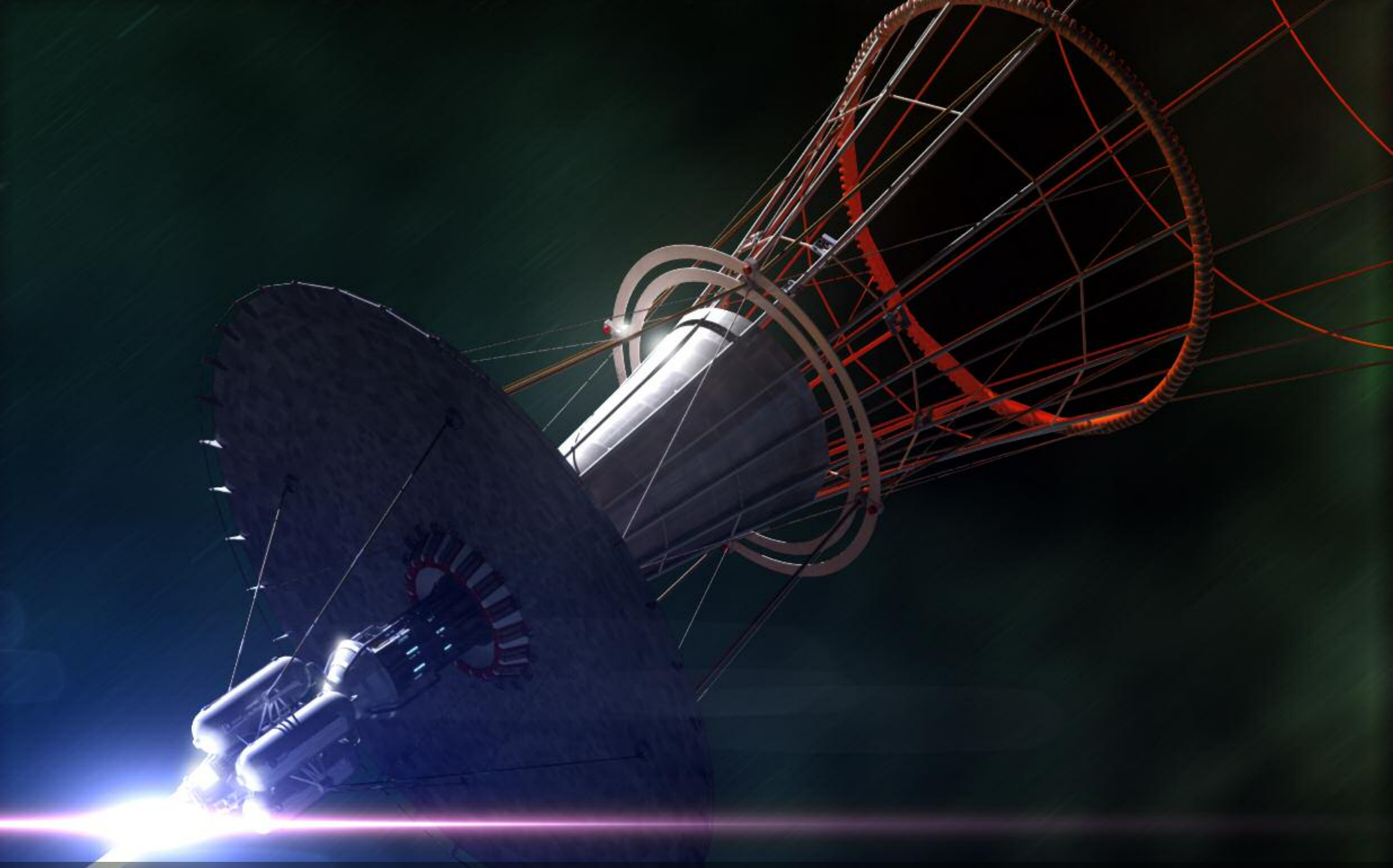

PRINCIPIUM

The Newsletter of the Institute for Interstellar Studies™

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INSTITUTE FOR INTERSTELLAR STUDIES™

Scientia ad sidera

Knowledge to the Stars

A letter from Gregory L Matloff

When my parents gifted me a 90mm aperture Skyscope Newtonian reflecting telescope for my thirteenth birthday, they had no idea where this would lead. I started with the Moon, wondering at its harsh geography through the not-so-clear skies of Brooklyn, New York. Later, through the clearer skies above our Long Island summerhouse, I graduated to the brighter planets, the stars and deep sky objects.

