOs, government and the space industry, analyse recent campaigns and interview the campaign organisers and online influencers, look at the costs and how to measure success, derive a list of effective campaign elements. (One other author, also ISU.)

Cassidy Cobbs - Bioscientist - Part 2

interviewed by Robert Kennedy and John Davies

Cassidy Cobbs is an evolutionary biologist by training. Currently, she is a Scientific Liaison at Memorial Sloan Kettering Cancer Center (www. mskcc.org), New York, New York. With her lab she is now on the front line of the defence against Covid-19 in New York. Opinions expressed in this interview represent only her own point of view, and do not imply anything about those of her employer.

Cassidy is the Secretary of the Institute for Interstellar Studies, the US-based part of our organisation. This is the concluding part of a lightly-edited transcript of an interview with Cassidy conducted by Robert Kennedy III and John I Davies on 14th April 2020. The first part was in our previous issue, P29 May 2020. More about Cassidy in that part.

In subsequent issues, we hope to bring further interviews with significant figures in i4is and interstellar studies.

The whole interview was published in May 2020 as a preprint in the i4is members area of the i4is website.

John Davies (JD) top left, Robert Kennedy (K3) top right, Cassidy Cobbs bottom centre

Section 4: Interstellar

JD: Ok, move on to the next one, Robert.

K3: Number 4, unless, wait she said "well…" you have more to say?

CC: No, go ahead. I was just gonna go ahead and comment on you know the lessons of all this…

K3: You're absolutely free to! What do you see the lessons are?

CC: I think for one, you know it kind of intensifies the need to continue thinking about these things. About interstellar travel, about the ability to spread ourselves beyond just Earth. You know I think that's a message of both just survival as a species and hope that things can improve from where they are now. But it's also a cautionary tale. The bugs are everywhere. They can come from anywhere. And you know they're also just trying to survive. So we have to make sure that we know how to deal with a plague. The best solution to coronavirus right now before we have a vaccine and especially effective treatments are behavioral, based on epidemiological data, not pharmaceutical or biological data. And I think that that's important. Understand, what's the first response when you have a case? Just like we have disaster plans for fire, or for a tornado, you know exactly what to do. But this really felt like everyone was running around with no idea what to do. Now that's not true, because there were plenty of people saying what needed to happen, it was more a matter of getting it done. But among the lay people certainly nobody really understood what was going to stop the spread or protect them. And I think that that gives us just one more thing to think about when thinking about travel in an enclosed space.

K3: Yeah.

CC: I don't think that's ever not been thought about just especially salient now.

K3: and not just viruses, and bacteria, but… fungi, and… no doubt other stuff we haven't even thought of.

CC: there's always prions.

K3: lovely, yeah.

JD: Those weird things. Yeah, the thing that strikes me, Rob Swinney just came back from Florida a couple weeks ago, I'm not looking forward to being on a metal tube for 8 hours or whatever it was.

K3: Well, getting back to interstellar, as opposed to intercontinental…

{all laugh}

K3: so, what do you want to see happen in our field say in the next three years? What concrete research…

CC: Assuming we can gather in the next three years,

K3: yeah…

CC: the focus should be on continuing to diversify the interests to different fields, you know, now we need to find an epidemiologist to bring in, you know…

K3: Yep!

CC: {laughs} …I think the focus has always, not exclusively, but been a lot on the space engineering, which is obvious, and I think everyone has had a lot of great ideas, and they're going to keep coming. But it's also time to really focus—and I know I don't have to tell you this—to really focus on, I guess, the INSIDE {laughs} of the ship. {all laugh}

K3: Yeah.

CC: if we're talking about a worldship, that's different than if we're talking about a smaller… A generation ship is a different concept than something smaller, but either way, there are a lot of biological considerations.

JD: You know, the elective we're doing at the ISU in a couple of weeks' time is focused around worldships, I don't know if you knew that, but…

CC: I think Robert mentioned it.

K3: not me, it would be somebody else, unless I was forwarding traffic. I actually did not know that.

JD: Andreas got hold of the idea. There was a worldship study done by masters students at the International Space University what was it three? maybe four? years ago?

K3: Almost five! That's the paper that Cassidy was the first author on.

JD: Oh, right!

K3: She contributed to the ISU, you know we took kind of an outside view of their project.

JD: that was when Chris Welch and I got involved in any ISU stuff…

…but I was aware it existed, sorry, I didn't realize you were…*

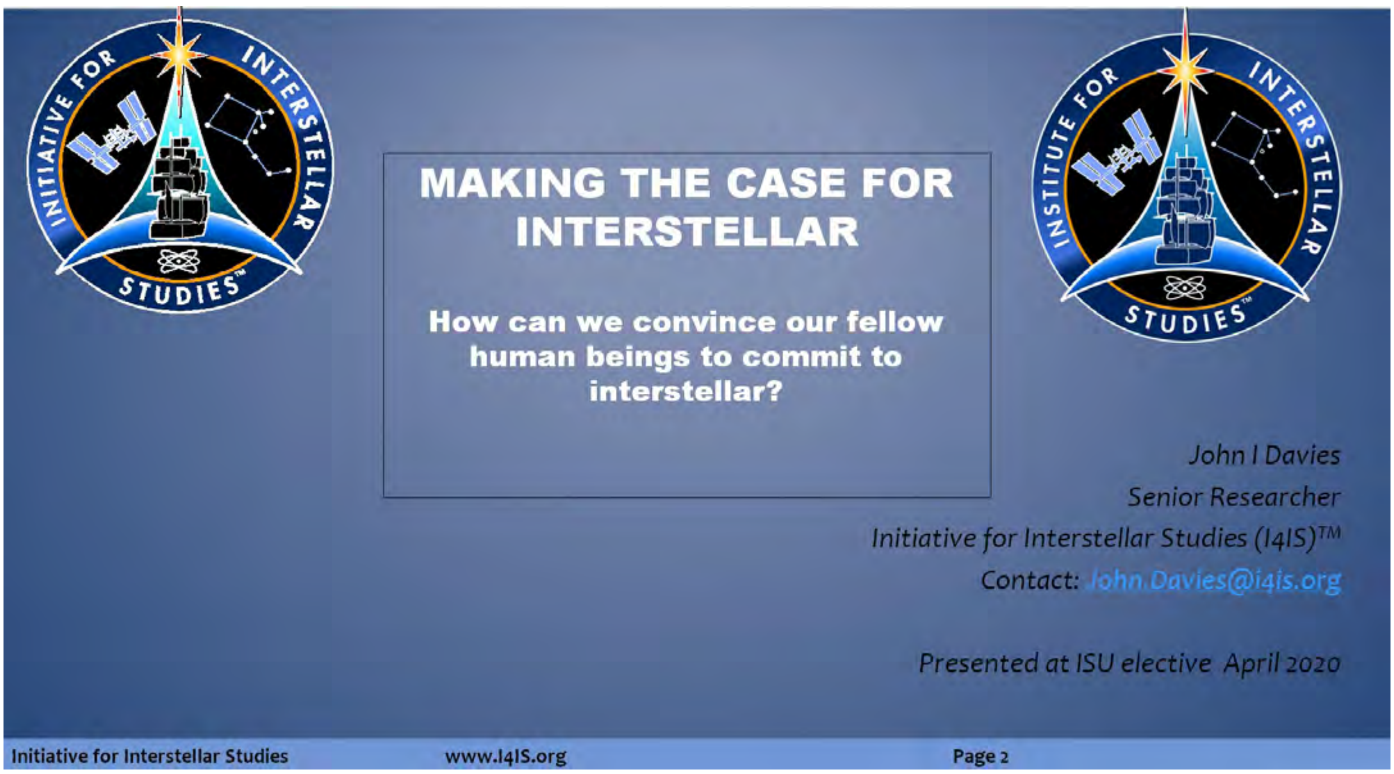
CC: no, no, no that's fine {laughs}

K3: time flies, that's why I was surprised, "oh, what? they're doing worldships again already?" but it's been five years

JD: yeah, yeah

K3: So a worldship

JD: We've got about three-four days of presentations, and the rest of it is project work for the rest of the two-week time. I'm doing some sort of slightly less sharp-end stuff. I've taken a long-term interest in artificial intelligence, particularly artificial general intelligence so I'm doing a couple of things on that. I also did, when we did it a couple of years ago, I did a piece on making the case for interstellar, because it's a pretty far future sort of thing. One of the questions I wanted to ask Cassidy was, how do you see making the case for interstellar? What interests your friends and colleagues in interstellar, if at all?



CC: Um, I think it's in the scope of most of my colleagues. I think a lot of the draw for me, personally, is the idea that we could actually form the sort of interdisciplinary team necessary to build something like that.

It's a very kind of hopeful view of human future, culture, being willing to pay for something. It's not something that would happen in late-stage capitalism {laughs} because it's not a profit-generating venture. It's about just humans and, um, I think there's a bit of an optimistic view that we can get there someday, and that's one of the things that draws me to it. But I think the science is really fun to think about, and to muse on what the problems would be, what the potential solutions would be. That's definitely a big aspect of it for me as well.

* Professor Chris Welch is one of the co-authors of the JBIS paper that Cassidy led, as a product of TVIW's 3rd workshop in November 2014—see C C Cobbs, C Welch, M Lamontagne, E Hughes, R G Kennedy (as corresponding author), and J Beall, *Ecological Engineering Considerations for ISU's Worldship Project*, Technical Note in Tennessee Valley Interstellar Workshop 2014 Special Issue of Journal of the British Interplanetary Society, volume 68, no 3-4, Mar/Apr 2015.

K3: Seems to me that there's much more of a viable path to research and productive work, productive research and work, to worldships via the ecological route than the propulsion route because, for example, take an asteroid colony a century or two hence, out there in the Main Belt, a bubble of rock and metal with thousands of people inside. Well, as an asteroid colony is basically a worldship that doesn't go anywhere.

JD: Hm.

K3: Stick an engine on it, and it's a worldship. I've always thought that. How many other people think that? Kim Stanley Robinson is the only one who ever articulated that it's going to be more like that (K3 later mentioned to JD "I forgot to mention The Expanse pentology because I haven't read it yet, only watched the show. But they draw the same general path of development.")

JD: well, the worldships that Bond and Martin devised way back just after the Daedalus work looked pretty much like O'Neill colonies with a rocket on the back. Hm, so that's quite a long time ago.

K3: My point is that getting the ecology right is going to be necessary a lot sooner than figuring out the propulsion of a worldship that I don't see how is less than five centuries off.

JD: Hm.

K3: At least. Maybe a millennium. But deep space colonies, I'll be shocked if we don't have them in less than a century. And to have a working deep space colony, you better know a lot more about ecology than we do now. So, over to you, subject…

CC: Yeah. I mean, that's absolutely true. Any work that you do pertaining to a worldship is going to be applicable to other cases. So not even deep space colonies, but Martian colonies, whatever. But when it comes to re-introducing species that have been absent from areas, or trying to develop using, uh, you know modern irrigation or other techniques to regions that have been unfarmed or devoid of plant life…{see the "Sahara Forest" project en.wikipedia.org/wiki/Sahara_Forest_Project }

…we do that sort of ecological engineering all the time on Earth. So anyway, as much as that feeds our understanding of what we need to think about for a worldship, anything we think about could also theoretically feed back into what we do here in Earth…

{see the effect that the discoveries from Mariners probes to Mars in the early 1960s, and Venus, had by informing/alerting science to the role of greenhouse gas (GHG) in climate change here on Earth.}

…it's not an angle that's totally speculative. The applications are…

K3: yes

CC: the applications are myriad even now.

K3: That's true, it's not speculative at all, unlike, say propulsion. What you say is true. Earlier you had said "so we need to diversify the disciplines that are brought into this". Which, as you know, I love that word, diversity,

{CC laughs, JD coughs}

JD: I have had that cough since Christmas!

{all laugh}

K3: OK, 'cuz you were giving us a little frisson, like eating a pufferfish…

{all laugh}

JD: There's a lot about personal background that explains it to some extent, but that's another story. Carry on, Robert.

Section 5: Diversity and SF

K3: so, "diversity" … question 5, so bringing in these other disciplines, which we've been somewhat successful at, but we need to be a LOT more, a much much greater scale. So, taking the long view, starting young, looking at this field, our field, our beloved field, as a generational problem. Tell us about the thing you first told me about maybe seven or eight years ago at a Libertycon.*

…I believe it was, about why you like science fiction, how you use science fiction to entice youngsters into science, especially girls. I have a number of friends who focused on bringing girls into math and science so… Tell us how YOU do it. And how the rest of us should get smart about doing that, growing the field.

CC: I think my impetus to start getting involved was just a kind of realization as I went to "cons" {SF fan slang for "science fiction CONvention"} that people were much more familiar with the line between science and the science fiction when it came to, for instance, propulsion. Or time travel. Or astronomy in general. Not that everyone has a working understanding of string theory, but I think it was a little easier to tell the line between fiction and science. I found that with biology, most people found the line a lot fuzzier. And it was funny to me because it kind of went both ways, because there were people that had no idea what we were capable of in terms of genetic engineering or understanding of evolution or anything like that and so, it all seemed crazy. And then there were people who were, "what? we can't just get a genome and understand it and what the organism looks like?" The understanding of the line was a lot fuzzier, so that's sort of what led me to start doing the panels about biology and science fiction, and talking a little bit about that line. That panel we did at Libertycon I thought was really fun, with my friend Eva, the neuroscientist. But science fiction right now, I think more than ever, has become a lot more diverse in terms of the voices that are being heard, as well as the areas that are being speculated about. I think I read a lot more speculative biology, geology—the "Broken Earth" trilogy—as I do speculative space travel. Or, um, what's that molecule?...

K3: "protomolecule" {a reference to *The Expanse* pentology, cited abpve}

CC: dimensional manipulation of protons like in *The Three Body Problem*.

K3: oh, right! I just finished that!

CC: I did too! {laughs}

JD: What's that?

Cixin Liu trilogy see en.wikipedia.org/wiki/The_Three-Body_Problem_(novel)

Front cover art trilogy *Remembrance of Earth's Past* Liu Cixin Credit: Tor Books / Stephen Martiniere.

* Where Robert and Cassidy first met, "Libertycon" (libertycon.org) is an annual science fiction convention in Tennessee. It is widely considered to be the most literary and science-oriented of all the "cons".

K3: Unpeeling a proton and making it as big as a planet, and then inscribing on it like a giant integrated circuit. Just… Chinese are strange.

JD: Who wrote this?

K3: Caixin ? … something … you can look it up, "The Three Body Problem" …

JD: Oh, yeah! I never managed to get to the end of it. Sorry!

K3: The second one is called "The Dark Forest", which apparently is seriously grim, and what's important to the three of us is that "The Dark Forest" appears by name on the cover of one of the red-cover JBISs.

JD: Really?

K3: Actually in the same…

JD: ...issue as that our, either Cassidy's, the article that Cassidy did with me and the others, or the issue right after that, the one that's got the SETI work by Sam Lightfoot and me and Eric Hughes …

(K3 later mentioned to JD: "I neglected to mention Paul Shuch, oops. See R S Lightfoot, E Hughes, R G Kennedy (as corresponding author), and H P Shuch. 2015. *Communication, S.E.T.I., and Strategies*. Technical Note in Journal of the British Interplanetary Society, volume 68, no. 5-6, May/Jun 2015, p.167-171.")

JD: …in that issue is an article by two Chinese people called "Fermi's Paradox and the Dark Forest Rule" or something like that. Don't read the article unless you've had a stiff drink or three.*

JD: {laughing} I read the sequel to The Dark Forest thing, what was it called…?

K3: Well, there's three books so Three Body Problem, Dark Forest, and I forget what the third is called…

JD: I think I accidentally read the third, *Death's End*.

K3: Oh, well, no spoilers then.

{CC laughs}

JD: It's very striking. And not cheerful. Definitely not cheerful.

CC: No, no, it was NOT cheerful.

K3: So, Cassidy, YOU had brought up the Three Body Problem, we dropped the thread, so sorry…

CC: yeah, no no, I just read I guess a lot of different types of speculative fiction in the last three, five, years. I don't feel like I had that breadth when I was a kid. And I think that's something you can really capitalize on to bring in people who don't just think about space as their speculative focus. The people who think about, um, earth and what aliens might look like and what human society might look like. What our diseases will look like, what our medical treatments will look like, in the future. And, you know, I think every science fiction book has the potential to spark someone to think about something in a way they never have before that can, you know, end up guiding them in their career, if they're a younger person. And what they want to study.

K3: Earlier, you had articulated, when you were explaining to me what you meant by the word "core", you were talking about barriers to entry a field of knowledge, and the barrier to entry in fields that you work with quite high, which is why the "core" was created. I didn't articulate it in those terms, but I've been thinking along those lines in our field, in interstellar work, in flying ecologies, do we already have a "barrier-to-entry" problem?

JD: Hm.

CC: A good question.

K3: Because, like, I have zero free time for reading. I read The Three Body Problem…

CC: {laughs}

K3: …I don't know how the hell I had the time to read it, because I have no time these days, so...

CC: I think the way to combat that barrier to entry is something that I think you already do pretty well, Robert, which is recognize the areas hat you're not an expert in, then find people who are. Then you can talk about the problem from different points of view, expertise. Um, I think the issue for me, when you talk about as you say flying ecology, I don't even know that we know yet what we don't know…

* See Chao Yu and Jiajun Liu, *The Dark Forest Rule: One Solution to the Fermi Paradox,* Journal of the British Interplanetary Society, volume 68, no. 5/6, May/Jun 2015, p.142-144.

K3: yeah, yeah, I agree with you. "Unknown unknowns".

CC: …and I don't know that there's a great solution to that, except to keep going, and keep thinking, and keep trying to find those holes we gotta fill. Certainly there are many many people who are far more qualified to understanding ecological networks than I am. I would say my understanding is pretty rudimentary. And my expertise is also shifted in my professional career, which is normal.

JD: Hm.

CC: I know WAY more about cancer than I ever did before, that's for sure. {laughs}

K3: Well, you don't, you know, I think that "industrial", I'll call you an industrial lab, OK, right?

CC: Yep! {chuckles}Thanks.

K3: as opposed to "academic". You're practically industrial, and this industrial experience, your exposure to cancer, is gonna pay you GREAT dividends in the future. As opposed to becoming narrow. I don't, the human race still has far too few generalists. Um – non-bullshit generalists. We do have lots of bullshit generalists.

JD: Yes.

CC: An important distinction.

K3: Yeah! {all laugh}

CC: I didn't mean to imply that you forget your earlier expertise when you move on and develop. I think, for me, it's not that I've forgotten everything that I know, but I haven't been active in that body of literature in the past five years, and the way things move, you miss stuff. But it's hard to remain active in every field you've ever been interested in, or worked in, as I'm sure, you also experience.

K3: {snorts, makes face} Yeah.

JD: I couldn't do systems programming anymore, and that's what I did with my life for about 20 years. Couldn't do it now.

CC: I would …

K3: go on.

CC: …in this virus-testing atmosphere, kind of fun to get to go back to doing a little bit of benchwork. It's been a couple years since I was on the bench. It's like riding a bike. But it's been fun, you know, to play with the robots again. I just really like the work - move small volumes of colorless liquids around again, but…

K3: John, over to you. Closing…?

JD: There was a couple of questions I had prepared. The thing that occurs to me now is that we do have a biologist here, and we definitely need more biologists, and other science disciplines, and disciplines beyond science, as well. Um, and you're an instance, Cassidy, that's outside the hard science and engineering group that inevitable dominates the things that Robert and I do. Getting outside that bubble, what he's called "barriers to entry", is a really hard thing to do, and a really important thing to do, and, we sort of discussed it, and I just want to, it would be really interesting to have your long-term thinking about that, as an outsider from that point of view, what you might call hard science and engineering. We're very weak in that respect. We've got people with computer science degrees, people with electronics degrees, people with physics and maths degrees. Um, you know, even the people who are not the university people tend to be people like hard practical engineers, like Terry Regan who Robert knows well. They're not people outside that circle, so, um, your long-term thoughts about that would be very interesting to me.

CC: Yeah, um, I think that's what you say about it being difficult to go outside that bubble is really true. It's also hard to come in.

JD: Yes.

CC: It is intimidating, I think, to feel like an outsider in a way. I've never going to understand the propulsion talks. That's not gonna happen. And when you sort of put the demographic factors on top of that, no offense, but a room full of old white men…

{JD & CC laugh}

CC: …it can definitely be hard to feel welcome, even when many of you are extremely welcoming. But I also know it's also hard to bring people in. I know we did experience some pushback from people who wanted things to remain the same. I understand that from an emotional perspective when you have something you're really passionate about and that you spent a lot of time on. Sometimes it's hard to share, and it's hard to hear people dismiss ideas you've had for so long because they're coming from a different perspective. But one of the most important things we can do as scientists is to let that happen and to listen and to be able to admit when we're wrong, or could be wrong.

CC: I think that long-term, the goal should be to continue to push that envelope, to take an idea that we have about how a worldship might work, or how the ecology might work, and find someone who can challenge it.

That's that only way we're gonna figure out our unknown unknowns.

Obviously there has been progress, and will continue to be. It's just that has to be the long-term goal, to keep making the bubble bigger.

{JD, CC laugh}

JD: Oh yeah, OK.

> CC:long-term, the goal should be to continue to push that envelope, to take an idea that we have about how a worldship might work, or how the ecology might work, and find someone who can challenge it.
> That's that only way we're gonna figure out our unknown unknowns. That has to be the long-term goal, to keep making the bubble bigger.

K3: So we'll pretend your questions you're about to ask were asked earlier.

Section 6: School to Sloan Kettering

JD: Well, they sort of are, related to the first question you asked. How did Cassidy end up as a lab scientist in a New York teaching hospital from, from the background she came from? I'm sort of interested in, what were things like at school? You've told me a bit about your mum and dad, particularly your mum's professional background in forestry, the natural world. What was it like at school, what was the atmosphere like? I guess it was a co-ed school. You don't get single-sex schools much in the USA anyway. I went to one. But uh, yeah, what was it like? What was the atmosphere like, between about the ages of 10 to 15, I guess? That's the formative period, I always think.

CC: Yeah. Um {laughs} I don't have a lot of strong memories from school at that time. I found it pretty boring. I mean, I enjoyed school as a concept, and it had been instilled in me that making good grades should be a thing that I should do, and I did. But it was not particularly challenging. That's not a, that didn't have as much to do with me, as, these were small rural schools. They didn't have very many kids who didn't really fit what they were expecting. I think my whole middle school there were only three of us in the gifted program. {laughs} It was very small, very small school. Most of my, I would say, mind-expanding experiences, came from reading. I, we, did science projects every year. My mom was always really enthusiastic about science projects. I had some really fun ones in that age range that we did. There was one year that we I got ... I got to use power tools. We built these little wooden houses, like, small, with windows on various sides of the house, or skylights. We actually had leftover insulation from remodeling of our own house so we, uh, we basically did this comparison of south-facing windows versus windows on other sides, insulated versus non-insulated. We put these little houses up on our farm, across from the house up a hillside where they got sunlight. Put thermometers in them, measured twice a day, every day. You know, to look at how building choices construction choice could affect the efficiency, the energy efficiency of your house, although I didn't think of it that way at the time. I was 11. I think that really, my mom always really pushed science projects as a way to expand my thinking beyond school. But I think they were fun for her, too. {laughs}

JD: Yeah.

CC: At 16, I left for boarding school, which was a school of science and math. It was a public – oh, that means something different in the UK {laughs} – but…

JD: I know what "public" schools in the US are.

CC: It was a public boarding school in the state of North Carolina…

JD: Really?

CC: …for science and math. It's part of the North Carolina university system rather than the standard public school system. It's a unique place*.

And being there was very good for me, in a lot of ways that up to that point, sort of fell by the wayside. Like, my SOCIAL development. And actually spending time around, around people that were as smart or smarter than me. And that was really important…

JD: Hm.

CC: at the age where… if you're the smartest person in the room, you start assuming that all your ideas are right. And that's NOT good… {laughs} 'cuz… smart people have bad ideas all the time.

{everyone laughs}

CC: You have to be able to listen to the people who can tell you, that it's a bad idea. I can tell you that learning to do that at a relatively young age, was very helpful for my development as a person, as much as, as a scientist.

`CC: smart people have bad ideas all the time`

JD: Nobody with very very few weird exceptions like military families has what YOU would call "public school" which is residential, which is a boarding school in the UK. Which is only people that have got quite a lot of money that send their kids to boarding schools.

CC: Yeah, it was unique, and it was free.

JD: Yeah. Right. … Was that?—I'm just trying to get the geography right—there used to be a real hotshot bunch of universities called the … Triangle Universities …?

K3: Yes! That's North Carolina.

CC: Yeah. It's the University of North Carolina, North Carolina State, Duke University, and then usually Wake Forest is included, too.

JD: Yeah, 'cuz I can remember when we used to, when I was in computing at Edinburgh University back in the 70s, we used to get stuff from Triangle University Computer Center. But that was in the days when universities did have big computer centres of their own and...

CC: Right.

JD: Yeah, brings echoes to me. Yeah, "TUCC" they were… I don't suppose it exists anymore. You don't need big computer centres anymore. There are places where they do high performance computing you just need one room with decent air conditioning and you've got...

CC: {laughs}

JD: standard 1980s room with racks, where you've got blades in them. … I worked in a number of different outfits where the CDC-6600 and 7600s, IBM 370/195, Cray-1, Cray-2, Convex, all that sort of gear, um, yeah… that's what we did. Well, I didn't, I was working on the communication stuff to connect them to the rest of the world.

CC: Yeah?

JD: Yeah!

CC: It must have been…

JD: Different time, yeah. I'm getting into my anecdotage!

K3: Well, what else you got, John?

JD: I think there's that. Wait, you said your mum did forestry. What was it your father did?

Cray XMP at University of London Computer Centre in the late 1980s

* North Carolina School of Science and Mathematics (www.ncssm.edu)

CC: He actually was also a forestry major, that's how they met. My stepfather, also a forestry major. {laughs} They all went!

JD: Yeah?

CC: Yeah, he went on to get an MBA, and worked mostly in sort of commercial real estate. He went the "I had a kid, I'm gonna get a grown-up job". Whereas my mother was a little freer after college, she worked as a landscaper. My stepdad worked for the Forest Service in South Carolina for awhile and he and my mom were eventually Christmas tree farmers. So we have a tree farm. So I guess the "forestry" continued. My dad has the same degree, just professionally wasn't as … didn't use it as much, I guess? And also, he always lived in cities, so there wasn't as just much, where, we might go for a walk but it's not like we're gonna see a native salamander. In Atlanta. {laughs}

JD: Yeah.

CC: {laughing} it's a different type of education. My dad is also a very, um inquisitive sort of person. Which certainly you know …

K3: Apple didn't fall too far from that tree.

{all laugh}

K3: sticking with the tree motif.

JD: Yeah, well. I guess my father was the classic British sort of autodidact who left school at 14, went to Workers Education Association {en.wikipedia.org/wiki/Workers'_Educational_Association} classes. Knew more about more things than a lot of my, even my secondary school teachers. All of which he just learned off his own bat. Not very much from school. Yeah. Um. My mum was very much two feet on the ground, worked in a cotton mill in Bolton in the north of England in the days when the cotton industry was a really big deal. Um. Interesting pair, but that's another story.

{CC laughs}

JD: I've diverted you again. {laughs} Right—I think that's my questions.

K3: OK. That was a GOOD interview

About the Authors

Robert G Kennedy III, PE, is President, Ultimax Group Inc and President of the Institute for Interstellar Studies - US, the American sibling organization of the Initiative for Interstellar Studies. He is the author of numerous papers in Interstellar Studies and was co-author of *Project LYRA: Sending a Spacecraft to 1I/'Oumuamua (formerly A/2017 U1), the Interstellar Asteroid*. He was a co-founder of Tennessee Valley Interstellar Workshop (tviw.us).

John I Davies is a retired software engineer and mobile telecoms consultant. His graduation job was in the UK space sector where he worked on ground checkout for the Bluestreak base stage of the Europa launcher and contributed to an early design study for the Hubble telescope. He spent most of his career in system software development for networks and in messaging and packet switching for mobile networks. He now edits Principium, leads school outreach for the i4is Education committee and manages requirements issues for the i4is membership system.

LETTER TO THE EDITOR:
India in Space

From: Pranjal Samarth

Dear Editor,

I remember that the first time ISRO (Indian Space Research Organization) became a common Indian household name was during the end of 2014 when ISRO successfully put their orbiter "Mangalyaan" in an orbit around Mars. But interestingly, the reason behind most of this popularity was not the technical achievement or the success of the mission on ISRO's first attempt, but the fact that the entire mission cost just a fraction of what similar missions by other countries did.

The Indian Department of Space has several remarkable feats in the Space sector under its belt, such as its very own successful launch vehicles, PSLV (Polar Satellite Launch Vehicle) and GSLV (Geosynchronous Satellite Launch Vehicle) the Lunar orbiters "Chandrayaan-1 & 2", an attempt to land on the Moon's surface, and plans to send humans into space by 2022. But the interest in the Space sector in the country has only been popularized by a very few visionaries such as the likes of Vikram Sarabhai and A P J Abdul Kalam.

But things are about to change drastically for the Indian Space sector as in a historic decision at the end of June 2020, the Indian Union government opened India's space programs, technology, and infrastructure to private companies through the IN-SPACe (Indian National Space Promotion and Authorization Centre) initiative. This initiative will allow private players, who were previously restricted to manufacturing and fabrication of rockets and satellites, to have access to use ISRO's infrastructure, scientific and technical resources, and data.

This sudden decision comes due as the requirement for space applications in the country such as remote sensing, disaster management, mobile connectivity, military, and weather modelling, which have boomed in the last decade. According to the current ISRO chairman Dr Kailasavadivoo Sivan, ISRO needs to expand to over ten times its size to cater to India's growing needs, and since several private companies have expressed their interests in expanding their space programs, a national initiative like this would be ideal for them.

Having graduated from a major Indian University only last year (2019), I see this as a major motivator and career-changing move by the Indian Union government. I have met and worked with a lot of very talented and hardworking students who wanted to pursue a career in space applications and aerospace but were restricted in doing so due to the lack of opportunities and unappealing government salaries. But with the expected rise in private space companies and funding in India, I can see this shifting rather remarkably.

India is a nation of almost 1.4 billion people and the capacity and power to bring about a drastic and sudden change by the people has been evident due to several controversial decisions made by the government in the last few years. Hence it is pertinent to use this national interest and recent trends like "Make in India" as a rallying point to popularize the need for developing the space sector in India and reduce the stigma of space being only required for astronomy and military applications. This will also allow for a stable platform for the next generation of visionaries who could help propel the Indian space programs into uncharted territories.

I believe the world needs to watch India and its space activities more closely in the next few years and I hope to contribute to my nation's accelerated involvement in space technology. If we can build a Mars probe which works at the very first attempt and at just 15-25% of the cost of NASA and ESA then maybe we are the right nation to build that first interstellar probe?

Sincerely,

Pranjal Samarth

Pranjal Samarth is a chemical engineer currently pursuing his Master's degree in space sciences at the International Space University. You can find him on LinkedIn at: www.linkedin.com/in/pranjal-samarth-6a808014b/

Interstellar News

John I Davies reports on recent developments in interstellar studies

Z-pinch fusion - sheared-flow stabilization

Uri Shumlak is often cited in connection with Z-pinch fusion as a potential fusion rocket principle (note especially *Reaching the Stars in a Century using Fusion Propulsion, A Review Paper based on the 'Firefly Icarus' Design* by Patrick J Mahon in P22, August 2018).

Dr Shumlak is Professor of Aeronautics and Astronautics, University of Washington. His new paper for the Journal of Applied Physics, *Z-pinch fusion*, notes that the Z pinch has been plagued by fast growing instabilities that limit plasma lifetimes but reports recent approaches that provide stability including sheared-flow stabilization to produce an equilibrium Z pinch to sustain the compressed plasma state for much longer durations. He suggests recent experimental and simulation results encourage pursuit of stabilized Z pinch to explore its fusion performance limits.

Toroidal Solar Sail with emitting coating

Professor Roman Kezerashvili (New York City College of Technology) has added another to his many contributions to interstellar studies*. With collaborators he has published *Inflation deployed torus-shaped solar sail accelerated via thermal desorption of coating* (arxiv.org/abs/1908.06761).

The sail is accelerated by a combination of solar photon pressure and, innovatively, by the effect of solar heating on the coating applied to the flat component of the sail.

The paper will appear as - Kezerashvili, R Y, Starinova, O L, Chekashov, A S, Slocki, D J, *A torus-shaped solar sail accelerated via thermal desorption of coating*, Advances in Space Research (2020),

doi: https://doi.org/10.1016/j.asr.2020.06.041

BIS Project Orbital Ring

A recent BIS Newsletter announces a new BIS study - www.bis-space.com/2020/08/10/25325/project-orbital-ring

Here's a very brief précis of *Project Orbital Ring* by Ryan Pickell (August 10, 2020).

An Orbital Ring is a LEO satellite in orbit around the Earth consisting of a strand of metal wire completely encircling the Earth and rotating around it at the required velocity to maintain its orbit. Ryan reports that the original 1982 research paper on this subject was written by a BIS member, Paul Birch. Ryan tells us that while Mr Birch's original paper is sound, much of its assumptions about the launch platform and materials involved, among other factors, are desperately out of date, and will need modernising to produce a workable design suitable for the present. Ryan needs engineering and physics talents (he says he is only suitable to be a "research lackey") on any project aiming to bring the idea into the modern world. He is looking for volunteers to help lend much needed expertise to the project.

Toroidal Solar Sail configuration
Credit: Kezerashvili et al

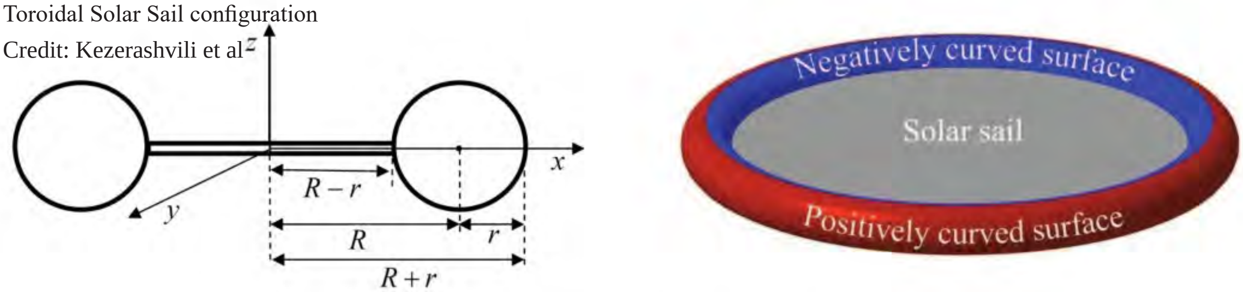


FIG. 1: (Color online) Torus-shaped solar sail and its geometric characteristics.

* See Principiums - P17 | May 2017 page 14 & P18 August 2017 page 22-23, P28 (both FISW NYC), P23 November 2018 page 30 (IAC 2018) and several JBIS.

This looks like a project with similar but more modest objectives than the Space Elevator. Low cost access to LEO is a vital step on the way to interstellar so we are happy to publicise this BIS idea.

We don't want to distract you from our core objective but, to quote Gully Foyle -

Gully Foyle is my name
And Terra is my nation.
Deep space is my dwelling place,
The stars my destination

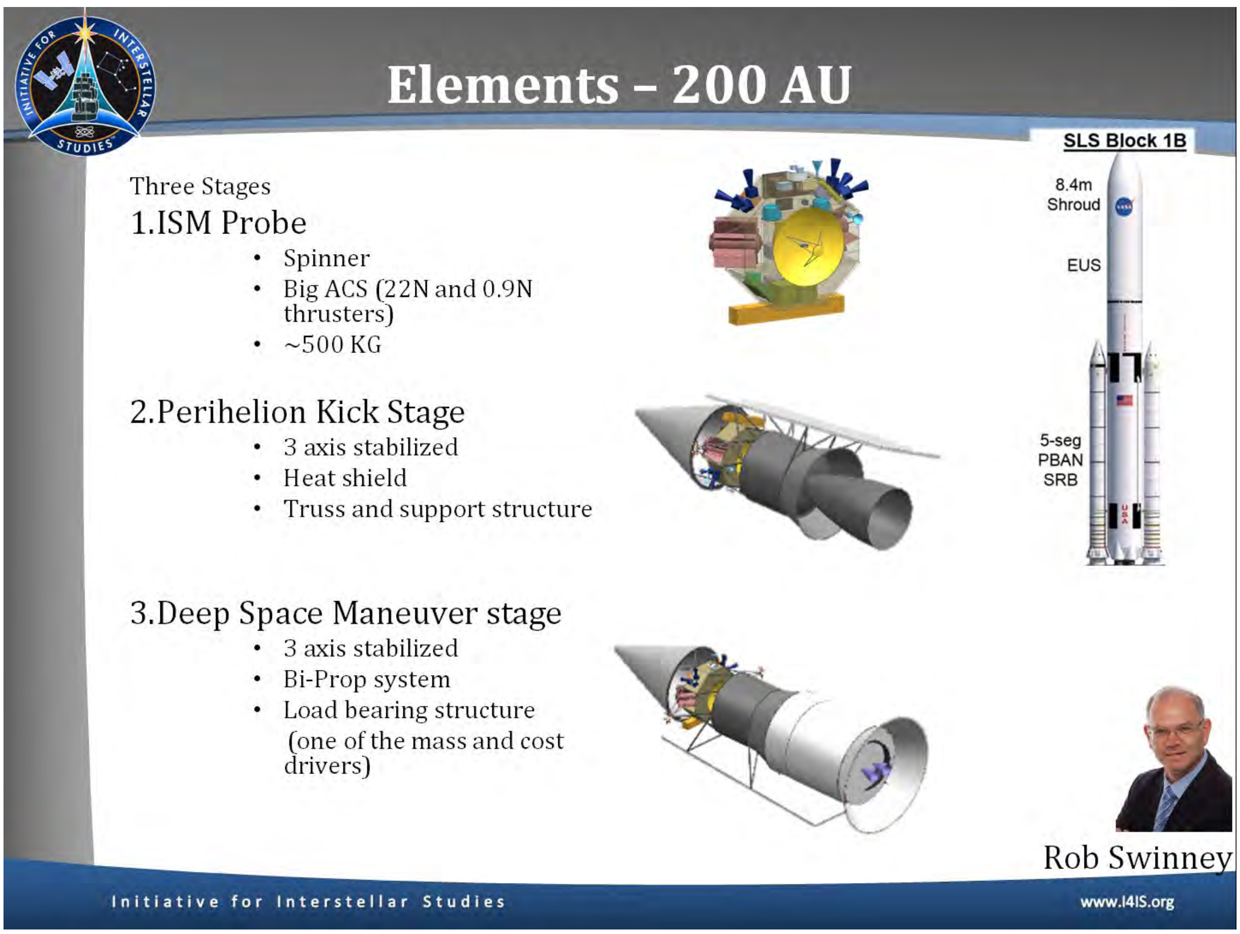
- from *Tiger! Tiger!* by Alfred Bester 1956 (also titled *The Stars My Destination*).

Our nation, Terra, needs to dwell in deep space before it can reach that destination.

Contact Ryan via - www.bis-space.com/forum/index.php?topic=596.0 - and let us know if you decide to get involved [Principium@i4is.org.](mailto:Principium@i4is.org)

BIS West Midlands Interstellar Presentation

Like most other events in the current situation, Rob Swinney's presentation to the very active West Midlands group of the British Interplanetary Society was online. On 2 May 2020 Rob, Deputy Director and leader of our Education work, presented - *Going Interstellar!* In addition to an overview of i4is, its achievements and objectives, and a brisk tour of where we are in interstellar studies he explained the near term mission to the interstellar medium (ISM) planned by JPL and Caltech starting in 2014. This "Super Voyager" would reach the ISM in 10-15 years, rather than 36 as for the Voyagers. One of the big decisions will be whether to use a solar Oberth manoeuvre, with that risky perihelion burn (see our Project Lyra work, reported most recently in Principium 29 Interstellar News, *More Interstellar Objects and more controversy*). He covered fusion and laser propulsion in some detail, of course and wrapped up with some inevitable scepticism about any near chance of FTL missions.



Elements of a 200 AU Mission
Credit: Swinney

Recent Interstellar Papers in JBIS

The **Journal of the British Interplanetary Society volume 73 #4 April 2020** was titled *Putting Astronauts in Impossible Locations*. This long range thinking is what we will need to go interstellar, not least to build the interplanetary culture and economy we need. Papers of particular interest are -

- *Missions to the edge of the visible*, an examination of science-fiction depictions of voyages to Saturn and its moons: one specific example of an 'impossible location' for astronautical adventures, and 'missions to the edge of the visible' with the focus on near-future scenarios, featuring crewed missions predicated on reasonably realistic technologies by Stephen Baxter.
- *The Prospects for Human Expansion into the Solar System*, Bob Parkinson examines the issues inhibiting the human colonization of the Solar System (flight times, radiation, gravity and environment) and some possible approaches for a future human/machine society (extreme insulation, short range teleoperations, integrated human/machine cyborgs, adapted human beings) and their implications.
- *Fast Transits in the Solar System using Nuclear Electric Systems,* a companion piece by Bob Parkinson to his Prospects paper - propulsion technologies to achieve the shorter transit times than those currently used by unmanned spacecraft including an example mission to achieve a transit to the Jupiter system in one year.
- *Cycler Links between Earth and the Gas Giant Planets, 1: Trajectories*, Stephen Ashworth presents preliminary concepts for suitable repeating orbits with short-range shuttle links at each planetary flyby.

JBIS Volume 73 #5 features *Thermal Thorium Rocket (THOR) – a new concept for a radioactive decay heated thermal rocket engine*. Gábor Bihari (University of Debrecen, Hungary) suggests that a radioactive heat powered thermal rocket (using the Th-228 isotope due to its high thermal output and very high melting point of its oxide) is a viable concept at the level of currently available technology. It can operate continuously for several years, with low thrust - allowing it to move large masses in the Solar System.

JBIS Volume 73 #6 is titled *BIS SPACE Project Special Issue 2,* with papers by

Stephen Baxter, Richard Soilleux, Stephen Gunn & Adam Manning. More in this issue - Lead Feature of *Implications for an Interstellar World-ship in findings from the BIS SPACE Project* Richard Soilleux.

JBIS Volume 73 #7 is another *General Interstellar Issue*. John W Traphagan & Ken Wisian (both University of Texas at Austin, Religious Studies & Anthropology and Bureau of Economic Geology respectively) present *Protocols for Encounter with Extraterrestrials: lessons from the Covid-19 Pandemic.* Arguing that the Covid-19 pandemic represents an opportunity to think through challenges that may arise in response to contact with ETI because it represents a potential threat to the entire population of Earth, thus forcing nations to implement similar measures, even if specifics and levels of restrictions vary from one country to another. Frédéric Marin (see part two of M8-ISR-L14 Worldship Population Dynamics in our next issue Principium 31) & Camille Beluffi (both Université de Strasbourg) discuss *Water and Air Consumption aboard Interstellar Arks.* Milan M Cirkovic & Branislav Vukotic (both Astronomical Observatory of Belgrade, Serbia) present *Habitability of M Dwarfs: a problem for the traditional SETI*, arguing that the flaring nature of these stars would further adversely impact local development of radio communication and that, therefore, their circumstellar habitable zones should be preferentially studied by other methods. Undermining the universality of cultural convergence as one of the major premises of the traditional SETI. In *On a Spectral Pattern of the Von Neumann Probes*, Z Osmanov (Free University of Tbilisi, Georgia) builds on previous work considering the spectral characteristics of interstellar non-relativistic von Neumann probes launched by Kardashev Type-II and Type-III civilizations. These might be visible in both infrared & ultraviolet spectral bands and with differential power dips for equally spaced frequencies, which might be a significant fingerprint. Thomas Cortellesi (University of Chicago) suggests *Reworking the Seti Paradox: METI's Place on the Continuum of Astrobiological Signaling*. Arguing that passive SETI's low likelihood of success in the short-term is a serious obstacle to sustainable funding, alongside a 'giggle factor' enhanced by a pernicious fear of contact. Therefore the scientific community must integrate an active approach to better ensure both the continuity and eventual success of SETI. Harold White, Paul Bailey, James Lawrence, Jeff George & Jerry Vera (all NASA Johnson Space Center) present *Dynamic Vacuum Model and Casimir Cavity Experiments* summarising a pilot wave interpretation of quantum mechanics known as the dynamic vacuum model, presenting recently published findings, this model and new insights associated with the Casimir force (and the possibility of being able to measure the phenomenon in the lab). This may have two propulsion related benefits - to provide larger amounts of negative vacuum energy density for a space warp or wormhole and as an in-space propulsion system with the ability to push on the dynamic vacuum medium.

Tying the Celestial Reference Frame Directly to Black Hole Event Horizons

Marshall Eubanks has published a paper on space navigation reference frames, *Anchored in Shadows - Tying the Celestial Reference Frame Directly to Black Hole Event Horizons,* May 2020 (arxiv.org/abs/2005.09122). He notes that both the radio International Celestial Reference Frame (ICRF) and the optical Gaia Celestial Reference Frame (Gaia-CRF2) are derived from observations of jets produced by the Super Massive Black Holes (SMBH) powering active galactic nuclei and quasars. These jets are inherently subject to change and will appear different at different observing frequencies, leading to instabilities and systematic errors in the resulting Celestial Reference Frames (CRFs). Recent observations show that the event horizons of these reference objects are observable directly and their positions are more stable. He suggests a space VLBI mission to observe SMBH event horizons could much improve the accuracy and stability of the ICRF. This is primarily an astrometry requirement but deep space navigation need these reference points to be as accurate as possible.

Was 'Oumuamua made of molecular hydrogen ice?

Darryl Seligman and Gregory Laughlin published one of the first papers on reaching and researching the interstellar object (ISO) 1I/2017 \`Oumuamua*. They have been thinking again about its mysterious motion and have presented a new theory about its composition which might account for its anomalous non-gravitational acceleration away from the Sun, *Evidence that 1I/2017 U1 (\`Oumuamua) was composed of molecular hydrogen ice* (arxiv.org/abs/2005.12932). They suggest that energy balance arguments indicate this acceleration is inconsistent with a water ice sublimation-driven jet of the type exhibited by solar system comets but this can be explained if it contained a significant fraction of molecular hydrogen ice.

Seligman and Laughlin's conjecture may be correct but unless we observe another similar ISO in the next few years a mission to 1I/\`Oumuamua may be the only way to solve this mystery. The continuing mission of i4is Project Lyra is to plan for this.

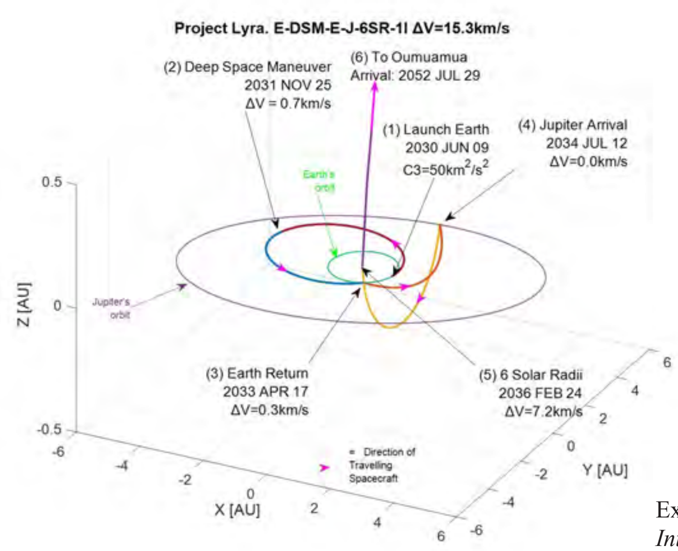
Exobodies in Our Back Yard

An i4is team of T Marshall Eubanks (Space Initiatives Inc), Andreas M Hein, Adam Hibberd and Robert Kennedy working with Jean Schneider of the Paris Observatory Laboratory for the Universe and Theory (LUTh) have been contributing to the *Planetary Science and Astrobiology Decadal Survey 2023-2032* of the US National Academies of Sciences, Engineering, and Medicine (*www.nationalacademies.org/our-work/planetary-science-and-astrobiology-decadal-survey-2023-2032*).

The National Academies say "The Decadal Survey is the most powerful means for us to directly influence planetary exploration activities, priorities, and funding levels. Uncertainty in federal spending plans make this a particularly critical time for us as a community to come forward with a compelling and aspirational plan for our field. The Decadal must be completed and delivered to its sponsors by March 2022 to enable its incorporation into FY24 budget planning."

The team have developed - *Exobodies in Our Back Yard: Science from Missions to Nearby Interstellar Objects* July 2020 (arxiv.org/abs/2007.12480) and *Interstellar Now! Missions to and Sample Returns from Nearby Interstellar Objects* August 2020 (www.researchgate.net/publication/343678500_Interstellar_Now_Missions_to_and_Sample_Returns_from_Nearby_Interstellar_Objects)

The latter also including team members Dan Fries (i4is), Manasvi Lingam (Florida Institute of Technology / Harvard), Nikolaos Perakis (i4is/ Technical University of Munich), Bernd Dachwald (FH Aachen University of Applied Sciences) and Pierre Kervella (Paris Observatory).



Example trajectory to reach 1I/\`Oumuamua in 2052 from *Interstellar Now! Missions to and Sample Returns from Nearby Interstellar Objects.*

* *The Feasibility and Benefits of In Situ Exploration of 'Oumuamua-like Object* Darryl Seligman and Gregory Laughlin The Astronomical Journal, Volume 155, Number 5, 30 April 2018.