The late 1950s and early 1960s was a heady time for space enthusiasts. The Moon was in reach and the planets not too distant. Popular magazines dealing with astronautics speculated that even the stars might some day be reached.

So as I grew towards adulthood and moved my telescope's tube from one celestial target to the next, I wondered which of those shiny pinpoints might harbour life-bearing worlds. I devoured science fiction novels by Asimov, Bradbury, Clarke, Heinlein and other masters of that genre. And I wondered which stars might have planets with intelligent life.

Entering college at the age of 20, I soon realised that humanity's future on our planet was far from assured. The Cuban Missile Crisis proved that we were balanced on a knife-edge. One wrong decision and the world would come tumbling down.

So I studied physics as an undergraduate, and astronautics, astronomy and planetary atmospheres en route to my PhD. It was my fondest dream that I might participate in the discovery of some method of star-flight – some means of escaping the cataclysm that seemed imminent.

As I look back upon my career in research, development and academia, I am very happy that the nightmare of planetary destruction has at least partially receded. But it is with sadness that travel to the stars, while possible, seems to be a very lengthy process.

So it is with a combination of nostalgia, hope and sadness that I accepted the post of chairing the Senior Advisory Council for I4IS. The road to alpha Centauri may be long and hard, but I think that we can collectively contribute to achieving that goal.

A principal function of I4IS must be the advancement of in-space propulsion capabilities. These include both breakthrough and developmental technologies. Concepts worthy of attention include (but are not limited to) low-energy nuclear reactions (which seem to be enjoying a resurgence), graphene and other advanced solar sail materials, and the attainment of aneutronic fusion reactions. But propulsion is not the only area for further development. In the life sciences, more research is required on closed ecological systems, adaptation to the space environment and the possibilities of human hibernation.

Hopefully, the work of I4IS will inspire new generations of researchers to investigate these and other topics. They will be the ones to decide whether sleeper ships are superior to world ships or embryo ships and if human essences can be uploaded into the memory banks of future quantum computers.

So when I observe the stars as an older (and I hope wiser) person, I still wonder which of those shiny stellar orbs harbour life-bearing or intelligence-bearing planets. I realise now that, alas, I will not personally travel aboard a ship from Earth entering the interstellar void. But perhaps the young people I inspire through my contributions to I4IS might bring the day of humanity's galactic maturity closer.

Dr Gregory L Matloff
Chair, I4IS Senior Advisory Council

How to print a space station from an asteroid

New technology that allows 3D printing in zero gravity might be the key that allows us to turn the lock to asteroid mining.

That's the hope of a new company, Deep Space Industries (DSI), which also intends to send a swarm of cubesats into space to prospect some of the 9,000 known near-Earth asteroids as the first step on the path to industrialising space, helping to create the infrastructure that could one day support an interstellar mission.