Asteroid mining with small spacecraft - a "filling station" beyond our gravity well

A recent paper Asteroid mining with small spacecraft and its economic feasibility (arxiv.org/abs/1808.05099) by our Deputy Technical Director Dan Fries (Georgia Tech, USA) with colleagues Pablo Calla and Professor Chris Welch (both International Space University, Strasbourg) explores the possibility of performing asteroid mining operations with spacecraft of mass under 500 kg. They consider a specific application, the mining of water from Near-Earth Asteroids (NEA), within a range of about 0.03 AU of earth's orbit. That's 4.5 million km or about 12 times the Earth-Moon distance. A swarm of such small spacecraft may be viable as a source of spacecraft fuel, for radiation shielding, and water for life support systems. Fuel, in particular, has a long and expensive haul up that mighty gravitational hill from the Earth. A "filling station" well clear of the gravity well which we all live in could be extremely attractive. In effect, refuelling would be much cheaper.

The team examine both spacecraft and on-asteroid systems, water mining techniques, power and mass budgets and the business case for this small spacecraft approach. Potentially delivering an early and vital building block for a solar system economy.

The video agency Kurzgesagt (kurzgesagt.org) has featured this work at - youtu.be/y8XvQNt26KI (English) and youtu.be/Gih8R-f_KMo (German).

See *Kurzgesagt – In a Nutshell* about asteroid mining at - sites.google.com/view/sources-asteroidmining/).

Inverse design for efficient lightsail propulsion

Work on lightsail propulsion continues apace. We noted *Inverse design of lightweight broadband reflector for efficient lightsail propulsion* (arxiv.org/abs/2005.04840) by researchers at Stanford and at the Technion-Israel Institute of Technology, Israel, applying large-scale optimization techniques to a generic geometry based on stacked photonic crystal layers. Showing propulsion efficiency involving a tradeoff between high broadband reflectivity and mass reduction. Breakthrough Starshot provided both representative input values and funding.

Limitless Space Institute student competition

As in our Members Newsletter on 7 June the Limitless Space Institute announced a student essay/poetry competition, in collaboration with i4is and TVIW with the topic: "Why human exploration of the outer solar system and the stars?"

Our congratulations to the winners -

www.limitlessspace.org/student-papers/

University Winners
First Place Shivani Patel, TN USA
Second Place Henry Yaeger, NY USA
Third Place Sarah Watson, Southampton UK
Highschool Winners
First Place Ben Puckett, TN USA
Second Place Ethan Hackett, VA USA
Third Place Ishaan Mishra, CA USA

i4is is also working with the Limitless Space Institute in other areas. We'll keep Principium readers well informed of progress.

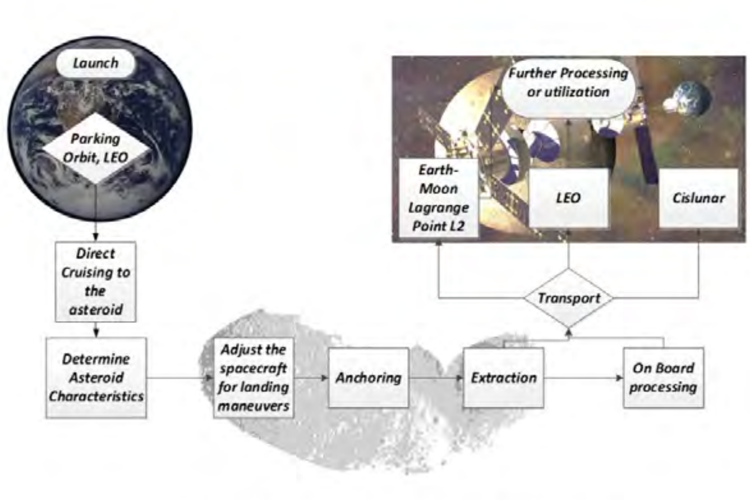


Figure 3: Proposed architecture for asteroid mining using small spacecraft.

Proposed architecture for asteroid mining using small spacecraft
Credit: Calla/Fries/Welch

LightSail 2 continues

LightSail 2 is a initiative by the US-based Planetary Society as an in-orbit demonstrator of solar sailing. Launched June 2019 the Planetary Society has announced an extended phase of operations from June 2020. Its extended mission goals are summarised at www.planetary.org/blogs/lightsail-2-extended-mission.html. The spacecraft, like all LEO satellites experiences orbital decay but judicious use of its sail has succeeded in counteracting this and, occasionally, raising the orbit.

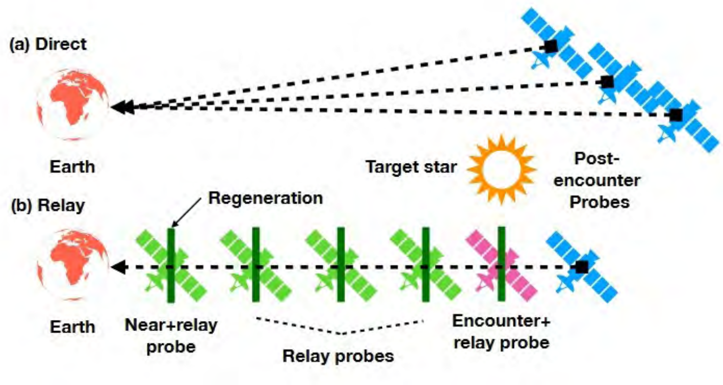
Relaying Swarms of Low-Mass Interstellar Probes

Our early option for interstellar probes, tiny spacecraft propelled by massive laser power, presents a particular problem in the downlink communications from (say) Alpha Centauri to Earth or near Earth receivers. A simple consideration of the inverse square law over 4 light years distance gives an idea of the scale of the problem and there are other challenges such as power supply and accurate pointing of the on-probe transmitters.

The paper *Relaying Swarms of Low-Mass Interstellar Probes* (arxiv.org/abs/2007.11554) by David Messerschmitt (UC Berkeley), Philip Lubin (UC Santa Barbara) and Ian Morrison (Curtin University, Australia) compares two configurations to address the problem -

- Optical transmission from the probe to a terrestrial receiver employing a large photon collector;
- A relay configuration with probes spaced at uniform intervals acting as regenerative repeaters.

In the relay case the downlink passes from each probe post-flyby through regenerative repeaters carried by all more recently launched probes. On the whole the authors favour the simpler direct configuration but the issues are complex including resilience and capital versus recurrent cost.



Direct versus relay communications
Credit: Messerschmitt, Lubin, Morriso

Near Term Self-replicating Probes

In our last issue, Principium Issue 29 May 2020 our colleague Olivia Borgue told us about her work with Andreas Hein in *Current technological feasibility of self-replicating probes for interstellar exploration*. Olivia and Andreas have now published *NearTerm Selfreplicating Probes -- A Concept Design* (arxiv.org/abs/2005.12303). They propose a concept for a partially self-replicating probe for space exploration based on current and near-term technologies, with a focus on small spacecraft - aiming to chart a path towards self-replication with near-term benefits. The probe would be capable of replicating 70% of its mass. Components such as microchips are not replicated and early technology gaps to self-replication are identified. They conclude that small-scale, partially self-replicating probes are feasible near-term.

Adam Hibberd on the Space Show

Adam Hibberd is the i4is team member responsible for the Optimum Interplanetary Trajectory Software (OITS) which is an essential part of our Project Lyra work defining intercept missions to interstellar objects like 1I/'Oumuamua and 2i/Borisov.

Hear him discussing his work on *The Space Show* - www.thespaceshow.com/show/14-jun-2020/broadcast-3527-adam-hibberd.

More about Adam's work in -

- *Project Lyra: A feasibility study for a mission to the interstellar asteroid 'Oumuamua*
  Andreas M Hein, Principium 20 | February 2018
- *News Feature: Oumuamua, Project Lyra and Interstellar Objects*
  John I Davies & Adam Hibberd, P24 24 | Feb 2019
- *News Feature: Latest on Oumuamua, Project Lyra and Interstellar Objects*
  Patrick J Mahon & John I Davies P 25 | May 2019
- *How to reach Interstellar Visitors - Optimum Interplanetary Trajectory Software*
  Adam Hibberd, P 27 | November 2019

- and numerous other articles and published papers.

Manoeuvring using magnetic sails in the solar wind

Nikolaos Perakis (Technical University of Munich and Initiative for Interstellar Studies) of the i4is Technical team has published his work to evaluate the performance of magnetic sails as means of manoeuvring through solar wind. Changing the inclination of the orbital plane requires change in the velocity vector, DeltaV, just like acceleration or deceleration. Nikolaos shows how this can be achieved without propellant. His paper is *Maneuvering through solar wind using magnetic sails* in Acta Astronautica, V 177, December 2020, Pages 122-132 (doi.org/10.1016/j.actaastro.2020.07.029)

Project Lyra: Laser and Fission Probes

The i4is Technical team have been busy with further Project Lyra studies -

- *Project Lyra: Catching 1I/'Oumuamua -- Using Laser Sailcraft in 2030* (arxiv.org/abs/2006.03891)
- *Project Lyra: Catching 1I/'Oumuamua Using Nuclear Thermal Rockets* (arxiv.org/abs/2008.05435)

The Laser study by Adam Hibberd and Andreas M Hein is based on a scaled-down Breakthrough Starshot beaming infrastructure with lower sailcraft speeds of 0.001c, relaxed laser power requirements (3-30 GW) and more massive spacecraft (1-100 kg) to achieve minimum flight duration of 440 days launching in July 2030. Given the scale economies of laser-push this could be a multi-craft mission.

The Nuclear study by the same authors notes that nuclear propulsion has a higher TRL than laser-push since NASA built a number of prototypes in the 1960s. For example a launch in 2031 with payload mass around 2.5 metric tonnes could reach 1I/'Oumuamua within 14 years. Both laser and nuclear offer shorter transit times than the conventional rocketry of the earlier Project Lyra studies.

Elsewhere in this news you will find an account of *Interstellar Now! a Mission Concept White Paper for the Decadal Survey on missions to interstellar objects*.

As the official "oldest inhabitant" of the i4is team I used to be quite relaxed about interstellar missions in my lifetime and I still believe I won't see a probe to another star but I'm beginning to worry about seeing a launch to an interstellar object. So I'm not so relaxed anymore - but probably happier!

KEEP AN EYE ON OUR FACEBOOK PAGE

Our Facebook page at - www.facebook.com/InterstellarInstitute - is the place for up to date announcements of our work and of interstellar studies in general. It's a lively forum much used by our own Facebookers and others active in our subject area.

Here's a typical posting -

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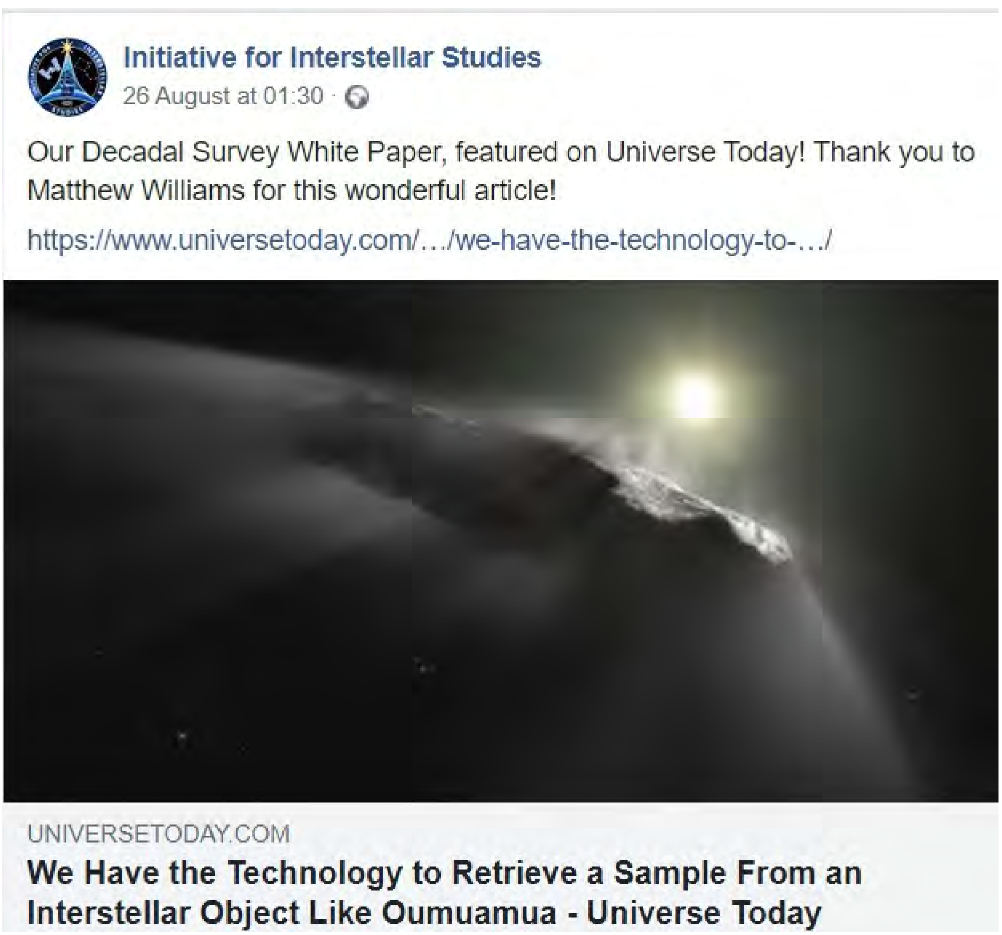


i4is and Amateur Astronomy

Astronomy is perhaps the branch of science in which amateurs have historically made the most significant contribution. A recent example is the discovery of the interstellar object 2I/Borisov by the amateur for whom it is named. i4is has conversed and worked with amateur astronomers and their societies since its foundation most recently we have been reaching UK astronomical societies electronically during the pandemic -

• Papworth Astronomy Club & Cambridge Astronomical Association 8 July 2020 - joint meeting - title: *Interstellar Probes - How can we do it?*

• Leeds Astronomical society 10 June 2020 - title: *1I/'Oumuamua and 2I/Borisov - the unexpected and the half-expected interstellar visitors.*

• Cockermouth Astronomical Society 26 May 2020 - title: *Interstellar Probes - How can we do it?*

We'll be conversing with two societies, scientific and astronomical, in October -

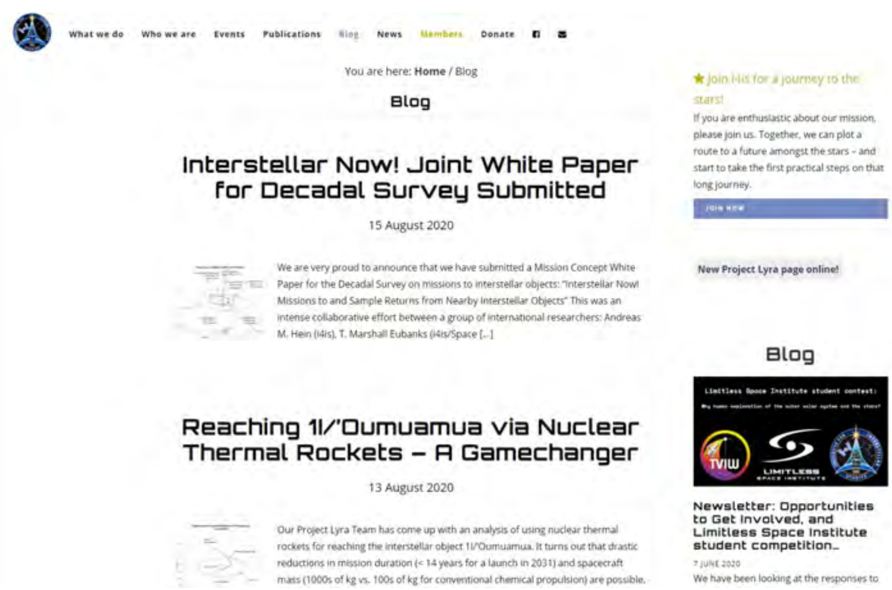
• *First Steps to Interstellar Probes* - *i4is Project Glowworm* - at the Herschel Society and Bath Royal Literary and Scientific Institute with BIS South West - ticketed www.eventbrite.co.uk/e/first-steps-to-interstellar-probes-i4is-project-glowworm-tickets-116794923761?aff=ebdssbonlinesearch

• *Interstellar Objects – Oumuamua, Borisov & objects in between*, Loughton Astronomical Society (las-astro.org.uk/)

KEEP AN EYE ON OUR WEBSITE

Our website is the place to find up to date announcements of our work. Here are some recent examples -

- Interstellar Now! Joint White Paper for Decadal Survey Submitted + 15 August 2020 i4is.org/blog/
- Reaching 1I/’Oumuamua via Nuclear Thermal Rockets – A Gamechanger + 13 August 2020 i4is.org/reaching-1i-oumuamua-via-nuclear-thermal-rockets-a-gamechanger/
- i4is Magnetic Sail Paper in Acta Astronautica + 31 July 2020 i4is.org/i4is-magnetic-sail-paper-in-acta-astronautica/



The i4is Members Page

The i4is membership scheme launched in December 2018 and we are now adding new members-only material to the website regularly. This page features currently available content and what is planned. Membership of i4is draws together all who aspire to an interstellar future for humanity. Your contribution, together with the voluntary work of our team and their donation of their own expenses, helps us to take the vital early steps toward that goal.

You need to login with your i4is identity to access members' content. If you are not yet a member you can sign up via - i4is.org/membership - or simply find out more about membership. We'll keep you up to date as we add to this content, both in the next issue of Principium and in our members' email newsletter.

Members' Newsletter

Members have received 9 Newsletters so far this year-

- Newsletter: 2023-2032 Planetary Science and Astrobiology Decadal Survey & five new preprints 20/08/2020,
- Newsletter: New videos & Technical Team updates 28/07/2020
- Newsletter: Opportunities to Get Involved, and Limitless Space Institute student competition... 07/06/2020
- Newsletter: Videos from our ISU module now available 28/05/2020
- Newsletter: Share a One Year Free Trial with a friend, and much more... 06/05/2020
- Newsletter: i4is Annual Report, mini-research projects and more...01/04/2020
- Newsletter: Opportunities to Get Involved + more preprints 28/02/2020
- Newsletter: Could electric sails be better than light sails? + Membership Survey 02/02/2020
- Happy New Year from the Initiative for Interstellar Studies 03/01/2020

Principium preprints

This is a bumper issue of Principium and we have had to postpone publication of our account of some of the presentations at our two-week Interstellar Elective for masters students at the international Space University, Strasbourg. But you will find the whole account already available to members as a Principium preprint. We'll be publishing much of the content of P31, our November issue, in the same place well before November. We encourage all who share any part of our interstellar vision to support us by becoming members but we also like to offer a few privileges to members. These preprints are just one.

Become active in i4is

We need all your talents - computing, maths & physics are important but many other talents are needed. The time and the unique skills of our members and, especially, our active volunteers are vital to all we do.

Take a look at P27 (November 2019) and P28 (February 2020) to see the breadth of these contribution to our work.

We need more - and an even wider diversity of occupations, talents, backgrounds and nations - to help us to do more in pursuit of that interstellar vision. Whatever skills and interests you have we would love to hear from you. You will find us a friendly and welcoming bunch! Contact us via info@i4is.org and we'll get back to you.

Help us to grow!

Tell your friends and colleagues. Share a One Year Free Trial with a friend if you have been a member for at least one year (see your personalised link in your 6 May Newsletter). And our student discount is now 90%!

To members who have been with us for more than one year receive a single-use code that they can share with a friend, giving their friend a **One Year Free Trial** on their new membership of the Initiative for Interstellar Studies (i4is.org/members/free-trial/). We hope that many of you will take this up especially on behalf of the rising generation in full time education. In subsequent years their student membership will be £5, just over $6 and just under €5.

Print our general poster on page 81 (black background) and the student posters on pages 26 (black background) and 62 (white background). All four posters are at i4is.org/i4is-membership-posters-and-video/.

Videos

Since the last issue, we have added much to the video content available to our members. For example -

Here's the list right now -

- Interstellar Probes: How can we do it? by John Davies
- FISW2 [25 videos]
- 1I/'Oumuamua and 2I/Borisov — the unexpected and the half-expected interstellar visitors
- ISU Interstellar Studies Module [13 videos]
- Sending Ourselves to the Stars
- Starship Engineer [6 videos]
- Project Dragonfly [5 videos]
- i4is 3rd Anniversary
- World Science Fiction Convention 2014
- Kelvin F Long at 59th International Astronautical Congress

- and we'll be adding more in future. Go to i4is.org/videos/ and log on using your member id and password - and tell us what you think via all the usual media.

And finally

As always, we hope all i4is members, Principium readers, the interstellar studies community and all we know and love are getting through this time of trouble for humanity.

If our interstellar vision can add a little long-term hope to the situation that can do some good.

Become an i4is member

John I Davies & Patrick J Mahon

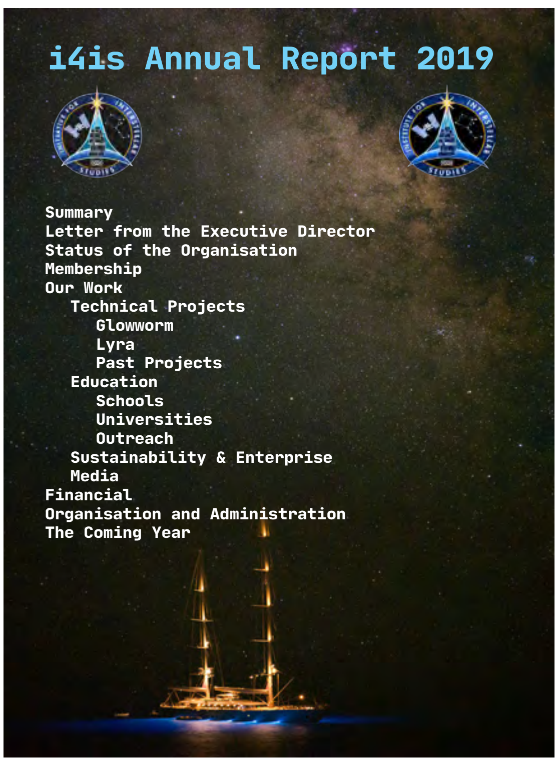
How becoming a member of i4is helps our work and delivers exclusive benefits to you

We are a growing community of enthusiasts who are passionate about taking the first steps on the path toward interstellar travel now. The best way to support the mission of i4is is to become a subscribing member. You will be directly supporting the interstellar programme. If you wish to, and have the time, we would love you to get actively involved with our projects. But we appreciate that not everyone who shares our interstellar vision has the time or resources to do this.

The latest Interstellar Issue of JBIS July 2020

As you will discover in this issue of Principium, we and our interstellar studies colleagues contribute to peer-reviewed journals including the Journal of the British Interplanetary Society (JBIS) and Acta Astronautica.

In addition to supporting the programme, members have access to privileged content. We now have 55 videos available to members including the entire lectures from the second Foundations of Interstellar Studies workshop last year and all the lectures from the Interstellar Studies Module we delivered to the Master of Space Studies students at the International Space University, Strasbourg.



Early drafts of Principium articles are also shared with members before general publication of each issue.

More details are on the i4is members' page, also in this issue of Principium. You will get access to all this content, and much more, if you choose to join.

We send a regular news email exclusively to members, containing the latest news on interstellar developments and our own activities. And members receive our annual report early in the following year. Here's an exemple from May 2020 - i4is.org/newsletter-videos-from-our-isu-module-now-available - this year's issues listed on page 78. To see the other benefits of membership, or to join, please go to i4is.org/membership.

Join i4is and help us build our way to the Stars!

News Feature: The Cathedral and the Starship: Learning from the Middle Ages for Future Long-Duration Projects

Reported by John I Davies

Our Technical Director, Andreas Hein, has long been pondering the parallel between two long-term endeavours of our species. The medieval cathedrals of Europe typically took hundreds of years to conceive and build. When we contemplate starships we face many of the same very long term commitments of effort, ingenuity and expenditure, Andreas has published a draft paper, The Cathedral and the Starship: Learning from the Middle Ages for Future Long-Duration Projects, and an entry with the same title in Paul Gilster's "blog of record" of the interstellar studies community, Centauri Dreams. The title echoes *The Cathedral and the Bazaar: Musings on Linux and Open Source by an Accidental Revolutionary*, Eric S Raymond 1997, a highly influential work in the philosophy of software engineering.

Andreas tests three common assumptions about cathedral building - that they are -

- A collective long-term achievement;
- A feat in long-term project management and engineering;
- A monument lasting for future generations.

- concentrating on project management, project finance, and systems architecture.

He presents a literature survey, statistical analyses of building and finance and suggests implications that may be applied to future long-duration projects in the space domain, notably starships. He suggests that cathedrals were in use more-or-less throughout their construction thus having utility and significance to generations which never saw their completion. These were projects which maintained continuity despite periods of inactivity.

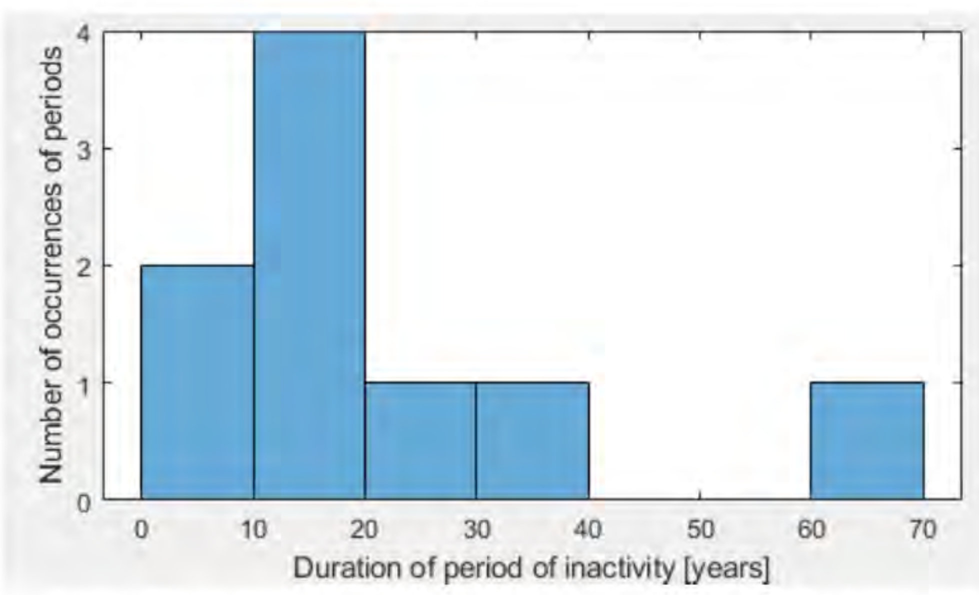


Figure 5: Distribution of inactive periods in the construction of the Canterbury Cathedral

Histogram of inactive periods in the construction of Canterbury Cathedral,
Credit: Hein

The elements of the cathedral exhibit modularity at several scales from the principal architectural elements to the components. Continuity of expertise and finance went hand-in-hand with agreed and celebrated high spiritual purpose.

Andreas identifies some key characteristics of the cathedral building enterprise - value-delivery via a minimum viable product (church services). project finance instabilities mitigated by formal institutions and mechanisms, fundraising campaigns using spiritual "products" (indulgences, relics, and even miracles), extensibility via modularity (eg towers, chapels, flying buttresses), knowledge transfer between key personnel (eg architects and artisans), a mobile skilled workforce carrying expertise between regions and countries, stakeholder management (ecclesiarchy, municipalities, political powers, workforce and the faithful), patterns of expenditure (intermittent and much smaller than for palaces, castles, and fortifications).

He suggests lessons for future long-term, large-scale space projects in the form of general principles

- Modular architecture / interfaces / open architecture and information exchange;
- Value delivery - especially the idea of a minimum viable product. For interstellar travel an obvious intermediate product is enhanced interplanetary travel;
- Financial stability - designing for unstable finance - already seen past and current space programs. Institutional and financial mechanisms to mitigate this inevitability. A recent example is foundations and non-profits providing funding for research on interstellar travel (eg Breakthrough Foundation, Limitless Space Institute). We also have many more mechanisms and instruments which can finance long-term projects.

This has been but a brief summary of a thorough and thought-provoking piece of work. Read the originals below!

References:

- The Cathedral and the Starship: Learning from the Middle Ages for Future Long-Duration Projects, Andreas M Hein arxiv.org/abs/2007.03654
- Centauri Dreams: The Cathedral and the Starship: Learning from the Middle Ages for Future Long-Duration Projects, Andreas M Hein www.centauri-dreams.org/2020/07/17/the-cathedral-and-the-starship-learning-from-the-middle-ages-for-future-long-duration-projects/
- The Cathedral and the Bazaar: Musings on Linux and Open Source by an Accidental Revolutionary, Eric S Raymond 1997*

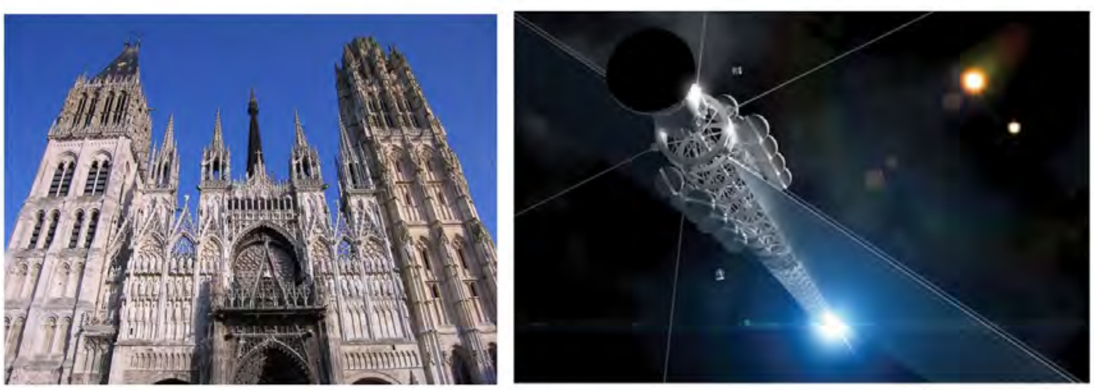


Figure 1: Rouen Cathedral and a starship (Credit: Wikipedia, Adrian Mann)

* Background: en.wikipedia.org/wiki/The_Cathedral_and_the_Bazaar

Online text: www.catb.org/~esr/writings/cathedral-bazaar/,

Published book: www.oreilly.com/library/view/the-cathedral/0596001088/,

Support your local bookshop (UK): www.hive.co.uk/Search/Keyword?keyword=The Cathedral %26 the Bazaar&productType=0.

Eric Raymond is an extreme libertarian. He is an entertaining and provocative speaker but many will find his political views rather extreme - en.wikipedia.org/wiki/Eric_S._Raymond#Political_beliefs_and_activism

His blog is at - www.catb.org/

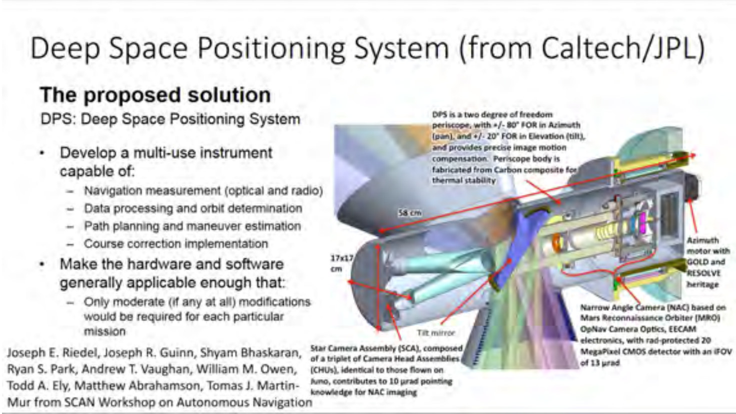
News feature: FISW2 videos and presentations on the i4is website

The Second Foundations of Interstellar Studies Workshop (FISW) 27-30 June 2019 was our last event at our former HQ. Some of the papers presented have already appeared in the Journal of the British Interplanetary Society.

We now have videos and slides of the presentations in the members area of the website - **Home / Videos / FISW2** (i4is.org/videos/fisw2/).

Interplanetary & Interstellar Communications and Navigation, Philip Mauskopf (Arizona State University)

Professor Philip Mauskopf presented the keynote talk, discussing the types of challenges associated with both communication and navigation at interstellar distances. Even though this is particularly challenging for probes such as the tiny Breakthrough Starshot types, there are no absolute challenges; only relative ones.



Deep Space Positioning System
Credit: Mauskopf

Colonies and World Ships, Mark Hempsell (BIS)

Mark talked about the differences between colony ships, which remain in orbit around the Earth, are economically linked to Earth, and can be resupplied from Earth; and worldships heading into interstellar space, which can't. So you can't just create a worldship by taking a colony ship and putting an engine on the back.

Calculations for a crewed interstellar Dysonship driven by microwave beam propulsion, Kelvin F Long (Interstellar Research Centre, Stellar Engines & i4is)

Kelvin explained how he validated the numbers underlying published worldship models by modelling in Fortran. He then uses this to model a crewed interstellar Dysonship.

Evolving asteroid starships: a bio-inspired approach to designing generation starships, Angelo Vermeulen (TU Delft)

In the last talk of the morning, Angelo demonstrates how he is using his expertise in biology and art to model a system which, through evolution and morphogenesis, an asteroid can be converted into an interstellar starship using 3D printers. Angelo explains how the complexities and uncertainties of interstellar travel call for such a system which can adapt to its changing surroundings.

Hyperloop: Martian Operations 1, Samar AbdelFattah (Cairo University)

Samar introduced the hyperloop concept – a rapid public transport solution involving carriages travelling through a tube. She talked about the ongoing work her team are doing to model a hyperloop on Mars using both simulations and experimental work. The low atmospheric pressure on Mars makes this easier, however the dust adds complications.

Space Elevators: Earth, Moon & Beyond, Peter Robinson (International Space Elevator Consortium)

Peter summarised the past research into space elevators, including a major 2013 study by ISEC. He then discussed the challenges of building a space elevator, including the strength & durability of the tether, the reliability & durability of the climber, and the need for active monitoring & control of the tether to move it out of the way of orbiting obstacles.

The use of near-term launch systems for developing a Stanford Torus, Richard Osborne (StellarDyne)

Richard explained that he was frustrated that our space stations were still basically ‘tin cans in space’, and proposed a much more ambitious alternative. A Stanford Torus was chosen as it is the smallest astroengineered megastructure, so would be easier than alternatives and would provide experience of space construction. The Torus is constructed from many near-identical truss segments.

Worldships – some ecological and resource constraints, Patrick Mahon (i4is)

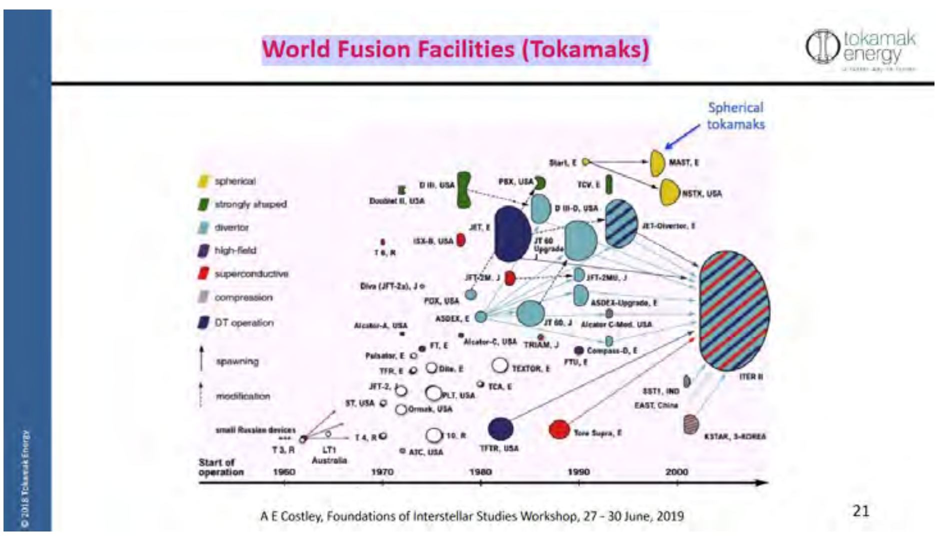
Patrick explained that a large worldship, carrying around 100,000 passengers for hundreds to thousands of years on the way to an interstellar destination, would need a completely closed ecology in terms of material resources. He identified several challenges to this, including the fact that recycling, even at very high levels, will never be sufficient, before suggesting potential solutions for each of these problems. He concluded with some suggestions for early research priorities.

Panel Discussion: A Near-Term Tactical Discussion on the Build of an Interplanetary Infrastructure Toward the Strategic Vision of Interstellar Flight Capability

Harold ‘Sonny’ White, Samar AbdelFattah, Ashford, John Davies, Angelo Vermeulen, Richard Osborne

Development for faster fusion at Tokamak Energy, Alan Costley (Tokamak Energy Ltd)

Alan summarises the progress of Tokamak Energy Ltd in researching low aspect ratio spherical tokamaks as an alternative to the larger and more costly, high aspect ratio ones such as ITER ($20B). Developments in the field of high-temperature superconductivity are a potential gamechanger. Currently, they are undertaking conceptual and experimental work and are on track for commercial electricity production by 2025-2030. Such a fusion powerplant could be compact and powerful enough to be used on an interstellar spacecraft.



World Fusion Facilities (Tokamaks)
Credit: Costley

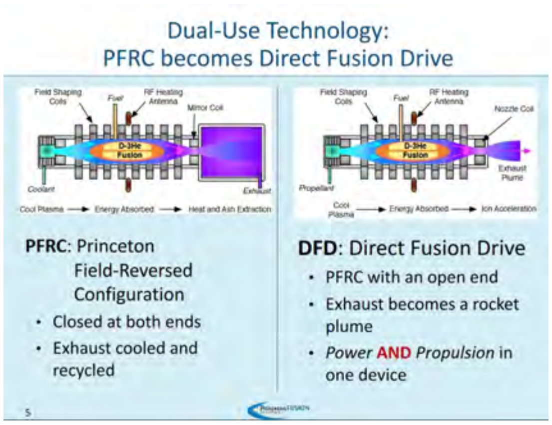
Project Icarus Fusion Starship Concept Design Solutions, Rob Swinney (i4is)

Rob summarised the history of Project Icarus, initiated in 2009 with the intention of revisiting BIS’s Project Daedalus four decades on. The project ran a design competition, the results of which were five competing designs for a fusion-powered uncrewed starship heading for Alpha Centauri: Firefly, Ghost, Resolution/Endeavour, Zeus and UDD. Of these, the Ghost design won the competition but later ran into problems. At the present time, the most developed design is the Firefly, which uses a Z-Pinch fusion engine.

Towards Direct Antimatter Annihilation Propulsion, Dr Ryan Weed (Positron Dynamics)

Ryan summarised the history of antimatter research and noted that the key problem, from the point of view of its value as a propulsion technology, is how to convert the energy to usable thrust. He outlined various potential solutions, although each has its own drawbacks. His company are currently investigating the use of radioisotopes of Krypton as part of the conversion process; they believe this may deal with some of the drawbacks of previous proposals.

Direct Fusion Drive for the Gravitational Lens Mission, Charles Swanson (Princeton Satellite Systems)



Presented by Harold ‘Sonny’ White

Sonny explained that they were developing a novel form of fusion engine, called the Princeton Field-Reversed Configuration (PFRC). This uses Deuterium and Helium-3, but the configuration is simple, small and clean, meaning it could potentially be ideal for many space missions. Charles had illustrated this with a short 13-year fusion-powered mission to send a probe 650 AU from the Sun, from where the Sun can be used as a gravitational lens.

Dual-Use Technology: Princeton Field-Reversed Configuration (PRFC) becomes Direct Fusion Drive

Credit: Swanson

Laser-powered electric propulsion precursor mission, Angelo Genovese (i4is)

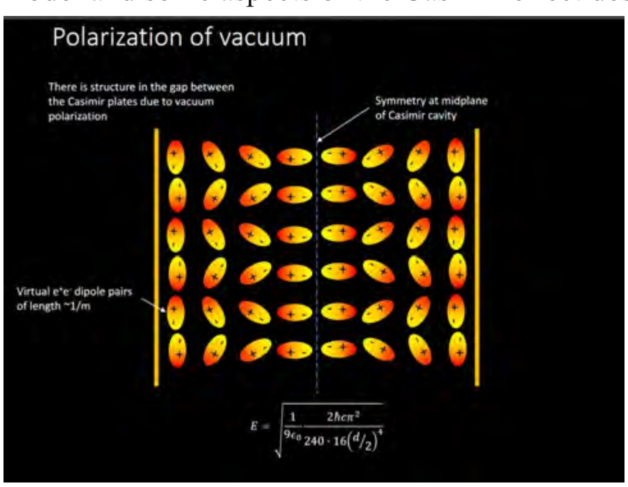
Angelo reminded the audience that chemical rockets were far too slow for interstellar missions. An alternative is electric propulsion such as ion thrusters. These have higher specific impulse than chemical rockets, but generally the thrust is tiny. Angelo explored various different ways of increasing the thrust from electric propulsion, and demonstrated the potential advantages of laser-powered electric propulsion (using large, space-based lasers beaming power to photovoltaic panels on the spacecraft), particularly for interstellar precursor missions – LEP should be able to get you to 200 AU within 30 years, and 1,000 AU within 50 years.

Engineering Quantum Vacuum Fluctuations, Jeremy Munday (University of Maryland)

Jeremy explained how quantum mechanics predicted that a vacuum is actually a ‘sea’ of quantum fluctuations, which have a positive ‘zero point’ energy. This has interesting implications, including the Casimir effect predicted in 1948. Casimir suggested that if you brought two parallel metal plates together, you would find an attractive force, pulling them together, purely because empty space is quantised. The effect is difficult to measure and has large error bars, but Jeremy’s team have been experimenting with different geometries to see if they can change the magnitude and even the polarity of the Casimir effect between two shaped metal objects, with the intention of finding out how to control and use the effect. Further, if you use anisotropic materials, such as optically polarised plates, you can turn the force into a torque. Again, the effect is very small and difficult to measure. However, if this can be controlled, it could have interesting space-related applications, such as in muon-catalysed cold fusion – for details, see their paper in Nature (Vol. 570, pp.45-51, 2019).

Dynamic Vacuum Model and Casimir cavity experiments, Harold ‘Sonny’ White (NASA)

Sonny described the ‘pilot wave’ interpretation of quantum mechanics, and discussed the mathematical formalism behind this approach. He showed how this could be applied to a hydrogen atom and a hydrogen molecule, getting results which agreed with experiment to within 1%. He explained that they were now exploring the implications for a radioisotope decay experiment, and noted the potential analogy between this model and some aspects of the Casimir effect described by the previous speaker.



Polarization of vacuum between Casimir plates.

Credit: White

Advances in Mach Effect Gravitational Assist (MEGA) Drive Experimentation, Professor Heidi Fearn (California State University, Fullerton)

Heidi explained that they were working, courtesy of NASA funding, on experiments to create a force on the basis of Mach's principle on the origin of inertia. They have built a small test rig – the MEGA drive – to try to measure the small force they have predicted. She explained how they derive the effect from General Relativity, and then presented their results and discussed the many suggestions they have received for ways to reduce potential sources of experimental error. They are continuing to refine their experiment with the aim of increasing the size of the force created by the MEGA drive.

Quantised inertia, propellant-less thrust and interstellar travel, Dr Mike McCulloch (Plymouth University, UK)

Mike presented his theory of quantised inertia, which proposes that inertia is caused by interactions between accelerating objects and distant horizons caused by two effects: an information boundary to one side which generates so-called 'Unruh' radiation, and the quantised nature of reality (as discussed earlier in relation to the Casimir effect). Mike showed how his theory can explain the energy that's been ascribed to dark matter, as well as various other anomalies such as the Emdrive and the Mach effect. He explained that if his theory is correct, it could be used to get to Alpha Centauri in just ten years, although the Emdrive that did this would need 29 GW to produce the required thrust. Mike has recruited a team to test this experimentally.

Directed Energy Propulsion – the path to interstellar flight, Philip Lubin (University of California, Santa Barbara)

After reviewing other propulsion technologies, Philip focused on directed energy propulsion (eg laser sails) as well as indirect energy propulsion (eg ion engines powered by photon-electric conversion). He proposed a parallel system of laser sources, as opposed to one large one. Given that slowing such probes down at the destination would be very difficult, Phil proposed sending hundreds of probes, separated in time, and building up data from hundreds of flybys.

Building Breakthrough Starshot, James Schalkwyk (Breakthrough Initiatives)

James discussed Breakthrough Starshot's plans for sending a gram-scale spacecraft to a habitable exoplanet within five parsecs of Earth, at 20% of the speed of light, within thirty years. They are focused on solutions involving solar or laser sails. James discussed the huge diversity of length scales across the project, from the 100 nanometre scale of the sail surface's nanostructure, right up to the 4 x 10^15 metre scale of the distance to Alpha Centauri – a variation of 22 orders of magnitude! If they can achieve a truly scalable solution, then creating genuine architectural megastructures could follow. To meet their requirements, they need to reduce the cost of the laser (price per Watt) by four orders of magnitude, and the cost of the optics by three orders of magnitude.

Casimir traversable wormholes, Remo Garattini (Bergamo University, Italy)

Remo introduced the history of wormhole studies, which started in 1916 with a wormhole identified by Flamm as a solution to Einstein's field equations of general relativity. Einstein and Rosen generalised this in 1935, coupling general relativity and electromagnetism, and creating what is now called the Einstein-Rosen bridge. John Wheeler did more work on this in 1962, showing that if such a wormhole were created, it would be non-traversable – ie its throat would close before anything could travel through, thus preserving causality. In 1988, Kip Thorne demonstrated that you could 'steal' a wormhole from the quantum foam using the Casimir effect, and make it stable. Remo demonstrated this mathematically, before concluding that a traversable wormhole is currently 'completely useless' as it's too small to use. However, there may perhaps be some way to amplify it in future.

Wormholes, warp drives and interstellar travel, Francisco Lobo (University of Lisbon)

Francisco's starting point was to ask not what is currently feasible, or what might be feasible in a few decades, but what the laws of physics allow to happen. Starting from Einstein's field equations, Francisco discussed the mathematics of wormholes, showing as he said that 'Physics is geometry'. He then noted how the physics of wormholes had been adopted in the Hollywood blockbuster 'Interstellar', which used Kip Thorne as a consultant and was thus pretty accurate. Francisco briefly moved on to the physics of warp drives, summarising Alcubierre's work, but noting Krasnikov's conclusion in 1998 that an Alcubierre warp bubble can neither be created nor controlled by a member of the starship's crew, making it of limited practical value. He concluded with a few words on the possibility of time travel along closed time-like curves.

Neutrino Beacons for Interstellar Communications, Al Jackson (Triton Systems)

Al explained that his proposal was that an advanced civilisation might choose to use beamed neutrinos, focused by a gravitational lens, as their means of interstellar communication, the advantage being that neutrinos are not easily extinguished by contact with matter, so will be able to communicate over extremely long distances. The lens would be a black hole or neutron star, and this could amplify the signal significantly. Even so, the signal strength would be very weak, so it is likely that the civilisation would build a Dyson swarm of transmitters orbiting a neutron star, which would boost the signal significantly. This implies that such a mode of communications will only be available to a Kardashev Type II civilisation.

Is the Kuiper Belt inhabited?, Greg Matloff (City University of New York)

Greg reminded the audience of the Fermi paradox, but then noted that if intelligent aliens had encountered our solar system, they would get to the resource rich Kuiper Belt before they got anywhere near the planets.

Greg also noted that recent observations suggest that our solar system is approached to within around one light year by another Sun-like star roughly every million years.

Greg pointed out that if a suitably advanced and long-lived civilisation was to wait until the next close approach, and thus double the number of star systems they visit every million years, they would be in more than one billion star systems after thirty million years.

In the light of this, Greg suggested that it would be worth surveying the Kuiper Belt for infrared and visible emissions, or for potentially artificial Kuiper Belt Objects. However, if no evidence is found it would strengthen the argument that we truly are alone.

Discussion session: Megastructures, SETI and interstellar communications

Al Jackson, Greg Matloff and James Schalkwyk.

Left to right: James Schalkwyk (Breakthrough Initiatives), Al Jackson (Triton Systems) and Greg Matloff (City University of New York)

James makes a point to a couple of old hands Al (NASA Apollo programme) and Greg (Author of The Stadflight Handbook).

Credit: Rob Swinney

For more details of what happened at FISW2 see FISW 2019 - i4is.org/fisw-2019.

Educating i4is: the i4is Education Team

What we do and who we are

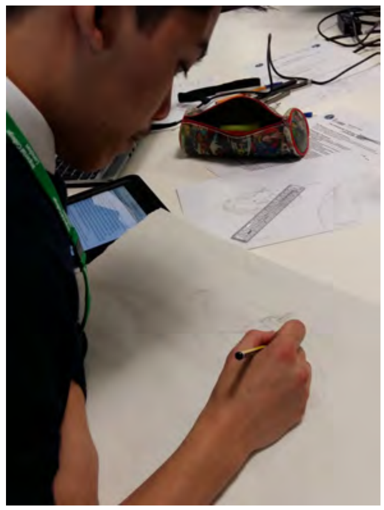
Robert W Swinney, Education Director

Rob Swinney was one of the two co-founders of i4is (with Kelvin Long) and has overseen our education engagement - from primary school to postgraduate research and development since the beginning. Here he gives us a quick tour of the work of the team and introduces us to the key contributors.

Education is one of the four main pillars of the Initiative for Interstellar Studies; Education, Technical, Enterprise and Sustainability. With the forbearance of the other directors, education is effectively the foundation of everything i4is does. From school and youth outreach to University studies up to Masters level, i4is members are involved across a variety of activities. If, after reading some details here, you would like to engage further with the i4is education team feel free to get in touch. (rob.swinney@i4is.org). Note we can work with any preferred conferencing technology (Zoom, Facetime, Webex, MS Teams, etc).

Schools

Members of the team have supported primary school activities including using their Solar System model. Others ran the schools 'Interstellar Challenge' which was a day challenge for teams of age 16-17 (UK Year 12s) to think about what it might really take to travel to the nearest stars.



Interstellar Challenge - Space Studio West London (SSWL) student visualising a rotating vehicle.

Credit: SSWL

We have also provided bespoke sessions for the older students often based around the infamous 'Ideal Rocket Equation' and illustrating Newton's laws of motion and calculus (with a non-calculus solution for younger students).