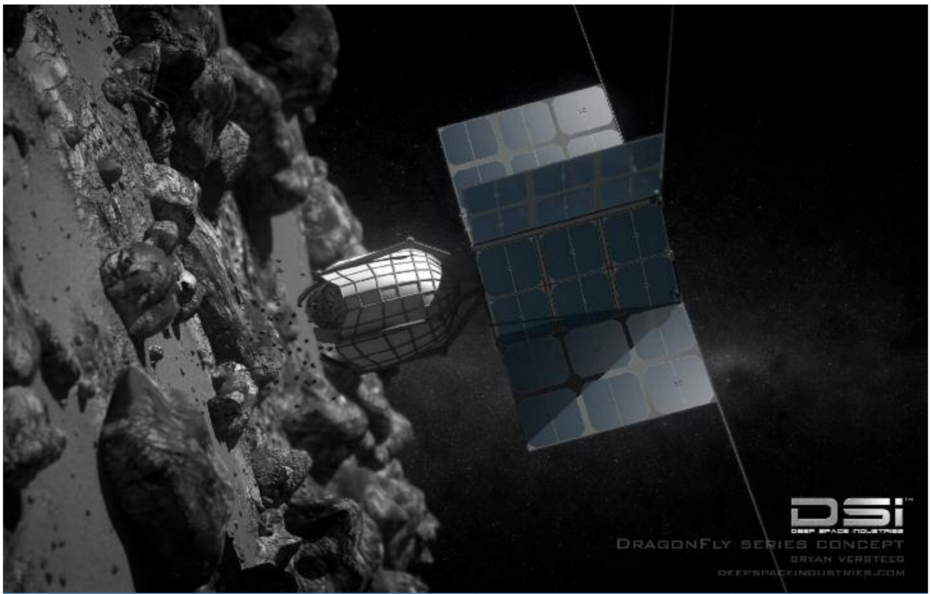
Initially DSI intend to launch a fleet of 'Firefly' craft, based on cubesats (see *Principium*, Issue 1), in 2015. Each Firefly will have a mass of just 25 kilograms and many can be launched together, piggybacking on the launch of larger satellites, keeping their cost low. The Fireflies will operate for two to six months, locating interesting asteroids prior to the launch in 2016 of the Dragonflies – slightly larger probes with a mass of 31 kilograms that will make round-trips to asteroids of interest, returning home with samples for analysis.

Asteroids are repositories of useful materials. Some are stony, some are metallic with copious amounts of nickel and many are carbon-rich and coated in plenty of water-ice. Platinum-group metals, which are rare on Earth (indeed, some of the largest platinum mines on Earth are linked to asteroid impact sites, such as Sudbury Basin in Ontario, Canada.) are laced throughout asteroids, but the secret to DSI's hopes of success isn't just to leech out the valuable metals.

"Mining asteroids for rare metals alone isn't economical, but it makes sense if you are already processing them for volatiles and bulk metals for in-space uses," says Mark Sonter, who is on DSI's board of directors. This approach is more cost-effective, but it is easier said than done – exactly how do we turn asteroid material into useful things?

Print whatever you want

This is DSI's ace-in-the-hole. They've got a new 3D printer, designed by Stephen Covey and patent-pending, that can transform the raw rock and metal of asteroids into intricate, high density, high strength metal components, and the crucial point is that it can work in zero gravity. Ordinary 3D printers sinter powdered metal, but this only works in gravity and produces a lower density and more porous structure compared to the high density metals required for the harsh environment of space. Instead, the Microgravity Foundry will use lasers to draw patterns in nickel-charged gas, causing the asteroid nickel to be deposited in precise arrangements to build almost anything that can be programmed into it.



An artist's concept of a Dragonfly sampling the surface of an asteroid. Image: DSI.

The Microgravity Foundry has the potential to revolutionise the use of resources in space. It could be taken to colonies on the Moon or Mars for example (the European Space Agency has recently launched a study into the possibility of printing a lunar base direct from materials found on the Moon), reducing the effect of being cut off from Earth. If something breaks, astronauts can use the 3D printer to simply build a replacement rather than waiting days or months for a resupply ship. Meanwhile, in Earth orbit, individual communications satellites will be replaced with communications platforms built in situ from raw asteroid material, while other satellites can be refuelled, again from refined asteroid material, extending their operational lives and saving millions of dollars. Eventually, DSI also want to build solar power stations out of asteroids that can be hauled into orbit and beam microwave energy down to Earth.