Finally, for students either aged 15-16 (UK GCSE) or 17-18 (UK A level) we have delivered a day programme called 'Skateboards to Starships' where they can learn how the principles of reaction using a skateboard can be very informative on how rockets work – this day includes a fun practical activity (which is not water rockets!) estimating the thrust of an air balloon. This programme was delivered at the Royal Institution (Mr Faraday's place) in 2018 and 2019. We had been invited back for 2020 when the pandemic struck and we will develop a distance-learning version if the virus is still with us next year.

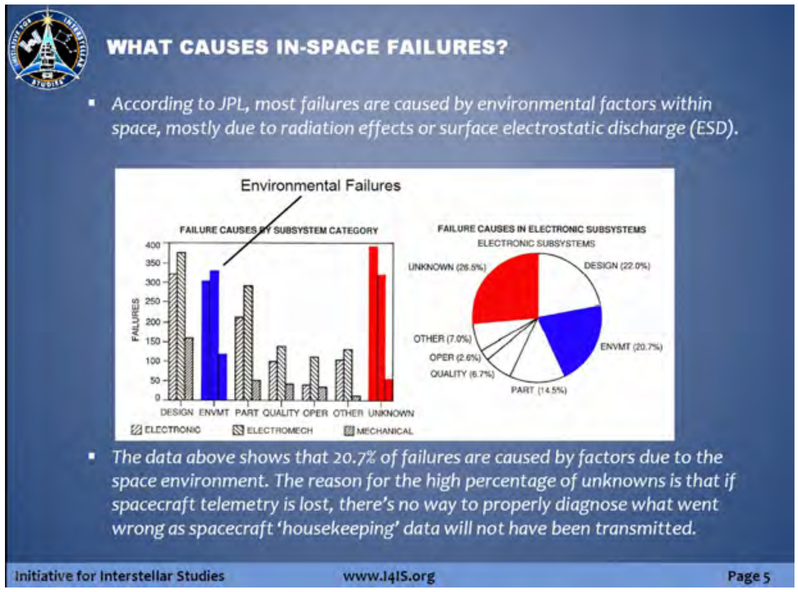
Satinder explains a point to a very engaged student at the Royal Institution, 2019.

Credit: Rob Swinney

Universities

Our main programme involving university students is to collaborate with departments to offer individual projects for students to undertake as part of their degree. i4is create the 'Interstellar-themed' projects, often at the Masters level but occasionally for first degree level too, and then provide a specialist to co-supervise the project in partnership with the host university supervisor. This can often be a great benefit to our i4is team members who can expand their experience working with students. But our projects are primarily excellent learning vehicles where the student often must take some aspect of 'standard' science or engineering and push the boundaries of what is known, to what we think of as 'extreme aerospace'. In doing so this can significantly reinforce mainstream learning.

We have relationships with a number of universities but our strongest is with the International Space University (ISU) in Strasbourg where we have now been involved since 2012. Indeed we have also co-supervised a team project (50% of the course, over 20 students) and created and delivered a number of 'Elective Modules', two-week Interstellar Studies packages, selected by the students.



Marc Casson of Surrey Satellite Technology Ltd (SSTL) presented on "The space environment and spacecraft systems engineering" at the i4is ISU elective in 2016. Here he makes some points about the causes of in-space failures. See also his article in Principium | Issue 15 | November 2016 page 10.

We also worked with partners to deliver a two-week elective module on Chipsats at the International Space University in 2019. Collaborators on this were Mason Peck (Cornell University), Zac Manchester (Stanford University), Brett Streetman (Draper Labs), James Schalkwyk (Breakthrough Initiatives) and former ISU student Zac Burkhardt.

Another less formal aspect of our university connections is to set up real research programmes or competitions for students to get involved but as an extracurricular activity. These are usually paper/theoretical activities and the university teams have often been from around the world – for one competition, 'Dragonfly' it included teams from Cairo to California!

Samar AbdelFattah presents the Cairo University entry.
Still from video - Dragonfly competition presentations at BIS HQ 2015 i4is.org/videos/project-dragonfly/.

Collaborations.

The i4is in many ways was originally a spin off from the venerable British Interplanetary Society and we have shared many successful activities and events with them and received welcome support. A primary example would be the Starship Engineer Courses, a mixture of one, two-day courses (eg Imagineering Starships and Sci Fi Starships) and a five-day Summer school, all developed with support from Stellar Engines Ltd. Other organisations such as the US based Tau Zero Foundation and the Tennessee Valley Interstellar Workshop share many similar goals and dreams with i4is. More recently the new Limitless Space Initiative (www.limitlessspace.org) have involved the i4is team in a student 'Best Essay' competition (separate competitions for School and University students) and some of the winning essays should appear later in Principium.

Meet the team

Tishtrya Mehta - Deputy Education

Tishtrya is a recent postgraduate of the University of Warwick, having specialised in Solar Physics following her undergraduate degree at the University of St Andrews in Applied Maths and Theoretical Physics. A space enthusiast and active STEM Ambassador, Tishtrya enjoys getting involved with hands-on outreach and bringing science education to under-represented minorities in STEM. Tishtrya has represented i4is at a number of functions including Space Day at the BIS West Midlands and the UKSA Career days.

Tishtrya Mehta at the BIS West Midlands Space Day 2019

Credit: Anna Vestentoft

Marc Casson - Member

Marc is a spacecraft mission systems engineer currently working at Surrey Satellite Technology Ltd. He has a masters in Space Technology and Planetary Exploration from the University of Surrey before which he completed his MEng in Aerospace Engineering at the University of Sheffield. Marc has also successfully completed other courses in the fields of astronomy and astrophysics. See Universities above for his ISU contribution.

John I Davies - Senior Member

John is a lifelong engineer and a Londoner of over 30 years standing with northern English origins and strong Scottish connections. He has been fascinated by space travel ever since he read the Dan Dare stories in the *Eagle* comic in the 50s. He recalls contradicting his father who, despite being an engineer himself, thought that "rockets can't fly in space because there is nothing for them to push against". Once Sputnik One went up his dad became a bit of a space enthusiast too. John was the first person in his family to go to university, studying Electronics at Liverpool University. He joined Hawker Siddeley Dynamics Space Projects Division in 1968 and worked on the latter stages of the most substantial launch vehicle ever built in UK, Bluestreak. He also worked on satellite projects including a design study for a large space telescope which acquired the name Hubble about 12 years later. He spent most of his career in communications technology in both academic and commercial contexts with his last professional jobs in mobile data communications standardisation and technical sales. He's now retired but back in the space business and busier than ever with educational outreach to schools for the Initiative for Interstellar Studies, co-ordinating work on i4is website and email, and editing Principium, the quarterly newsletter.

John Davies presenting *First Steps to Interstellar Probes- i4is Project Glowworm* at the Astronomical Society of Edinburgh (ASoE) October 2019

Credit: ASoE

Rob Swinney - Director Education

Rob Swinney is a chartered engineer who completed his bachelor's degree in Astronomy and Astrophysics at the University of Newcastle Upon Tyne and his master's degree in Radio Astronomy at the University of Manchester (Jodrell Bank) in the 1980s. After several successful years working as a teacher of Craft, Design and Technology at Sherborne Boys School in Dorset he graduated from Cranfield University (then the Cranfield Institute of Technology) with a further master's degree in Avionics and Flight Control Systems.

After Cranfield University he undertook a challenging and rewarding career in the Royal Air Force as an Aerosystems Engineering Officer and he completed his RAF Commission in 2006 having attained the rank of Squadron Leader. Since that time he has been an independent Space Industry consultant.

Rob was inspired by Isaac Asimov, first by the great author's science fiction but later by the non-fiction that opened his mind to the future possibilities. As a boy he followed the Apollo adventure and as a young man the Grand Tour of the Voyager spacecraft; but after his studies he became restrained by the realities of life. As importantly, the boyhood images of Star Trek and such, some 40 years ago, appeared to be no more than pure fantasy. Now today, he believes the 'planets are aligning' again and, although it may still seem difficult, real practical steps on the road to interstellar travel are being taken.

Anna Vestentoft - Member

As a recent graduate of St Andrews University, Anna is particularly focussed on schools outreach and has supported many i4is activities already.

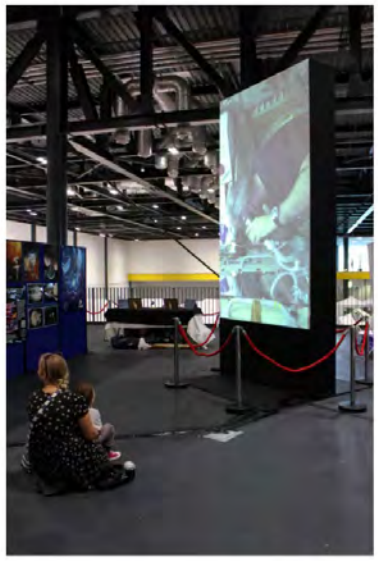
Terry Regan - Senior Member

Terry is the education team's common sense and practical guy. As a very much down-to-earth HGV motor technician he has nevertheless developed a reputation as a master model builder (from scratch materials rather than kits) and has specialised in spacecraft models (see his magnificent model of the Daedalus starship at BIS HQ in London).

And he also built the four metre high monolith (as in *2001: A Space Odyssey*) for the i4is stand at the Science Fiction Worldcon in London in 2014.

The monolith is in the exact proportions of the Clarke/Kubrick original - 1^2:2^2:3^2 or 1:4:9

One side in the authentic dark sheen and for the other.....



...here is the youngest space cadet watching an ISS astronaut cut his hair! We hope and believe we inspired all ages to an interstellar future.

His work features advanced future models such as Daedalus but also historical missions like Mariner, Pioneer and Voyager. For the education team he has represented i4is at various school events and built the i4is solar system model used with primary school children.

Satinder Shergill - Member

Satinder worked with us on much of our early schools engagement when he was a teacher at the Space Studio West London. He is working towards a PhD in In-situ Resource Utilisation (space mining and manufacturing) at the University of Cranfield in Bedfordshire. Satinder and John Davies developed the 'Skateboards to Starships' programme for the Royal Institution.

Get involved!

Most importantly you can **Get involved!** - at any level **from primary to university**. And **anywhere in the world**.

- »**Look at our online resources** (videos and presentations) - accessible to members and available on request to all who are interested. Get in touch and we will help you to adapt and originate.
- »**Remember our wider outreach to interest groups** including astronomical societies, professional engineers and scientists, WEA, University of the Third Age, adult education, SF societies.

Give us a call and we'll come running!

Contact john.davies@i4is.org or rob.swinney@i4is.org

We are a sociable lot!

The team - Rob Swinney, Rob Matheson, John Davies and Satinder Shergill in the pub after our Royal Institution gig 2019.

The Stars: Humanity's Destination

the evolution of FTL thinking

Gary L Bennett

"And by striving towards greater things you shall bring new worlds to our World…"

-- Luís Vaz de Camões, The Lusiads, 1572

Gary L Bennett is an aerospace engineer with wide experience in spacecraft power and propulsion systems and the author of the novel The Star Sailors. Here he outlines some of the ways in which scientists and engineers have attempted to overcome the apparently fundamental limit of the speed of light which constrains even our theoretical ability to reach any but the nearest stars in times less than the current life expectancy of our species.

Why Go?

Just as Lucretius and Bruno predicted, there are countless planets around the countless stars of our Universe. According to NASA, to date more than 4,000 exoplanets have been discovered and are considered "confirmed".[1] Those stars and planets beckon to us as James Strong wrote, "… I see the universe of stars as an arena that has been set for countless eons, patiently awaiting all comers. At any moment in time, any race--human or alien—that feels moved to pick up the gauntlet may do so. To whoever wins, the reward is survival".[2]

For most people the incentive for traveling to the stars is exploration and answering the age-old question "Are we alone?" But as Strong stated, "survival" may be the most important reason. Astronomers have pointed out that Earth is a target – it has been hit by asteroids in the past. Sixty-six million years ago, the Cretaceous-Paleogene (K-Pg) extinction event wiped out almost three-quarters of the plant and animal species on Earth. And if the asteroid that hit that peninsula in Chicxulub in what is now Mexico didn't do it, the lava flows known as the Deccan Traps in India may have spewed enough poisonous and climate-altering volcanic gases into Earth's atmosphere to kill most species. Earth's so-called "twin", Venus, may have had such a magmatic eruption about 800 million years ago.[3]

The possibility of hostile alien life (which one can read into James Strong's statement) cannot be dismissed. The science fiction literature is replete with stories of hostile aliens (a subject I dealt with in my own novel, *The Star Sailors*).

FTL in Principium

Principium has examined the possibility of faster than light travel in a number of issues. Here is a partial list of relevant features -

Issue 1 | December 2012
Ahead Warp Factor One!

Issue 9 | May 2015
Feature: Wormholes Come to London
Kelvin F Long

Issue 9 | May 2015
Book Review: " The Science of Interstellar"
Keith Cooper

Issue 10 | August 2015
Feature: Wormholes Come to London, "Interstellar Wormholes: Physics and Practical Realisation" Part 2 Kelvin F Long

Issue 10 | August 2015
Feature: Wormhole-Stargates: Tunnelling Through The Cosmic Neighbourhood Eric W Davis

Issue 13 | May 2016
Warp drive is possible Kieran Twaites

Issue 17 | May 2017
Is the Alcubierre Drive the answer to Interstellar Travel? Tishtrya Mehta

Issue 26 | August 2019
Dr Mike McCulloch of Plymouth University (UK) presented on *Quantised inertia, propellant-less thrust and interstellar travel.* reported by Patrick Mahon *News Feature: Foundations of Interstellar Studies Workshop 2019*

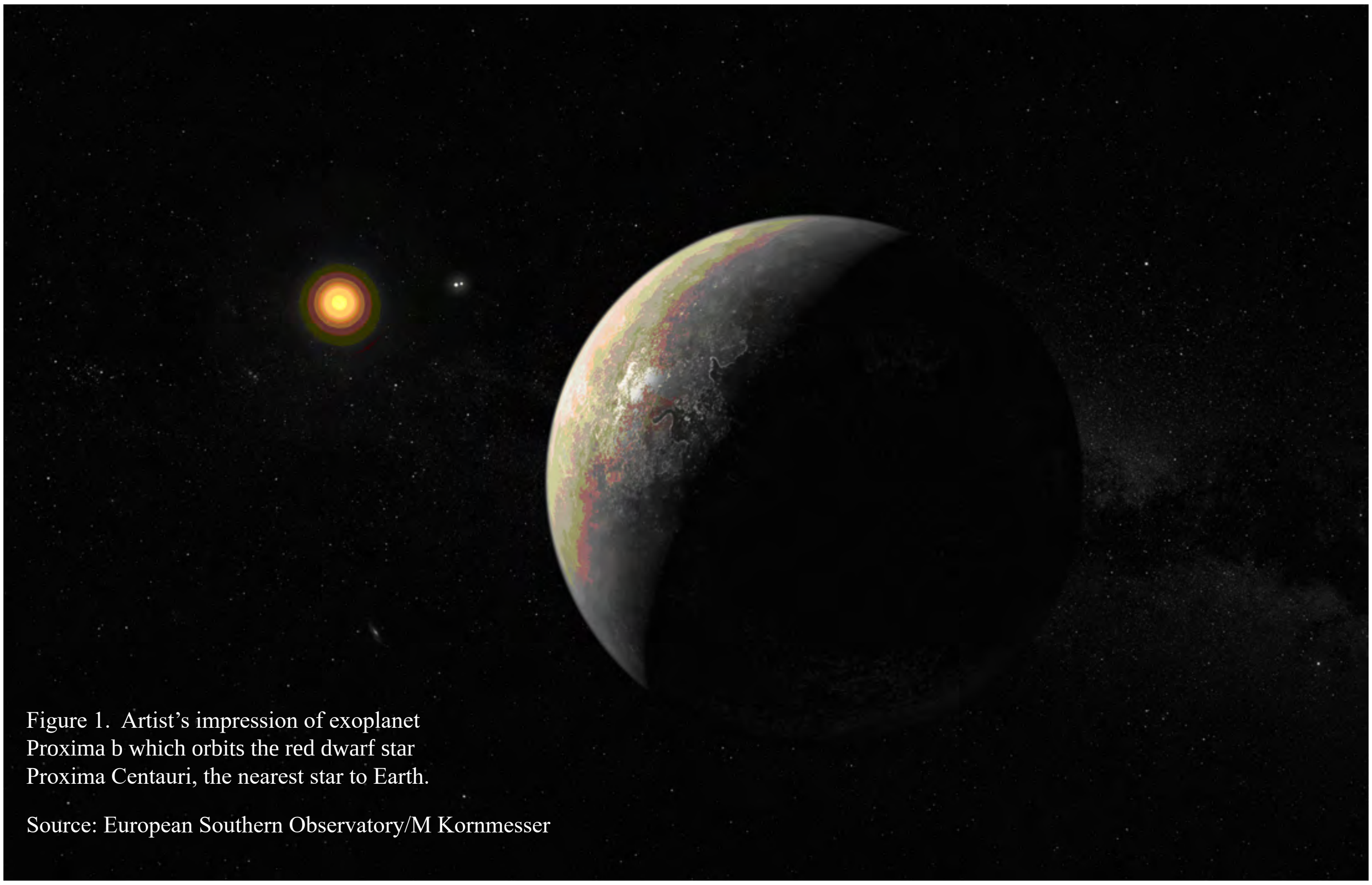


Figure 1. Artist's impression of exoplanet Proxima b which orbits the red dwarf star Proxima Centauri, the nearest star to Earth.

Source: European Southern Observatory/M Kornmesser

How To Go

Our nearest neighbor, Proxima Centauri is 4.22 light years away. While it is a small red dwarf, a fraction of the mass of our Sun, measurements indicate it has two planets (designated Proxima b and c); Proxima b may be habitable. But traveling at the speed of our (current) fastest spacecraft, the Parker Solar Probe, it would take about 6.6 thousand years to reach Proxima b. Figure 1 is an artist's impression of the exoplanet Proxima b.

Solutions have been proposed, such as "generation ships" (in which multiple generations live and die on a starship traveling below the velocity of light) and hibernation (in which the crew is "put to sleep" for the journey). But will humans put up with such long trip times? Will the life support systems last that long? And how will the star travelers communicate with Earth when communications can take years – after so many centuries, will they even speak the same language?

Such concerns lead to consideration of faster ways to travel, in particular, achieving faster-than-light (FTL) travel. But Albert Einstein's special theory of relativity (which has been well-confirmed by experiments) acts as a sort of speed limit. The special theory of relativity says that as a traveler approaches the speed of light, the traveler's time will slow to zero; the traveler's length will decrease to zero as well and the relativistic mass of the traveler will increase toward infinity (see Figure 2 below). As the T-shirt slogan says: "It's all fun and games until someone divides by zero".

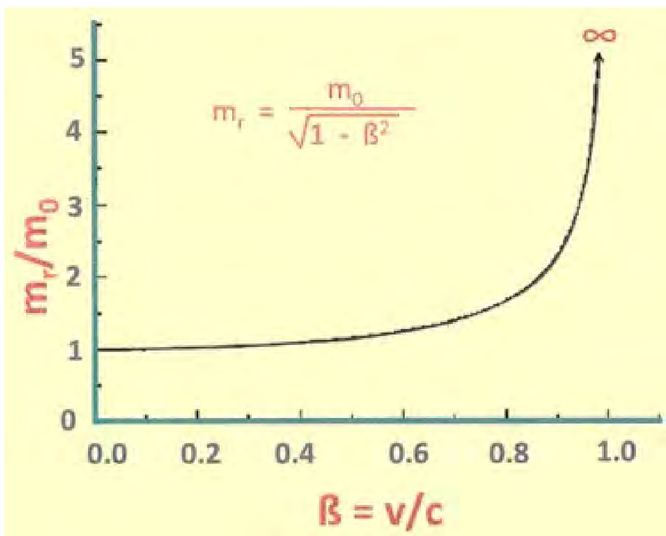


Figure 2. Variation in mass as a function of velocity.

Theoretical proposals for overcoming the light barrier (sometimes called the "luxon barrier") have been grouped into one or more of four general categories as illustrated in Figure 3. Three of those concepts (tachyons, wormholes and warp drives) will be considered in the following sections.

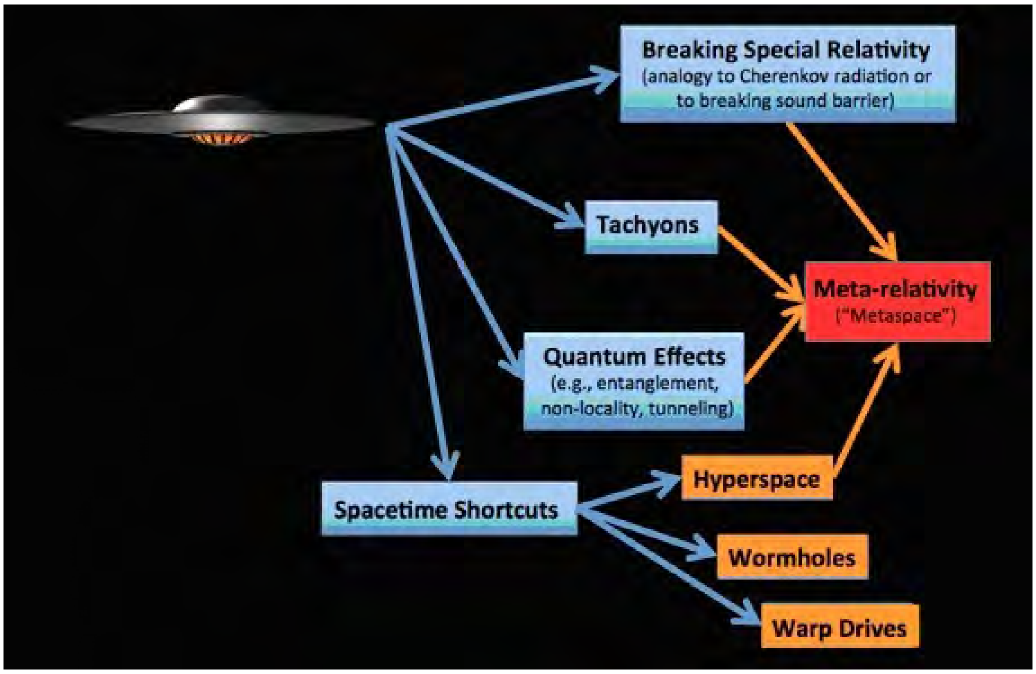


Figure 3. Diagram of general concepts for achieving faster-than-light (FTL) travel.

After M G Millis & E W Davis, *Warp Drives & Wormholes, Exploiting the Boundaries of Physics*, Tau Zero Foundation, 2013.

NOTE: The starship is modeled after United Planets Cruiser C-57D as shown in the 1956 movie, *Forbidden Planet*.

Tachyon Propulsion

In a 1962 paper on what they termed "meta relativity", O M P Bilaniuk, V K Deshpande, and E C G Sudarshan investigated the implications of hypothetical particles ("meta particles") created at superluminal velocities.[5] To be consistent with relativity theory, such hypothetical particles would have to have an imaginary rest mass, an imaginary proper length and an imaginary proper time. Gerald Feinberg dubbed such hypothetical particles "tachyons" from the Greek word **ταχὺς** (tachys) meaning swift or rapid.[6]

The obvious question is how does one transition from our sublight existence to the superluminal existence of tachyons? Takaaki Musha has suggested using quantum tunneling to move subluminal particles to FTL speeds.[7,8] This is analogous to nuclear physics in which particles can tunnel through the Coulomb barrier of the nucleus. (The idea of tunneling through the luxon barrier is part of the FTL technique I used in *The Star Sailors*.[4]) John G Cramer has described a tachyon drive in which tachyons are created and exhausted from the rocket engine to produce thrust.[9]

Traversable Wormholes

Wormholes, which are shortcuts through space, have often been invoked in science fiction as a way to achieve FTL travel. The concept of wormholes goes back almost to the beginning of Einstein's theory of general relativity when Einstein and Nathan Rosen dealt with the singularity predicted for the center of a Schwarzschild black hole (named for Karl Schwarzschild). Their analysis indicated the singularity was a portal to an extended spacetime which became known as a wormhole.[10] Figure 4 illustrates a wormhole bridge.

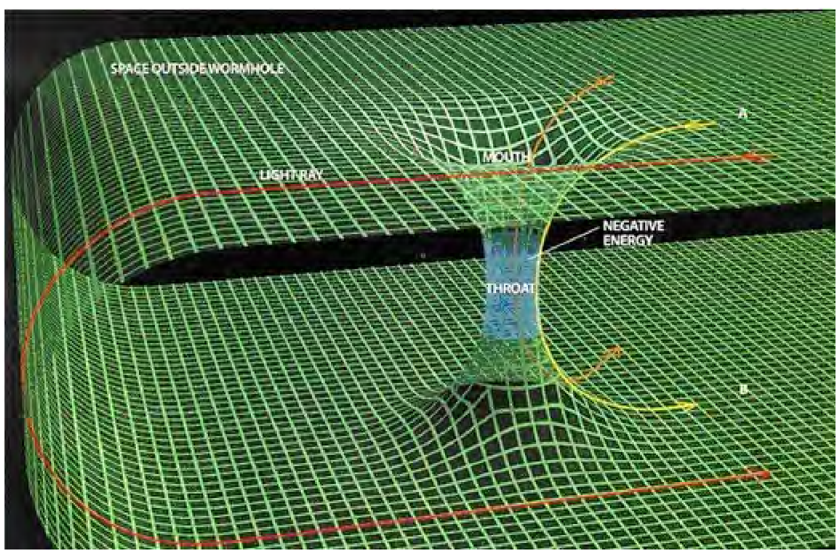


Figure 4. Artist's conception of a wormhole bridge connecting two mouths with a single throat or tunnel.