Gold rush

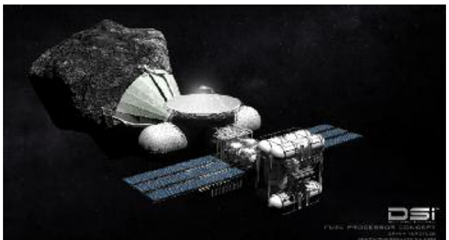
Vast riches await anyone who can unlock the resources of asteroids and industrialise space. Yet despite the impending 'gold rush', getting off the ground is currently the main focus. Fortunately private enterprise in space has also opened the door to advertising and sponsorship from companies such as Red Bull and Google, whom DSI hope can help fund the initial waves of Fireflies and Dragonflies. Once asteroids have been prospected and their true worth proven, asteroid mining will hopefully pay for itself. Companies such

Whole colonies could be spun out of asteroid material by 3D printing techniques. Image: DSI.

as DSI and its only current rival, Peter Diamandis' Planetary Resources, could ultimately become the economic powerhouses that smash down the doors to space and open it up to everyone. Indeed, part of DSI's strategy is to involve the public, including live feeds from mission control and online courses educating about the science of asteroid prospecting. Planetary Resources, meanwhile, announced in April last year their plans to identify asteroids worth mining, using a small, eleven kilogram space telescope – the Arkyd-100 – to spot useful near-Earth asteroids, before following up with interceptors and prospectors (Arkyds 200 and 300). You could call it a two-horse race between DSI and Planetary Resources, but in truth there are more than enough asteroids to go around. What's important is getting a thriving space industry off the ground and using it in a positive fashion to act as the infrastructure for even more ambitious projects – such as an interstellar voyage.

"We will only be visitors in space until we learn how to live off the land there," says DSI's Chairman, Rick Tumlinson. "This is the Deep Space mission – to find, harvest and process the resources of space to help save our civilisation and support the expansion of humanity beyond the Earth – and doing so in a step by step manner that leverages off our space legacy to create an amazing and hopeful future for humanity. We are squarely focused on giving new generations the opportunity to change not only this world, but all the worlds of tomorrow. Sounds like fun, doesn't it?

Deep Space Industries' Fireflies prospect a nearby asteroid in this artist's impression. Image: DSI.



Imagine a harvester attached to an asteroid, refining its raw materials for fuel. Image: DSI.

What is 3D printing?

Imagine having a desktop factory – that's essentially what 3D printing is. It is able to create objects through an additive process of layering material, simply by following a digital design, or a scan of an object to an accuracy of 40 micrometres. The computer takes the design and slices it into cross-sections that tell the printer how to layer the material, be it liquid, powder or sheets of whatever material is required. Each layer is a tenth of a millimetre thick and the entire model can be 'printed' within a few hours. Three-dimensional printers have been around in one guise or another since the 1970s, but the early printers were large, industrial-sized machines with limited capabilities.

The term 3D printer wasn't even coined until 1995 when two Harvard graduate students modified an inkjet printer to produce a binding solution onto a bed of powder. Today the technology has become readily affordable and it can build practically anything to surprising complexity, including moving parts. However, don't be mistaken for thinking it's a *Star Trek*-style replicator. It may be able to print a teacup but, if you want that pot of hot Earl Grey, you're still going to have to put the kettle on.

To see 3D printing in action, check out this YouTube video:

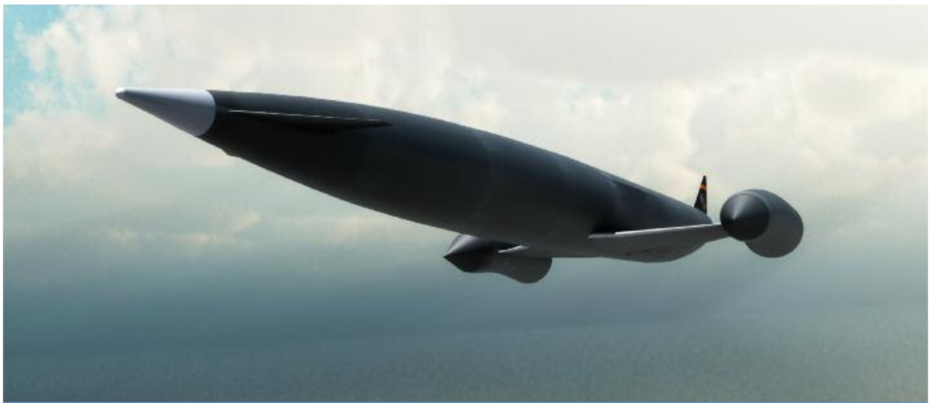
☛ http://www.youtube.com/watch?v=8aghzpO_UZE.

An artist's concept of the Microgravity Foundry 3D printer: take the raw stuff of asteroids and turn it into objects. Image: DSI.

Skylon revs its engine

SABRE, the air-breathing rocket engine that is hoped will power Reaction Engines' reusable Skylon spaceplane into orbit, has passed critical engineering tests on its pre-cooling system in what Reaction Engines describe as the "biggest breakthrough in aerospace propulsion technology since the invention of the jet engine."

A key component in building an industrialised infrastructure in space is getting into orbit in the first place. Skylon, a British design, is the brainchild of Alan Bond, who is the founder of Reaction Engines and who also led the British Interplanetary Society's Daedalus Project in the 1970s. The aim of Skylon is to build a ground-to-orbit vehicle that can then return to Earth after delivering a payload into orbit, all in a single stage. For comparison, the space shuttle was a three-stage system – solid rocket boosters, the external propellant tank and the shuttle orbiter itself.



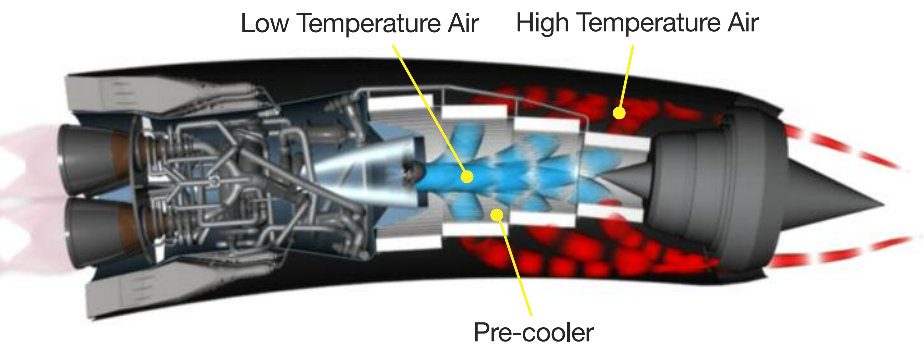
An artist's impression of the Skylon spaceplane in flight. Image: Adrian Mann (www.bisbos.com)/Reaction Engines Ltd.

SABRE is a fusion of rocket and jet technology that will allow Skylon to reach speeds of more than 30,500 kilometres per hour (allowing one to fly from London to Sydney in just four hours). To work, however, the engine must cool inrushing air at a temperature of 1,000 degrees Celsius to minus 150 degrees Celsius in a hundredth of a second, all the while avoiding frost build up. Now Reaction Engines have demonstrated, not just to their satisfaction but also to the satisfaction of both the United Kingdom Space Agency (UKSA) and the European Space Agency (ESA), that SABRE's pre-cooling technology works perfectly.

"These successful tests represent a fundamental breakthrough in propulsion technology," says Bond. "The Reaction Engines team have been trying to solve this problem for over 30 years and we've finally done it. The SABRE engine has the potential to revolutionise our lives in the twenty-first century in the way the jet engine did in the twentieth century."

With ESA's independent thumbs up, Reaction Engines are now proceeding onto the next stage of developing Skylon, aiming for test flights by the early 2020s. Full research and development of Skylon are estimated to eventually come to somewhere within the region of £7 billion, with an estimated unit cost of around £700 million, but the long term savings it can provide on regular rocket launches means that plenty of customers can be expected when Skylon one day comes to fruition.