Source: Wikipedia

While wormholes in theory offer a way to make short-time trips to other star systems it is imperative that the throat of the wormhole be held open long enough and wide enough for a starship to pass through. Wormholes have been popular in the science fiction literature because, in principle, they avoid many of the problems of other FTL travel schemes (time dilation, geometrical changes, radiation damage, etc).

To be useful as an interstellar transportation system, wormholes need to meet a number of requirements, including having reasonable transit times and they must be capable of being constructed with reasonable materials within a reasonable period of time.[11, 12, 13]

Warp Drives

Warp drives, which are another staple of science fiction[15], involve altering spacetime and/or mass-energy to achieve FTL speeds. In science fiction, warp drives have been given names such as "overdrive" (A E van Vogt, Murray Leinster), "star drive" (*Space Patrol*) and hyperdrive (*Star Trek*, where one often hears the term "warp factor"). (In *The Star Sailors*, I referred to the FTL transportation as "metadrive" in recognition of the early study of "meta relativity" by Olexa-Myron Bilaniuk, V Deshpande, and E C George Sudarshan[4,5].) Essentially the same desirable properties mentioned for wormholes apply to warp drives as well.

An often cited warp drive concept is that proposed by Miguel Alcubierre in which he argued that "… it is possible to modify spacetime in a way that allows a spaceship to travel with an arbitrarily large speed" "… within the framework of general relativity and without the introduction of wormholes".[14] In essence, as shown in Figure 5, the space in front of the spaceship is contracted and the space behind is expanded to allow FTL travel even though the spaceship travels at sublight velocities inside the bubble. A potential drawback that Alcubierre noted is that "… just as it happens with wormholes, exotic matter will be needed in order to generate a distortion of spacetime …" like the Alcubierre drive.[14]

As an incentive to continue studying the Alcubierre warp drive, Kelvin Long has listed these six benefits:[15]

•Removal of the interstellar distance barrier

•Conventional transport system (no wormholes)

•No time dilation effects

•No relativistic mass increase with velocity

•No requirement for rocket-type propulsion to achieve near light speed

•Technological and economic benefits to humanity

Concluding Remarks

This short and quick review of three hypothetical methods of achieving faster-than-light (FTL) travel indicates that there may be (in theory) ways to travel to the stars, that the speed of light (c) need not be a speed limit. If the history of life on Earth shows us nothing else, it shows that life wants to spread out from water to land to air and now into space. And by moving into every available ecological niche, life on Earth has ensured its immortality. As "Achilles" says in the movie *Troy*, "We are lions! Do you know what's there, waiting beyond that beach? Immortality! Take it! It's yours!"

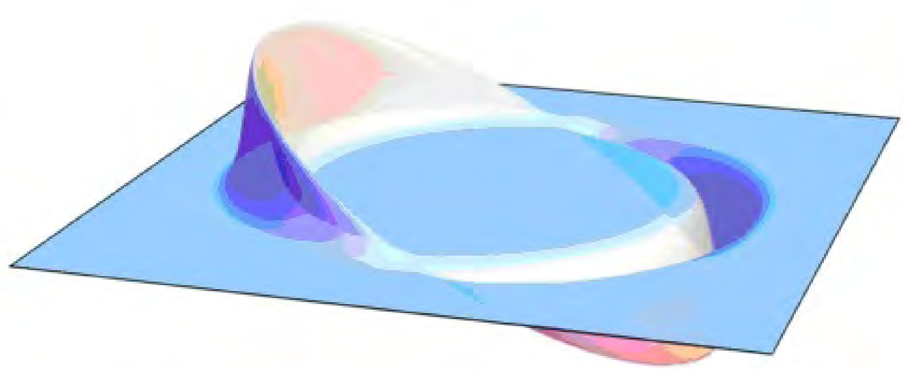


Figure 5. Two-dimensional visualization of an Alcubierre drive showing the opposing regions of expanding and contracting spacetime that displace the central region. In this diagram the starship would be moving from left to right.
Source: Wikipedia

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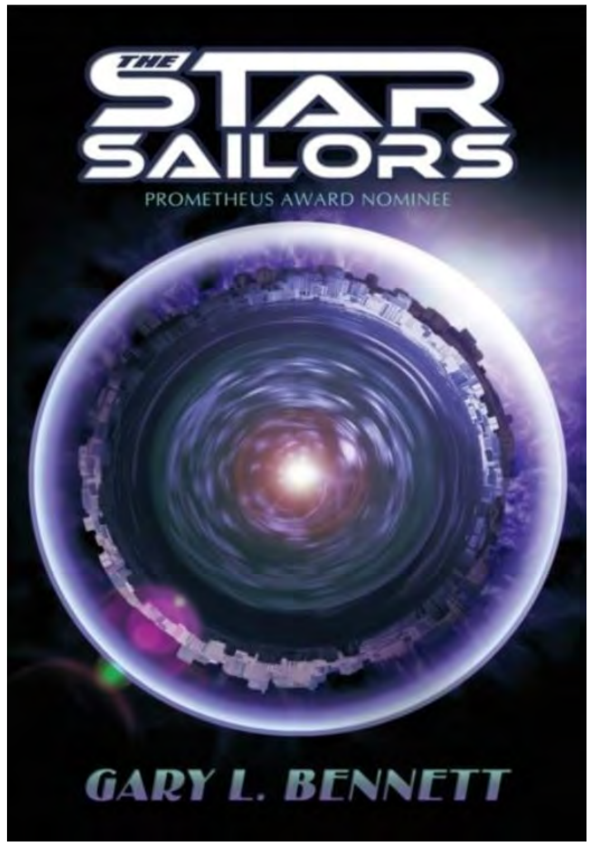

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Some Additional Resources

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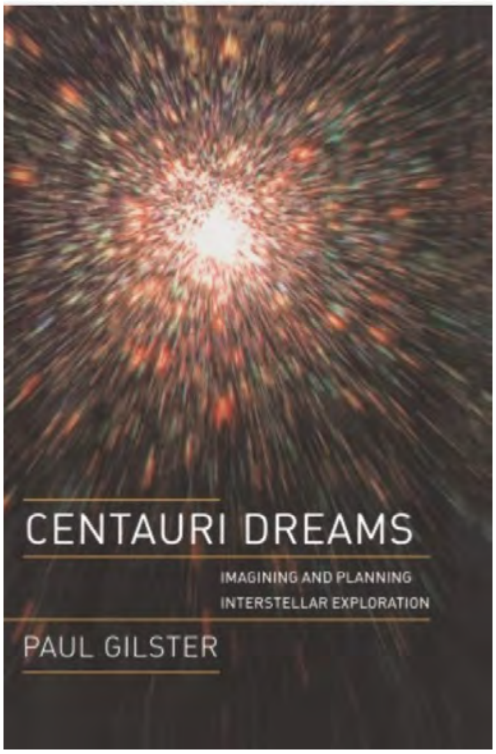

Cosmic Time Travel: A Scientific Odyssey by B Parker, Plenum Press, New York and London, 1991.

Deep Space Propulsion, A Roadmap to Interstellar Flight by K F Long, Springer, New York, 2012.

Faster Than Light, Superluminal Loopholes in Physics by Nick Herbert, New American Library, Canada, 1988.

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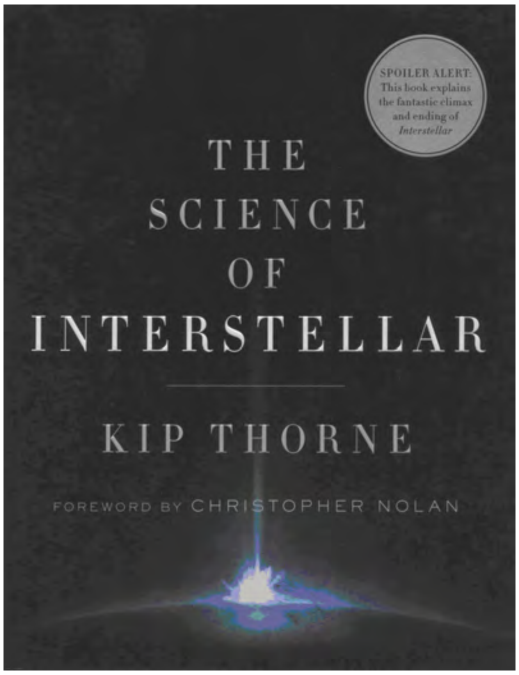

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About the Author

Gary L Bennett is an American scientist and engineer, specializing in aerospace and energy. He has worked for NASA and the US Department of Energy (DOE) on advanced space power systems and advanced space propulsion systems. His professional career has included work on the Voyager, Galileo, and Ulysses space missions, and is currently working as a consultant in aerospace power and propulsion systems. Amongst his many publications he was co-author with Robert L Forward and Robert H Frisbee of Report on the NASA/JPL Workshop on Advanced Quantum/Relativity Theory Propulsion 1995 fas.org/spp/eprint/quantum.pdf

He is also the author of the science fiction novel, *The Star Sailors*.

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Would you like to help drive the research needed for an interstellar future...
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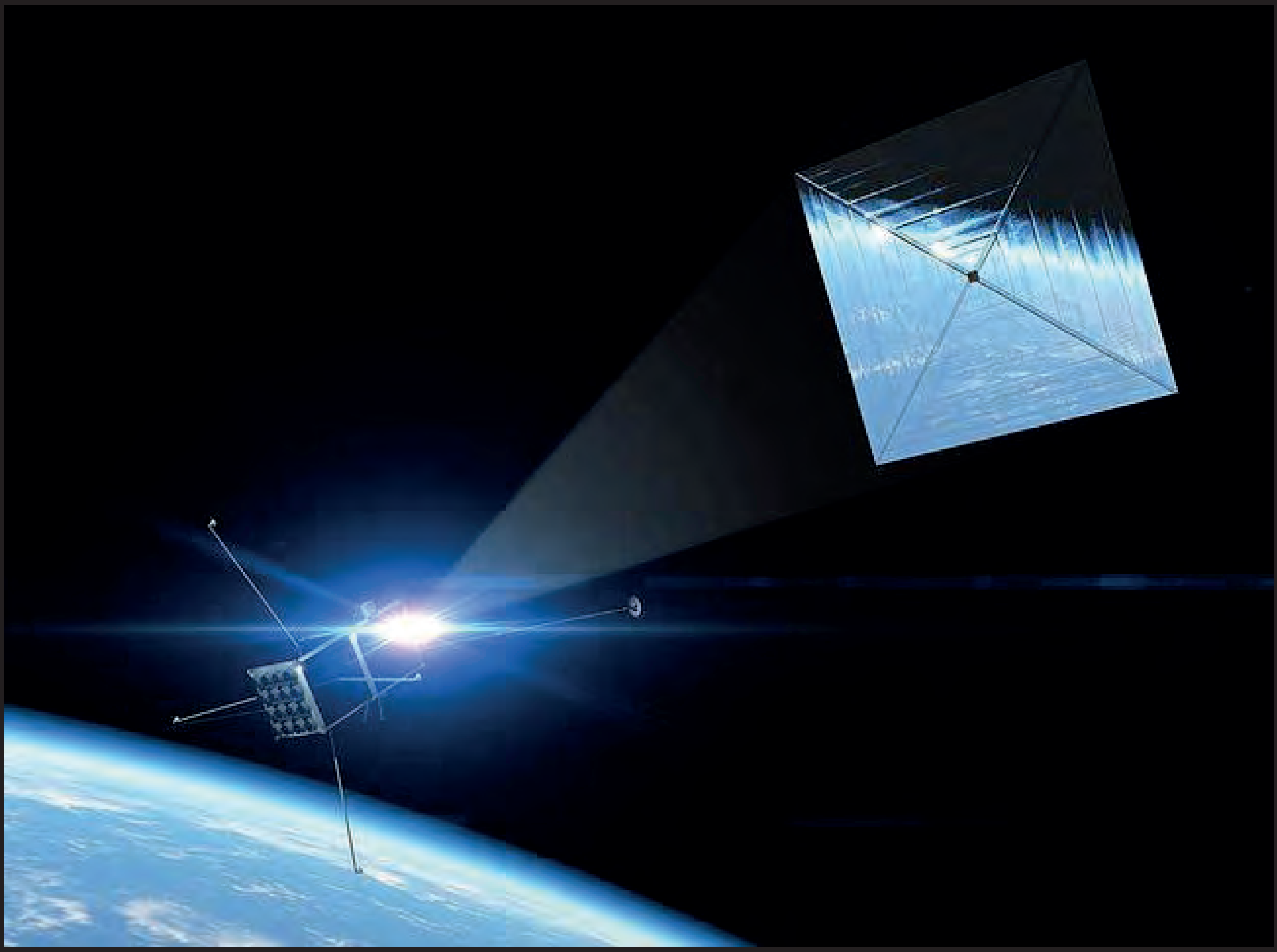


The Initiative for Interstellar Studies (i4is) has launched a membership scheme intended to build an active community of space enthusiasts whose sights are set firmly on the stars. We are an interstellar advocacy organisation which:

- conducts theoretical and experimental research and development projects; and
- supports interstellar education and research in schools and universities.

Join us and get:

- member exclusive posts, videos and advice;
- free or discounted publications, merchandise and events;
- advanced booking for special events; and
- opportunities to contribute directly to our work.

To find out more, see www.i4is.org/membership

News Feature: The 2020 ISU Masters Elective Module Part 1 of 2

John I Davies

This year the i4is team again led an Elective Module on Interstellar Studies for students of the Master of Space Studies at the International Space University Strasbourg. Here we summarise the first eight of the presentations by the i4is team which preceded them.

The current situation meant that this was all conducted online. We missed the personal element of being in Strasbourg with students and faculty at the ISU and we hope to be back in person next year.

The i4is Interstellar Studies Elective Module was run 'virtually' for the two weeks 27th April to 7th May. 23 students took part, we delivered 17 lectures and the four student teams each submitted a report.

The theme this year was Worldships and their implications.

The four reports which students developed during the workshop part of the two weeks of the elective will be summarised in our next issue with the remaining presentations by the i4is team.

The Lectures

This is a brief summary of the lectures which introduced the two-week elective. The presentations and videos are available in the member's area of the i4is website at - i4is.org/videos/isu-interstellar-studies-module/. The videos are at - i4is.org/videos/isu-interstellar-studies-module- and presentations are linked from the section headings - IMPRESS

The lecture schedule for the 2020 elective is reported in this and the next issues of Principium -

Lecture	Reported
M8-ISR-L01 Introduction to Interstellar Studies Elective	Principium 30 (this issue)
M8-ISR-L02 Background to Interstellar Studies and Scaling the Problem	Principium 30 (this issue)
M8-ISR-L03 Introduction to Worldships	Principium 30 (this issue)
M8-ISR-L04 Introduction to Assignment	Principium 30 (this issue)
M8-ISR-L05 Precursor Missions	Principium 30 (this issue)
M8-ISR-L06 Destinations	Principium 30 (this issue)
M8-ISR-L07 Spacecraft Systems	Principium 30 (this issue)
M8-ISR-L08 Worldship Conceptual Design	Principium 30 (this issue)
M8-ISR-L09 Artificial Intelligence for Worldships	Principium 31 (next issue)
M8-ISR-L10 Worldships in Science Fiction	Principium 31 (next issue)
M8-ISR-L11 Advanced Propulsion Systems 1	Principium 31 (next issue)
M8-ISR-L12 Advanced Propulsion Systems 2	Principium 31 (next issue)
M8-ISR-L13 Artificial Intelligence on Worldship Missions	Principium 31 (next issue)
M8-ISR-L14 Worldship Population Dynamics	Principium 31 (next issue)
M8-ISR-L15 Interstellar Travel using Einstein Physics	Principium 31 (next issue)
M8-ISR-L16 Worldship Documentary	Principium 31 (next issue)
M8-ISR-L17 The Case for Interstellar	Principium 31 (next issue)

M8-ISR-L01 Introduction to Interstellar Studies Elective IMPRESS

Rob Swinney opened the lecture series introducing i4is and the series content. As is standard practice at ISU and for all components of this series, he began with the expected Learning Outcomes. He introduced himself, i4is and its background in the British Interplanetary Society. He listed our accomplishments:

•1st general interstellar book: Beyond the Boundary

•Principium – the community-leading online quarterly

•Supervision of university student reports and projects

•Project Dragonfly - first small interstellar probe design

•Project Lyra – mission to Oumuamua

•Project Andromeda – for Breakthrough Starshot

•Schools and other Outreach

•Starship Engineer short courses

•Interstellar Elective Module at ISU 2016 and 2017

•Starship Engineer Summer School 2018

•Chipsat Elective Module at ISU 2019

Rob summarised the ISU MSS Student Team Projects supported by i4is and other educational and outreach work by i4is. The overall objectives of this elective were -

• M8-ISR-1: Describe possible motivations for interstellar exploration/travel and the implications of these.

• M8-ISR-2: Compare a range of potential deep space/interstellar technologies and systems.

• M8-ISR-3: Explain the prospective applications of worldships, their advantages and disadvantages and likely scenarios.

Example of i4is outreach - 2019 Summer School at the Royal Institution - London.

Rob Swinney is Deputy Executive Director of i4is and leads our Education team. He is a retired engineer officer (Squadron Leader) of the Royal Air Force, holds degrees in radio astronomy and astrophysics and in avionics and flight control systems from the universities of Newcastle, Manchester and Cranfield.

M8-ISR-L02 Background to Interstellar Studies and Scaling the Problem IMPRESS

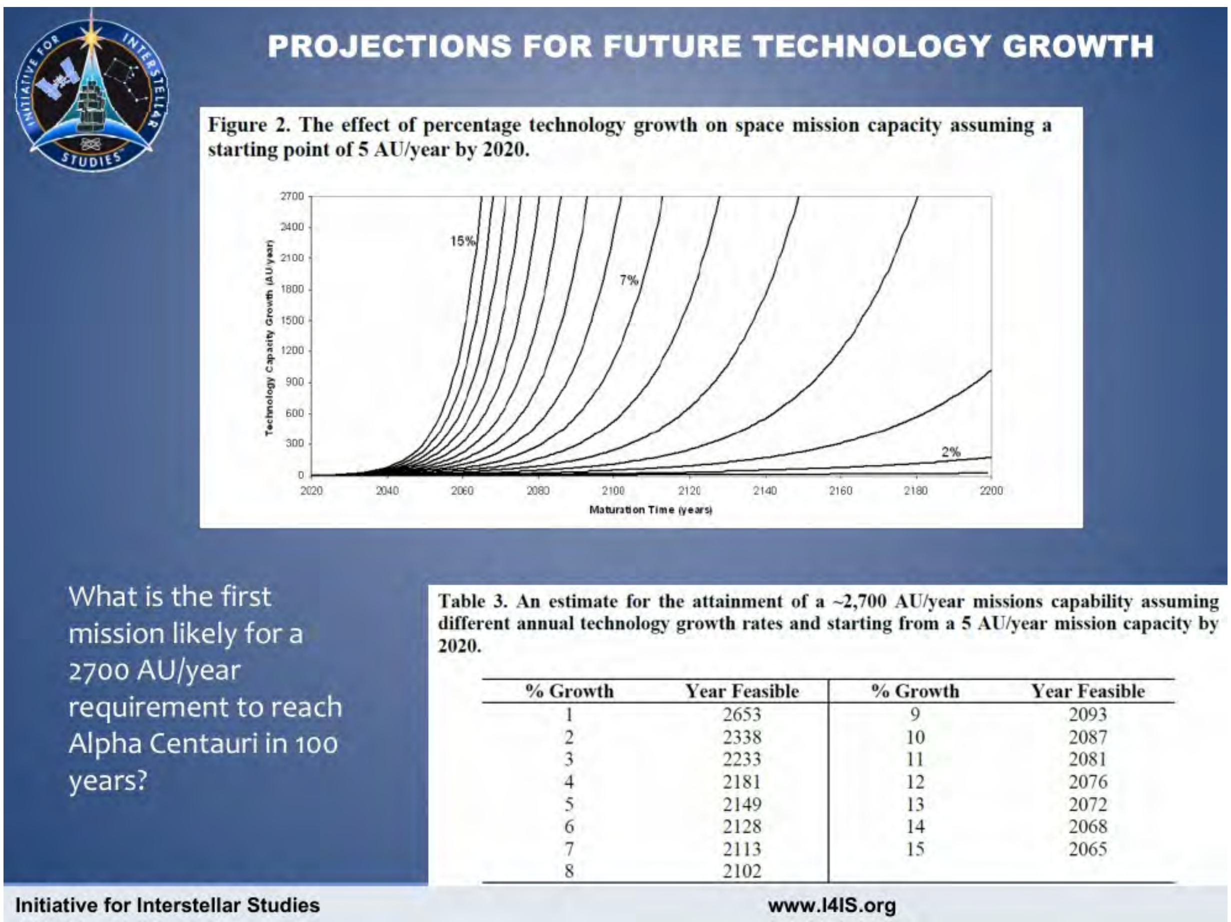
Rob Swinney gave us a History and Background to Interstellar Studies including some early interstellar concepts and an appreciation of the scale of the problem. The modern interstellar era began with the publication of the paper Interstellar Flight by Les Shepherd in the Journal of the British Interplanetary Society, JBIS, in 1952. Visionaries like Dr Robert Forward and Arthur C Clarke justified the view that interstellar travel, though extremely difficult and expensive, could no longer be considered impossible. JBIS has been publishing papers in the subject since 1974 and the BIS 1970s Project Daedalus set a benchmark for serious studies of the subject.

Probes from Voyager to New Horizons have demonstrated that deep space exploration yields science and images not available to on-Earth or even near-Earth instruments. Concepts driven by both engineering, such as Dyson's Project Orion nuclear-explosion powered craft, and by imagination, such as the Discovery in *2001: A Space Odyssey*, have broadened our thinking about what is achievable. Most recently -

- Project Daedalus has inspired Project Icarus, a series of fusion-propelled designs and
- the early thinking of Robert Forward and the laser propelled ideas of Breakthrough Project Starshot.

But the scale of the journey remains immense. Reaction propulsion is limited by Tsiolkovsky's rocket equation, an inevitable consequence of Newton's second law, so the most energetic sources of power are sought and energies equivalent to the entire energy output of our civilisation are seriously considered.

Sail propulsion offers an alternative but scaling is a problem. In the end it may come down to motivation and thus, inevitably, cost.



% Growth	Year Feasible	% Growth	Year Feasible
1	2653	9	2093
2	2338	10	2087
3	2233	11	2081
4	2181	12	2076
5	2149	13	2072
6	2128	14	2068
7	2113	15	2065
8	2102		

Projections for Future Technology Growth Credit: Swinney

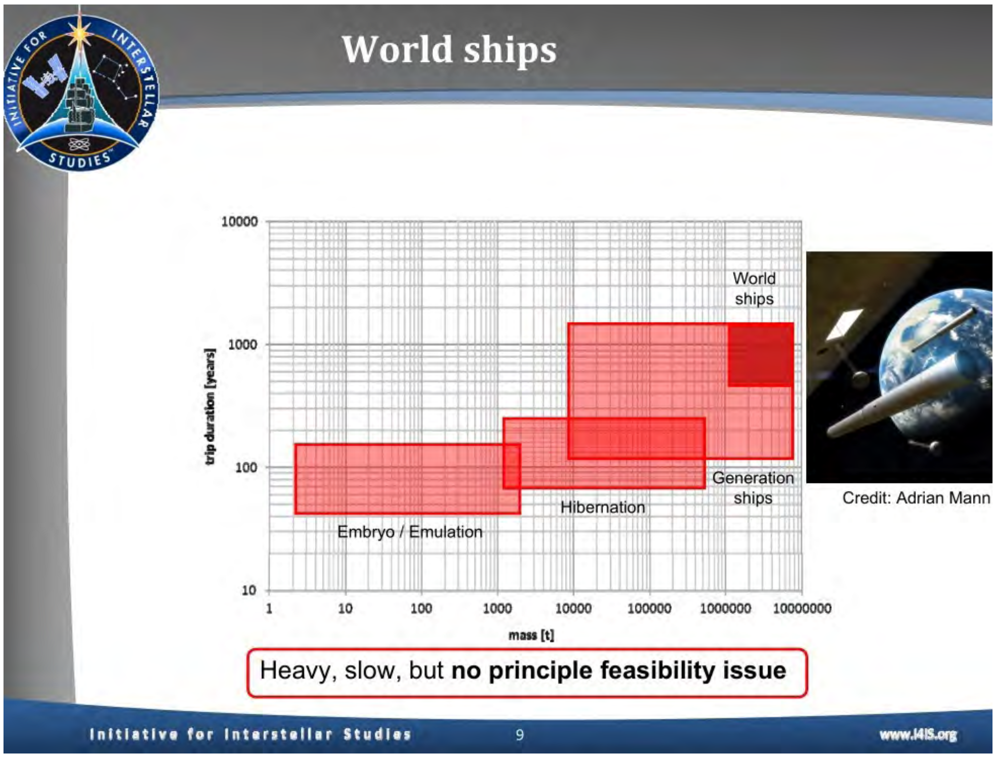
Rob concluded by recommending the two best books on the subject published so far -

Kelvin F Long – 'Deep Space Propulsion', Springer, 2012

Mallove and Matloff – 'The Starflight Handbook', Wiley, 1989

M8-ISR-L03 Introduction to Worldships IMPRESS

Andreas Hein introduced worldship concepts through a series of time-mass maps differentiating between Generation ships, Sleeper ships, Embryo/Emulation ships.