To learn more about Skylon, visit Reaction Engines' website at www.reactionengines.co.uk.



The SABRE engine pre-cooler takes 1,000 degree Celsius hot air and passes it through tubes no wider than a millimetres where it is cooled to –150 degrees Celsius. By having many narrow tubes it provides more surface area to transfer heat. Image: Adrian Mann (www.bisbos.com)/Reaction Engines Ltd.

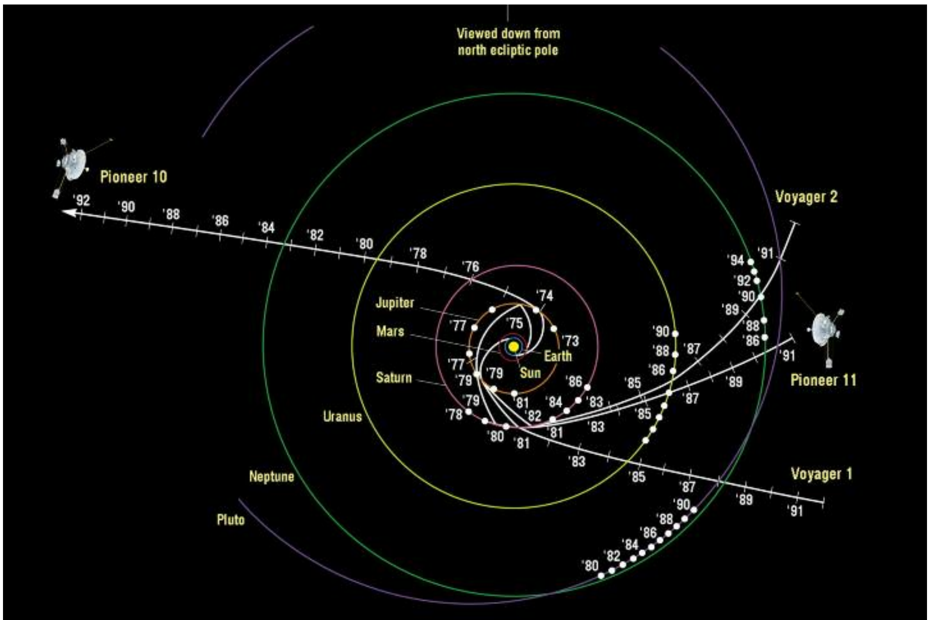
Listening Post

What a very good publication the second edition of *Principium* was! It looks really professional. However, there is an important erratum for the Voyager retrospective, regarding the work of Michael Minovich, who discovered the possibilities of gravity assists. Michael was a student intern at the Jet Propulsion Laboratory (JPL) in California when he made the discovery in 1961, not an engineer there as it states in the text (this is very important factually).
His first independent accomplishment was to solve the previously unsolved 'Three Body Problem of Celestial Mechanics' that then gave him the basis for his gravity assist discovery.

JPL told him that his work was against the laws of physics and not possible, so they did not support anything he was doing in that regard. He made his discovery completely independent of JPL and it was not the result of any JPL task assignment. Minovich decided to conduct his own investigation and was able to obtain a research grant from the University of California, Los Angeles that allowed him to use their new IBM 7090 computer, which at the time was the world's most powerful and fastest digital computer. That's the basis for his discovery of gravity assists.

Bill Cress
Director Icarus Interstellar
and I4IS Consultant

Via e-mail



The trajectories of Pioneer 10 and 11, and Voyager 1 and 2 as they visited the outer planets and headed into deep space. All used gravity assists to move on from one planet to the next, especially Voyager 2, which was able to utilise the manoeuvre three times at Jupiter, Saturn and Uranus. Image: NASA

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Open hailing frequencies!