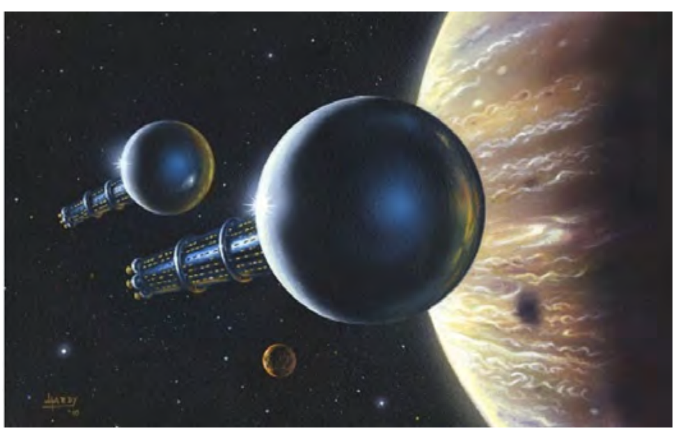
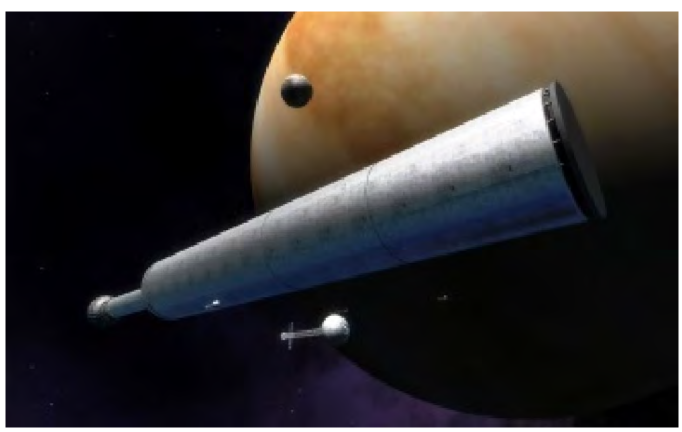


Mass Map
Credit: Hein/Mann

He cited the classic designs -

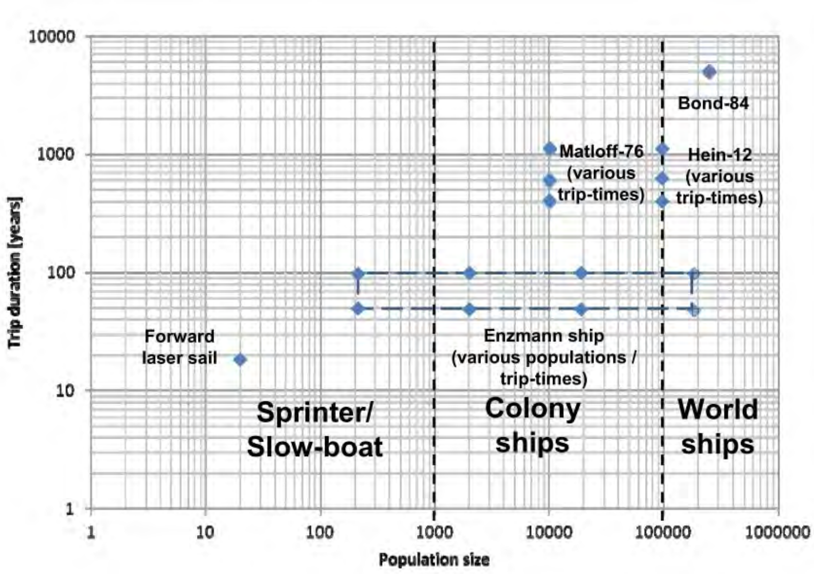
- Enzmann world ship 20,000 - 300,000 people based on a study by Crowl et al - JBIS, Vol. 65, pp.185-199, 2012 - tinyurl.com/crowlenzman
- Torus world ship 100,000 people based on a recent study by Hein et al - Acta Futura (European Space Agency) - 2020 arxiv.org/abs/2005.04100
- Dry and wet world ships 250,000 people based on the Bond/Martin designs - JBIS Vol. 37 page 254, 1984

Speeds 0.5% to 1% of c and dry mass (ie minus propellant) ranging from 300,000 tons to many billions of tons.

Visualisations of the Enzman (left) and Bond/Martin (right) worldships. Note the distant Enzman in the Bond/Martin image.
Both credit: Adrian Mann

The mass map may also be seen as a population map -



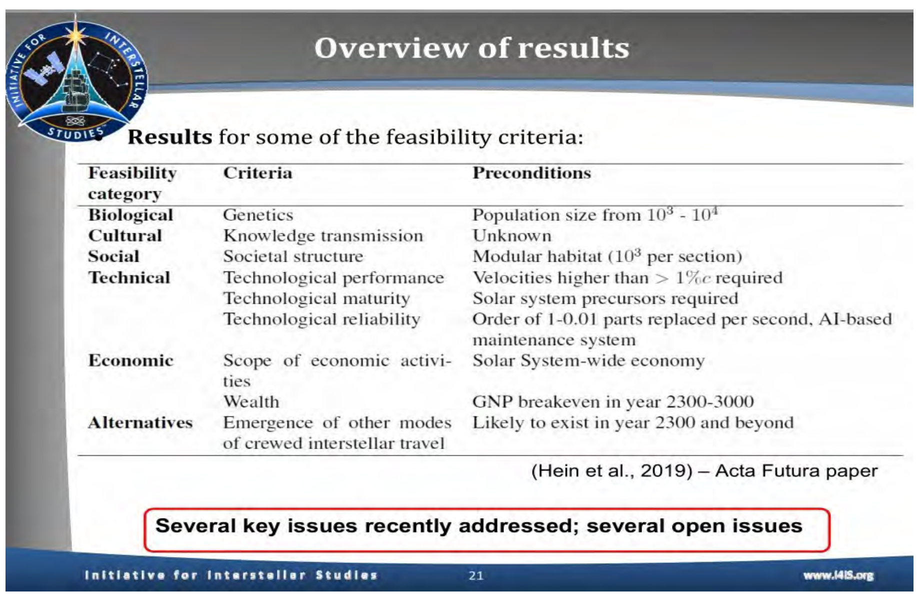
Replacing spacecraft mass by population size. Credit: Hein

Andreas looked also at genetics versus population size (see also 2.14 M8-ISR-L14 Worldship Population Dynamics below) and suggested that population sizes of the order of 1,000 – 10,000 would be needed.

Andreas concluded with some key feasibility issues:

- Maintenance
- Obsolescence due to other modes of transport
- World ships as mobile solar system habitats (see also the article by Richard Soilleux elsewhere in this issue- Implications for an Interstellar World-ship - findings from the BIS SPACE Project) and suggested future work on cultural and social issues for worldships.

Andreas quoted extensively from his paper in the ESA Acta Futura journal (www.esa.int/gsp/ACT/resources/acta_futura/) entitled World Ships: Feasibility and Rationale (Acta Futura: 75-104 2020 - zenodo.org/record/3747333).



Feasibility category	Criteria	Preconditions
Biological	Genetics	Population size from 10^3 - 10^4
Cultural	Knowledge transmission	Unknown
Social	Societal structure	Modular habitat (10^3 per section)
Technical	Technological performance	Velocities higher than > 1%c required
	Technological maturity	Solar system precursors required
	Technological reliability	Order of 1-0.01 parts replaced per second, AI-based maintenance system
Economic	Scope of economic activities	Solar System-wide economy
	Wealth	GNP breakeven in year 2300-3000
Alternatives	Emergence of other modes of crewed interstellar travel	Likely to exist in year 2300 and beyond

Overview of results

Credit: Hein

Andreas Makoto Hein is Executive Director and technical lead of i4is. He is a researcher and systems architect at CentraleSupélec - Université Paris-Saclay. He has degrees in aerospace engineering from the Technical University of Munich and conducted his PhD research at the same university and at the Massachusetts Institute of Technology.

M8-ISR-L04 Introduction to Assignment **IMPRESS**

Andreas Hein introduced the assignments for the course, to examine aspects of worldships and their potential for interstellar travel and settlement (see the resulting papers summarised in the Reports section of this article above)-

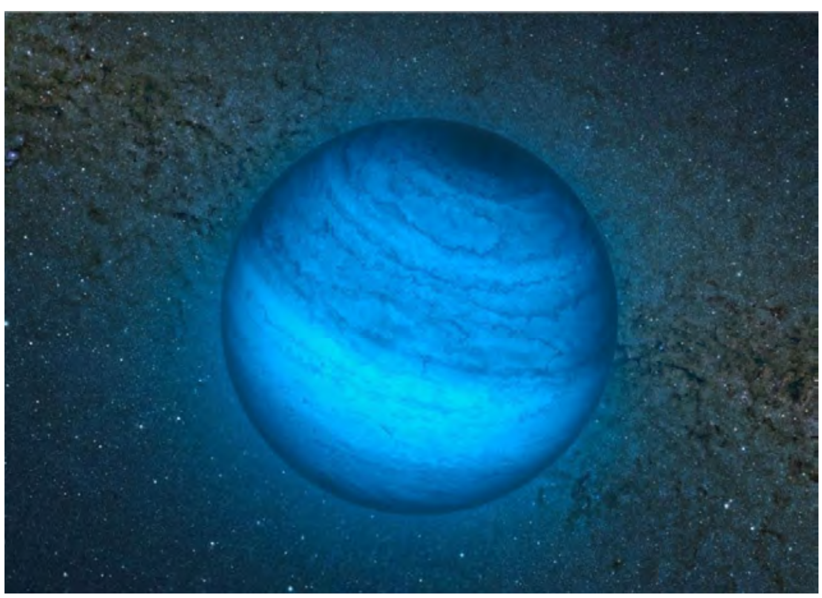
- The Impact of Life Extension on an Interstellar Worldship (EXTEND)
- Exoplanet Settlements (EXO)
- Interstellar Worldships: Exploring and Settling Rogue Planets (ROGUE)
- Hibernation and World Ships (HIBE)

Assignment teams Credit: Hein

A couple of illustrations Andreas used to illustrate the Rogue Planets theme -

Holiday on a rogue planet anyone? Credit: Hein/NASA

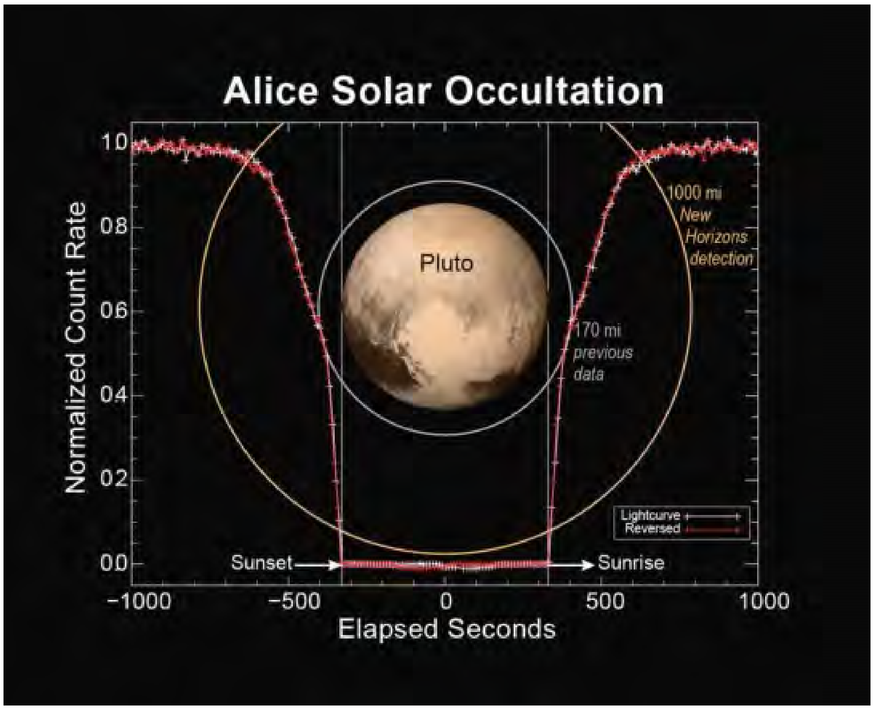
Artist's impression of the free-floating planet CFBDSIR J214947.2-040308.9. Credit: Hein/European Southern Observatory



M8-ISR-L05 Precursor Missions **IMPRESS**

Rob Swinney introduced the idea of interstellar precursor missions, extreme deep space missions to trans-Neptunian destinations - the Kuiper Belt, Oort Cloud and the interstellar medium (ISM) and also technologies intended to deliver these, such as increased speed and reduced propellant requirements.

The Pioneers, Voyagers and the New Horizons probes have already achieved much. For example New Horizons found an atmosphere around Pluto.



Solar occultation revealed the atmospheric structure of Pluto blogs.nasa.gov/pluto/2015/10/30/in-the-shadows-of-pluto-and-charon/.

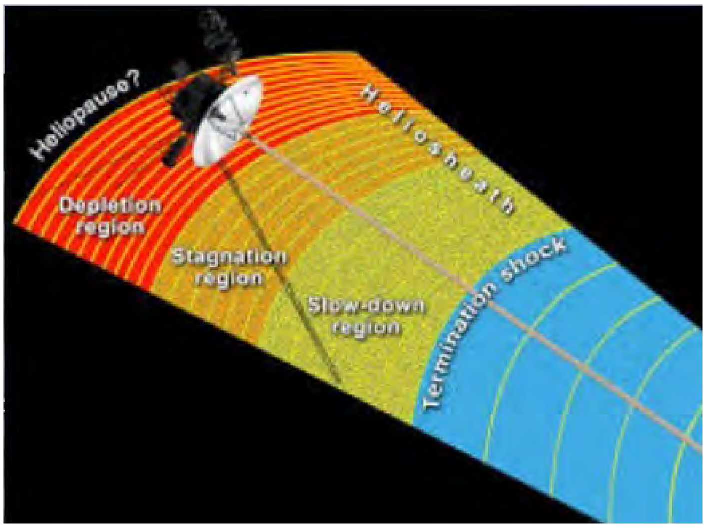
Credit: Swinney/NASA

Rob noted some study proposals over the last 20 years and the Keck Institute of Space Studies Workshops in 2014 and 2015 on building-

- capabilities (reaching the ISM in less than half the time it took the Voyagers, achieving solar system escape velocity, building probes to last more than 50 years) and

- science (Kuiper belt objects, the ISM and all in between).

The sort of mission Rob anticipates would reach 10 AU per year (47 km/sec or 105,000 mph) and thus 200 AU (well beyond the Voyagers eg voyager.jpl.nasa.gov/mission/status/) in 20 years and 500 AU in 50 years - using near term launchers. A solar Oberth manoeuvre (as in several of the i4is Project Lyra studies) would provide the additional velocity increment (delta V) required. Papers by Brandt and McNutt of Johns Hopkins University Applied Physics Laboratory describe the vehicle required [1]. There is much science to be done in the local ISM.



Heliosphere 2013 results from Voyager spacecraft.

Credit: NASA/JPL

But where do we get propulsion which minimises propellant mass and maximises deltaV? Ion propulsion offers the first of these, as in the NASA Deep Space 1 and Dawn probes. Dawn flew to the asteroid belt and visited Vestal and Ceres. Its 3 NSTAR ion thrusters used solar power to expel 400 kg of Xenon to achieve a total deltaV of 10 km/s. The VASIMR (Variable Specific Impulse Magnetoplasma Rocket) concept bridges the gap between high thrust + low specific impulse (chemical rockets) and low thrust + high specific impulse (eg ion thrusters) propulsion systems.

Lots of good science can be done by precursor missions and they improve both our knowledge and capabilities as we head for true interstellar probes.

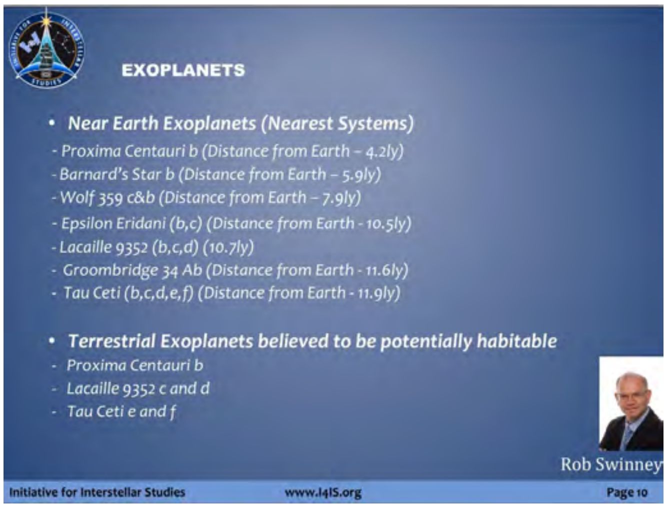
[1] Brandt et al, "Humanity's First Explicit Step in Reaching another Star: The Interstellar Probe Mission", JBIS, V72, No 6, June 2019

McNutt et al, "Near Term Interstellar Probe: First Step", Acta Astronautica 162, pp 284-299 2019 - [www.sciencedirect.com/science/article/pii/S0094576519303650.](www.sciencedirect.com/science/article/pii/S0094576519303650)

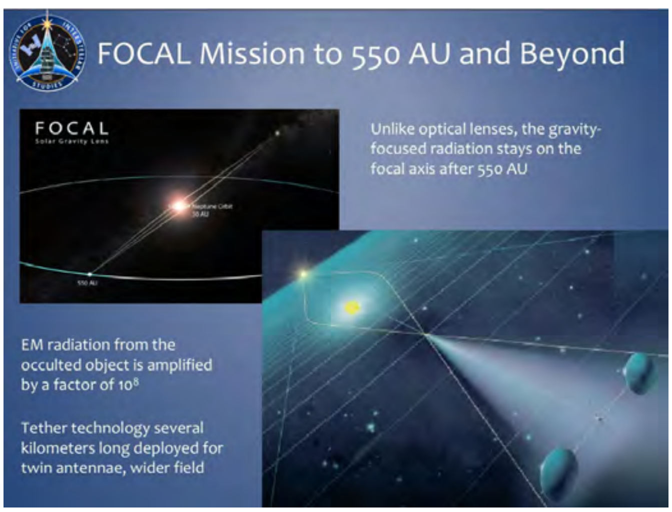
M8-ISR-L06 Destinations IMPRESS

Rob Swinney examined where we might go beyond the Solar System. Exoplanets are the natural focus of interest. We find them by the tiny wobble they induce in their parent star (Doppler shift) or the, also tiny, shadowing of their star as they pass between it and our observers (transit). We have found more than 3.000 of them and there is much science being done[1]. We have found at least five Earth-like exoplanets within 12 light years which are believed to be potentially habitable - Proxima Centauri b, Lacaille 9352 c and d, Tau Ceti e and f. Ocean and icy worlds may be habitable (some solar system moons may also be candidates).

But there are other objects of interest out there - the interstellar magnetic field, cosmic rays, interstellar winds, the possibility of primordial black holes and WIMPS (weakly- interacting massive particles), the

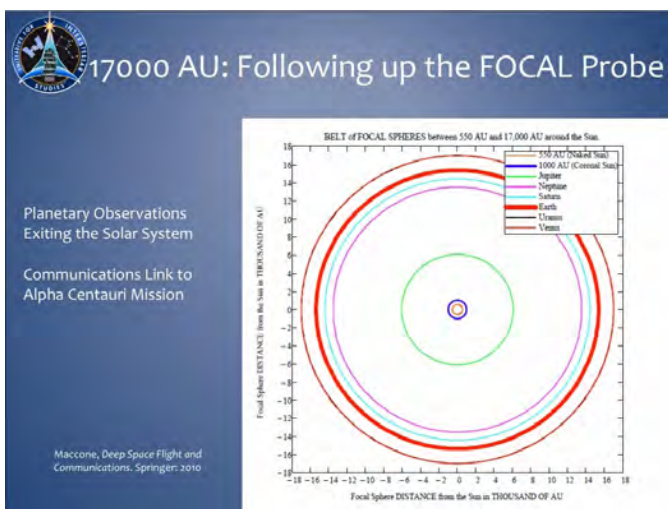


Oort cloud, nomadic planets, interstellar dust and organic materials. The solar gravitational lens focus at 550 AU and beyond offers an amplification factor of 100 million of the object in the line of sight beyond the Sun. And all the solar system planets can act as gravitational lenses - though at greater distances.



Science at the solar gravity lens focus (550 AU and beyond), the FOCAL Mission [2].

Credit: Swinney



Science at planetary graviational lensing points - see Maccone, *Deep Space Flight and Communications*. Springer: 2010.

Credit: Swinney

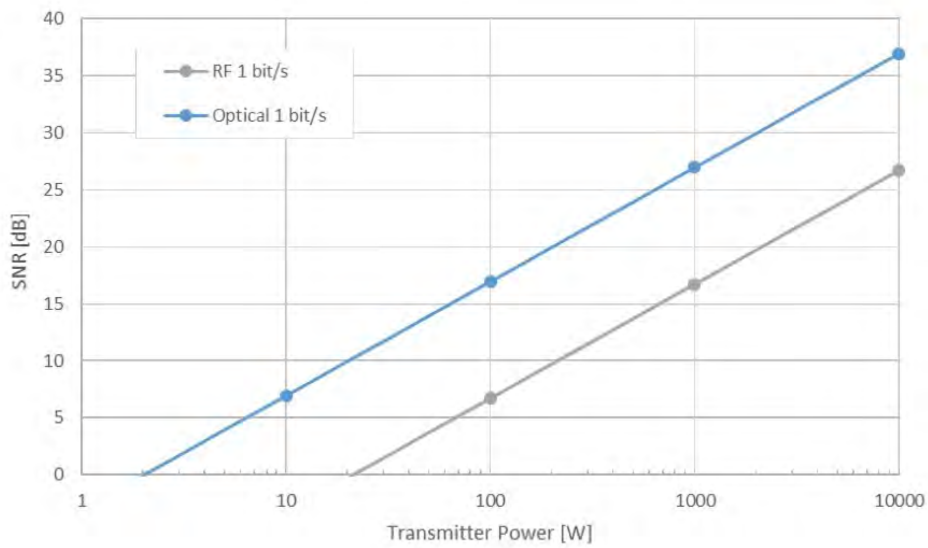
[1] For example the regular bulletins from TVIW tviw.us/interstellar-updates/ show several exoplanet-related papers per day.

[2] The FOCAL Mission: To the Sun's Gravity Lens www.centauri-dreams.org/2006/08/18/the-focal-mission-to-the-suns-gravity-lens/.

M8-ISR-L07 Spacecraft Systems **IMPRESS**

Andreas Hein explained the environment and the necessary systems to achieve the very deep space missions required. Reliability is a major challenge and experience shows that failures mostly arise from single event effects (eg cosmic ray particles, micrometeoroids, solar protons) and electrostatic discharge (ESD). Interstellar radiation is dominated by powerful but relatively low flux of cosmic rays and high energy particles whereas earth-orbit is dominated by less energetic trapped protons and electrons in the Earth's magnetic field. Shielding will be required to keep total ionizing dose (TID) down to acceptable levels. Radiation shielding, redundancy, error correction and autonomous layered recovery can all contribute. Though the dust density is low, collision velocities can be very high. Andreas quoted studies by the Daedalus team showing that for a spacecraft travelling at 10% of c, with a mean interstellar mass density of 1.4 x 10^{-23} kg/m^3, the eroded mass per unit area would be about 7.32 kg/m^2 over 60 years! [1]

Communication over interstellar distances is another challenge. Andreas showed an example of radio versus optical performance - with a distinct edge for optical.



Example of radio versus optical communication.

Credit: Hein

Some radical ideas include using the solar gravitational lens, optical occultation using parts of the laser sail to occult the target star resulting in a "morse-code" communication (as a back-up method) and using trailing communication relays along the path to the target star. Swarming is a natural candidate for very small but numerous probes but this would require optical clocks (10^-19 second frequency stability) and a phase-coherent optical array (position accuracy: ≤100 nm).

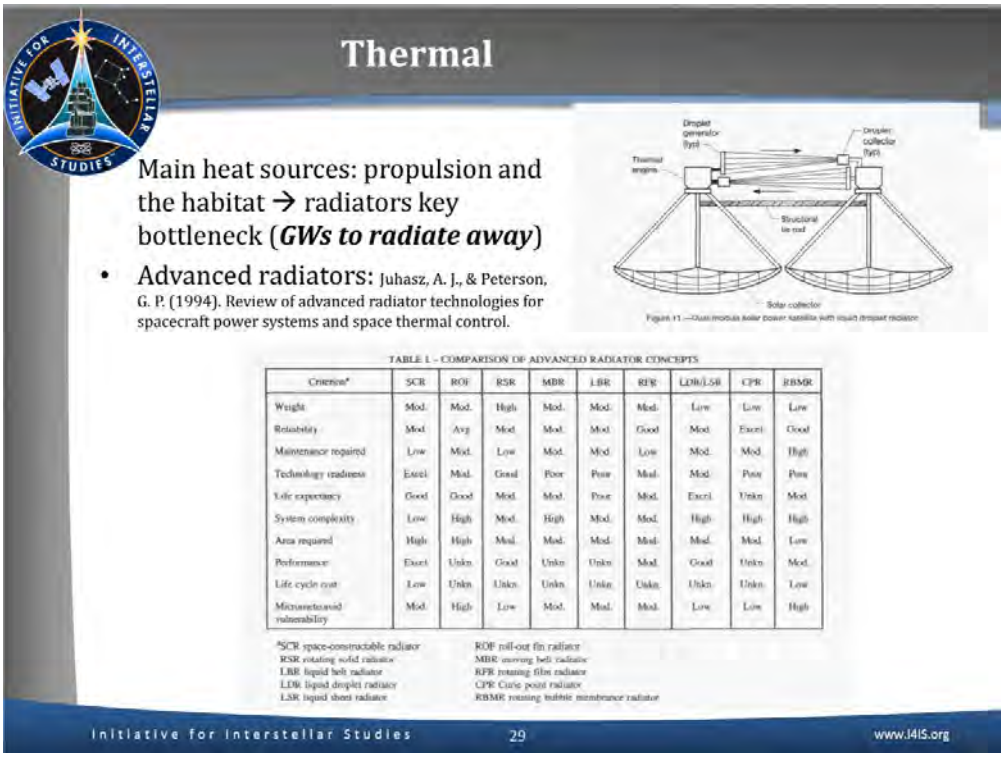
Power generation is a challenge for deep space craft. Andreas suggested a number of potential power sources internal (nuclear, bio fuel cell), natural external (galactic magnetic field, residual starlight, cosmic rays, interstellar matter) and artificial external (laser beam, microwave beam adapting Robert Forward's Starwisp propulsion idea). He concluded that the most promising external sources are charged interstellar particles (using an electromagnetic tether) and beamed laser power. Both fission and fusion may be practical internal sources, although the latter is still unproven in practice, of course.

Attitude and Orbit Control Systems (AOCS) - long term interstellar missions place new demands on both sensors and actuators. Interstellar vehicles require navigation beacons beyond the solar system. Pulsar navigation is a recently developed concept yielding the 3D position of a starship anywhere within the galaxy using their known positions and stable rotation frequencies. Actuators both internal (eg reaction wheels) and reactive (thrusters) may be similar to those of existing spacecraft (with some scaling for worldships! [2]).

[1] The Daedalus papers are collected in BIS book. *Project Daedalus: Demonstrating the Engineering Feasibility of Interstellar Travel* www.bis-space.com/eshop/products-page-3/merchandise/books/project-daedalus-demonstrating-the-engineering-feasibility-of-interstellar-travel/

[2] Very long-term human carrying vehicles place special demands on reliability - and attitude actuators tend to have moving parts.

Thermal control confronts all spacecraft. And worldships will have major heat sources both biological (eg the travellers) and physical (eg propulsion systems). Radiator technology will be vital[1]. Andreas cited ten advanced radiator technologies, based on - *Review of advanced radiator technologies for spacecraft power systems and space thermal control*, Juhasz, A J, & Peterson, G P (1994). They are - SCR space-constructable radiator, RSR rotating solid radiator, LBR liquid belt radiator, LDR liquid droplet radiator, LSR liquid sheet radiator, ROF roll-out fin radiator, MBR moving belt radiator, RFR rotating film radiator, CPR Curie point radiator, RBMR rotating bubble membrance radiator [2].



Criteria*	SCR	ROF	RSR	MBR	LBR	RFR	LDR/LSR	CPR	RBMR
Weight	Mod.	Mod.	High	Mod.	Mod.	Mod.	Low	Low	Low
Reliability	Mod	Avg	Mod	Mod.	Mod	Good	Mod	Excel	Good
Maintenance required	Low	Mod.	Low	Mod.	Mod	Low	Mod.	Mod	High
Technology readiness	Excel	Mod.	Good	Poor	Poor	Mod.	Mod	Poor	Poor
Life expectancy	Good	Good	Mod.	Mod.	Poor	Mod.	Excel	Unkn	Mod
System complexity	Low	High	Mod.	High	Mod.	Mod.	High	High	High
Area required	High	High	Mod.	Mod.	Mod.	Mod.	Mod.	Mod.	Low
Performance	Excel	Unkn.	Good	Unkn	Unkn	Mod.	Good	Unkn	Mod.
Life cycle cost	Low	Unkn	Unkn.	Unkn	Unkn	Unkn.	Unkn	Unkn	Low
Micrometeoroid vulnerability	Mod.	High	Low	Mod.	Mod.	Mod.	Low	Low	High

Credit: Swinney/ Juhasz & Peterson

Though our very deep space probes (eg Voyagers) have proved reliable for many decades a worldship on a journey at least 10 times longer with humans aboard is likely to require active repair capability with the assistance of artificial intelligence.
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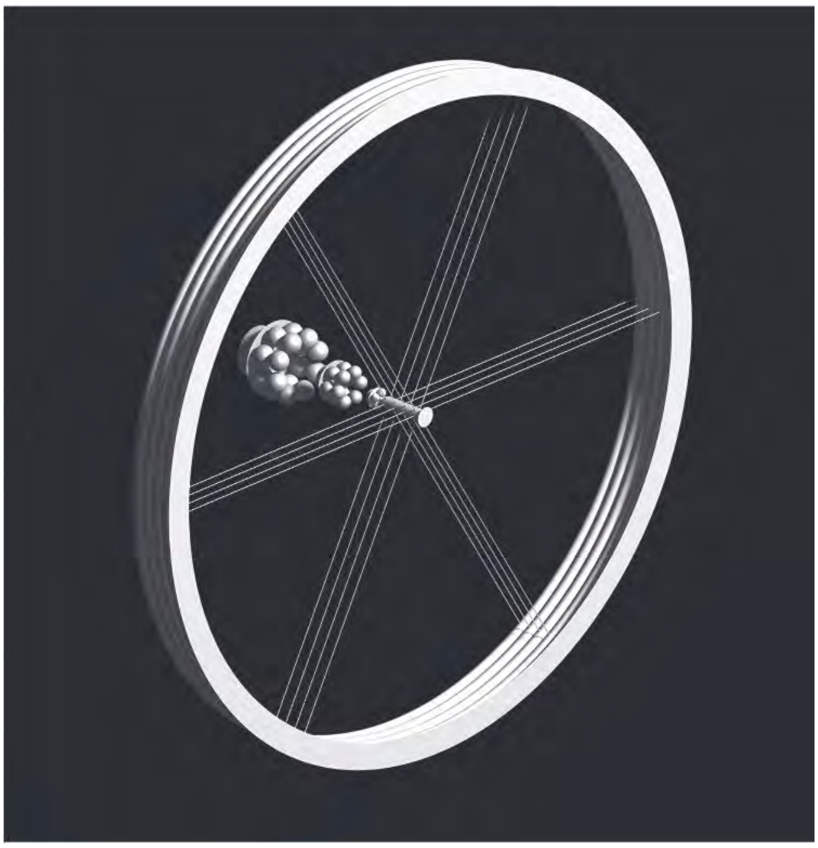


World ship concept based on stacked Stanford Tori and a Daedalus-type propulsion system (from Hein et al, World ships: Feasibility and Rationale, ACTA Futura, European Space Agency, Advanced Concepts Team, 2020).

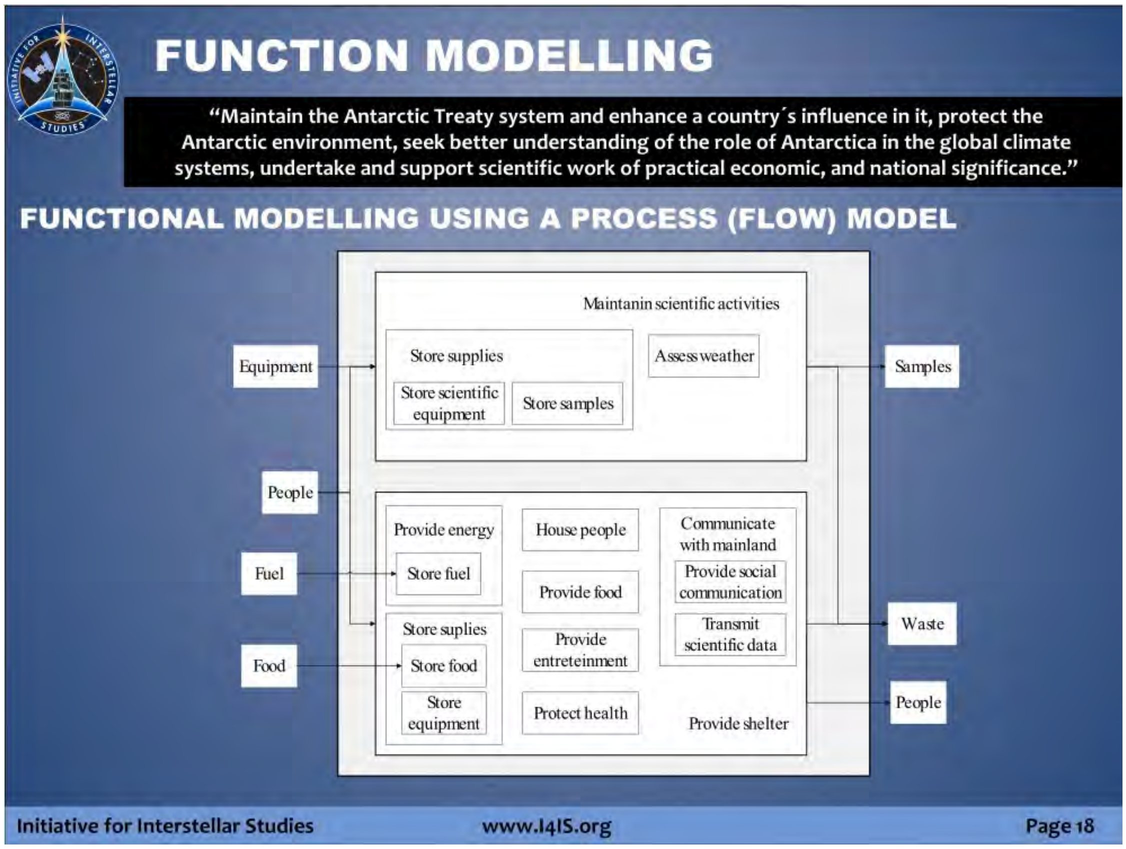
Credit: Adrian Mann

[1] Note the omission of them from the Discovery ship in the film 2001: A Space Odyssey (and their appearance in Clarke's novel) and the large radiators on the Icarus Firefly vehicle - see Reaching the Stars in a Century using Fusion Propulsion A Review Paper based on the 'Firefly Icarus' Design, Patrick J Mahon, Principium | Issue 22 | August 2018 (also i4is.org/reaching-the-stars-in-a-century-using-fusion-propulsion/).

[2] NASA Technical Memorandum 4555 June 1994, ntrs.nasa.gov/search.jsp?R=19940032314.

M8-ISR-L08 Worldship Conceptual Design IMPRESS

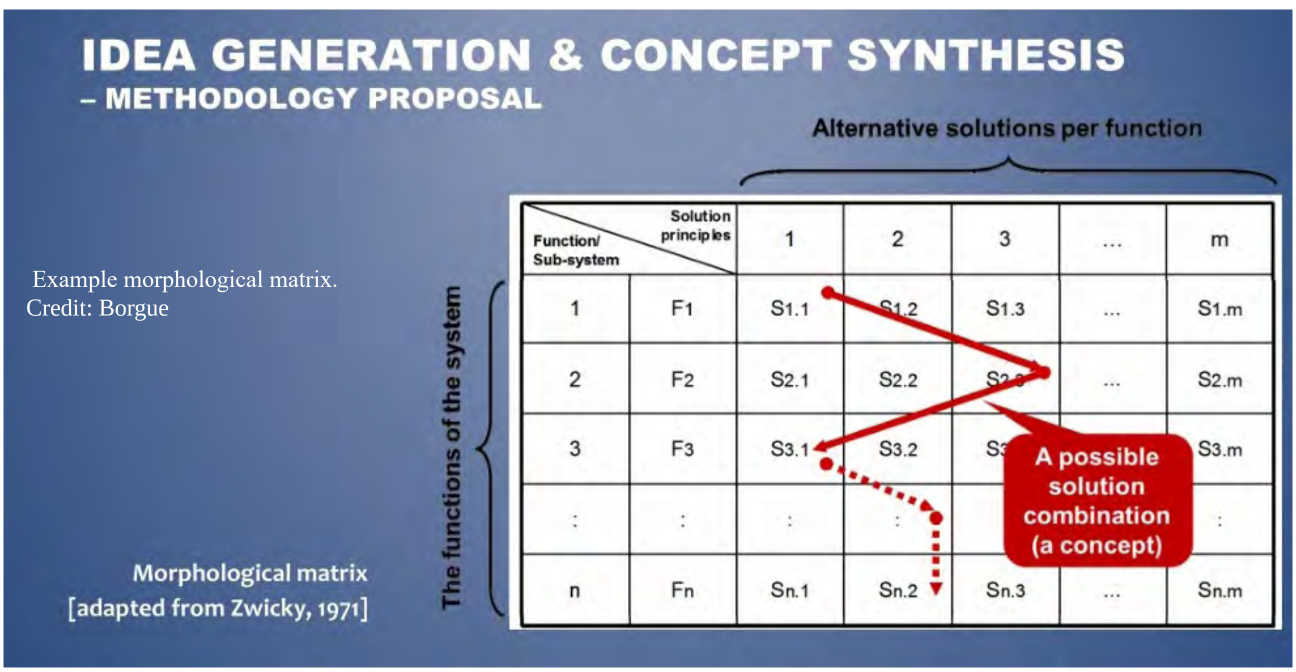
Olivia Borgue gave us a systematic approach to worldship design strategy with a mission statement and problem formulation, basing some of her ideas on engineering experience at an Antarctic research station. The problem formulation process breaks down into requirements specification, identification of functions, generation of solution proposals, synthesis of concepts, and evaluation against requirements specification. Functional decomposition requires definition in a black box fashion with clear interfaces and process flow. Hierarchical decomposition aids clarity.



example functional modelling using a process (flow) model with complex objectives

Credit: Borgue

Olivia advocates a systematic approach based on functional decomposition, idea generation, high diversity of alternative solutions, concept synthesis based on both creation and analysis - possibly supported by methods such as a morphological matrix [1] or a function-means tree [2].



Example morphological matrix. Credit: Borgue

[1] Example - Morphological chart,TU Delft wikid.io.tudelft.nl/WikID/index.php/Morphological_chart.

[2]: en.wikipedia.org/wiki/Function–means_tree.

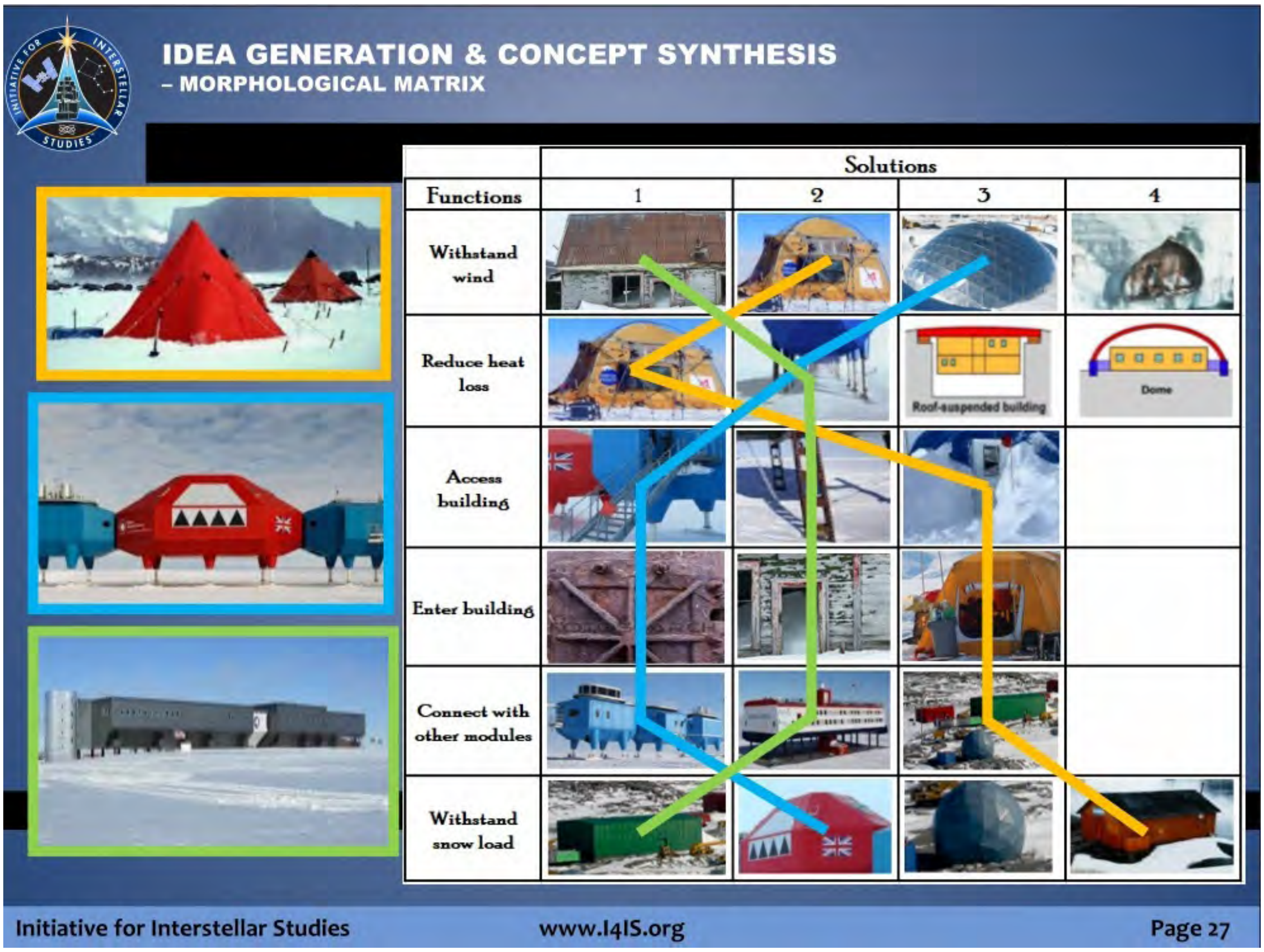
Techniques should include both these formal methods and others such as Pugh Matrices [1] and informal "methods": intuition, "gut feeling" and experience.

In the spacecraft context, especially for those using very advanced technologies, technology assessment is essential. Olivia cited two sources on Technology Readiness Levels (TRL)-

- ESA Technology Readiness Levels Handbook for Space Applications [2]
- NASA Systems Engineering Handbook [3]

K Eric Drexler [4] is another source of what he labels "exploratory engineering" and Olivia cited his *Exploratory Engineering: Applying the predictive power of science to future technologies*. Olivia also cited Thomas Edison and his relentless search for solutions as an inspiration in engineering innovation.

Olivia wrapped up with some further feasibility categories - economic (value creation), societal (accept, tolerate or embrace?) and normative (vs norms, standards, laws), and funding phases - private, angel investors, venture/corporate/government.



Olivia Borgue is working towards a PhD in Systems Engineering Design for on-orbit applications at Chalmers University of Technology, Gothenburg, Sweden. She is also working with Andreas Hein of i4is on a feasibility study of self-replicating probes. She has degrees in Mechanical Engineering from Instituto Balseiro, Argentina and Högskolan i Halmstad, Sweden. She has served as a mechanical engineer at Instituto Antártico Argentino, Carlini Station, Antarctica and is an EASA-qualified helicopter pilot.

[1] Pugh, S, Creating Innovative Products Using Total Design, Addison-Wesley Publishing Co, 1996.

[2] www.skatelescope.org/public/2011-11-18_WBS-SOW_Development_Reference_Documents/TRL_Handbook.pdf

[3] www.nasa.gov/connect/ebooks/nasa-systems-engineering-handbook

[4] Most famously author of *Engines of Creation: The Coming Era of Nanotechnology*, Doubleday 1994.

NEXT ISSUE

Book Review: Extraterrestrial Languages by Daniel Oberhaus

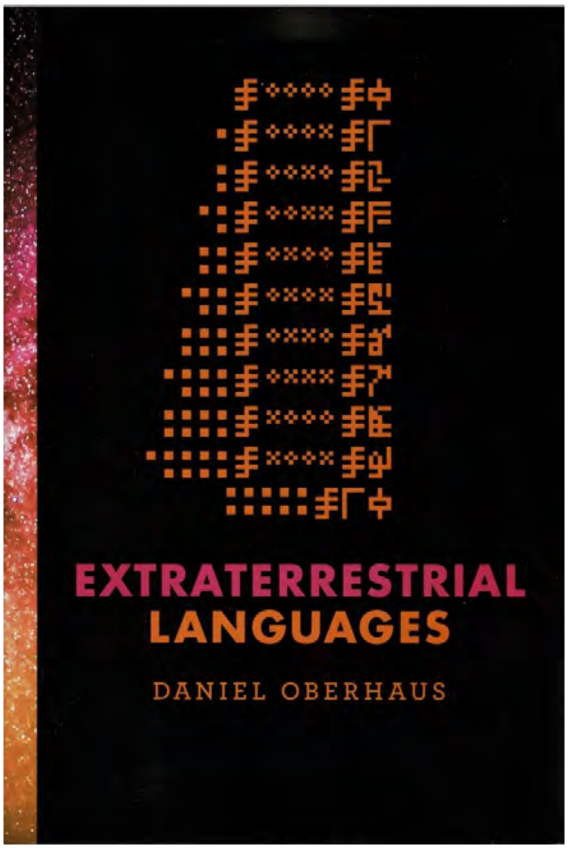


Image credit: The MIT Press

Report on i4is at the Starshot Communications Workshop
The Interstellar Downlink - an introduction
2020 ISU Masters Elective - Part 2 of 2

Cover Images

Front Cover

Our front cover is a worldship envisaged by Michel Lamontagne. Michel tell us that this was the result of the work done in the 2016 TVIW workshop in Chattanooga. It is part of a fleet of four ships, each built for 10,000 people. This separation into multiple ships allows for redundancy and both cultural differentiation and stability. Each worldship is divided into four contra-rotating sections, to cancel out angular momentum and each section is further divided into four sealable habitats, for maximum redundancy.   The Worldship has a diameter of 5 km and a length of 20 km, with about 15 km of that as habitat. The habitats have radiators on the outer hull because the heat from the lighting system required for agriculture cannot get out through the hull alone, an additional mechanical cooling system is required. At a maximum velocity of 2.5% of the speed of light, it's not going that fast. Shield requirements are proportional to the cube of the velocity, so the shield requirements are 175 times less than Daedalus. So unlike Daedalus or the Bond/Martin worldships there is no massive frontal shield. The Z-pinch type drive is similar to Icarus Firefly. Each Worldship's dry mass is about 2 billion tonnes and it carries 5 billions tonnes of Deuterium in a 12 km x 2 km diameter tank at the core of the ship.

Back Cover

NASA Lunar Reconnaissance Orbiter (LRO) pictures - Earthrise

The Earth straddling the limb of the Moon, as seen from above Compton crater. The large tan area in the upper right is the Sahara desert, and just beyond is Saudi Arabia. The Atlantic and Pacific coasts of South America are visible to the left. This image was taken when LRO was 134 km above the farside crater Compton (51.8°N, 124.1°E). Capturing an image of the Earth and Moon with LROC is a complicated task. First the spacecraft must be rolled to the side (in this case 67°), then the spacecraft slews with the direction of travel to maximize the width of the lunar horizon in the NAC image. All this takes place while LRO is traveling over 1,600 meters per second (faster than 3,580 mph) relative to the lunar surface below the spacecraft! As a result of these three motions and the fact that the Narrow Angle Camera is a line scanner the raw image geometry is distorted. Also, because the Moon and Earth are so far apart, the geometric correction is different for each body.

More at -lroc.sese.asu.edu/posts/895 - and see P26 back page for Apollo 11 site from LRO.

Mission

The mission of the Initiative 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 aspire towards an optimistic future for humans on Earth and in space. Our bold vision is to be an organisation that is central to catalysing the conditions in society over the next century to enable robotic and human exploration of the frontier beyond our Solar System and to other stars, as part of a long-term enduring strategy and towards a sustainable space-based economy.

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.

Editors: John I Davies, Patrick J Mahon
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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.

Front cover: Worldship fleet
Credit: Michel Lamontagne
Back cover: Earthrise from NASA LRO
Credit: NASA

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Scientia ad sidera
Knowledge to the stars