If you're interested in contributing to future issues of Principium, you can contact the editorial team via e-mail at principium@i4is.org. Or perhaps you're an I4IS team-member and would like your research featured in the newsletter – we'd also be delighted to hear from you.

Meanwhile, we would be fascinated to receive readers' correspondence on all matters interstellar, your thoughts on *Principium* and I4IS and your suggestions for future topics of discussion in these pages. We look forward to hearing from you!

The Editor reserves the right to edit or shorten letters.

A Learning Experience

Chris Welch describes how a new partnership between the International Space University and I4IS is paving the way for students to study the final frontier.

The International Space University central campus near Strasbourg, France.

Last year witnessed two auspicious events for visionary space organisations. The Institute for Interstellar Studies (I4IS) was founded, while the International Space University (ISU) celebrated its twenty-fifth anniversary. The two are now working together to enable the next generation of space pioneers to study interstellar spaceflight.

The International Space University was founded in 1987 as a not-for-profit, international, interdisciplinary institution of higher learning, dedicated to the development of outer space for peaceful purposes, education and research. The ISU has its central campus and headquarters in Illkirch–Graffenstaden, just outside the city of Strasbourg in France. Specialising in a '3Is' approach, ISU provides an interdisciplinary, intercultural and international environment for educating and training graduates and professionals.

The programmes offered by the ISU are dedicated towards advancing the future career development in space-related fields of graduate students and professionals from all nations. The aim is to create an understanding of the interaction between space-related disciplines such as space engineering, space applications, space science, human performance in space, space management, business, policy, economics and law, and so on. This all leads to a coherent view of space activities on a global scale and an appreciation of the challenges presented by their international nature, based on how different cultural and disciplinary backgrounds from all countries active in space influence space planning and decision making. In other words, we prepare for a future in space together.

Consequently, the ISU is tailored to the needs of the space sector and those who wish to work in it. Its annual programmes include:

- A twelve-month Master of Science (MSc) in Space Studies (MSS)
- A twelve-month Master of Science in Space Management (MSM)
- An eighteen-month Space Executive MBA (EMBA)
- A nine-week Space Studies Programme (SSP)
- A five-week Southern Hemisphere Summer Space Studies Programme (SHSSP)
- A one-week Executive Space Course (ESC) providing a basic introduction to space topics for executives and space sector employees.

The MSS, MSM and ESC are run at the Strasbourg campus, while the SSP and the EMBA operate at a variety of global locations and the SHSSP is based in Adelaide, Australia. In addition, the ISU also offers a variety of on-demand workshops and short courses. Participation in these programmes is open to individuals and institutions of all nationalities.

Symposia

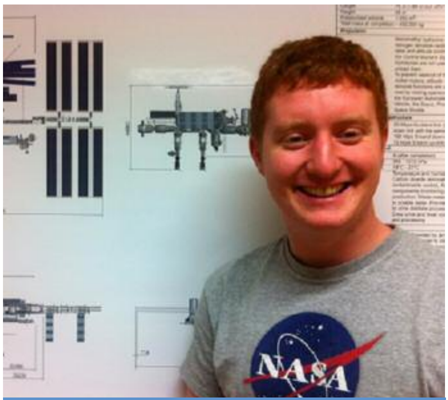
The ISU also organises an annual symposium at its Strasbourg campus. Dedicated to a different topic each time with broad interest both to space industry and space agencies, the symposium is timed so that the ISU's MSc students can all take part and benefit from interacting with the wide range of delegates that attend. Recent symposium themes have included 'The Public Face of Space' (2010), 'The International Space Station: Maximising the Return from Extended Operations' (2011), 'Sustainability of Space Activities: International Issues and Potential Solutions' (2012) and 'Space Technology and Tele-Reach' (2013).

To date, the ISU has prepared more than 3,500 students and programme participants from more than 100 counties for the challenge of international space cooperation. The university has also been granted a number of accolades. It is a member of the International Astronautical Federation (IAF) and has been invited to contribute to a number of international activities, having been granted full membership of the Space Agency Forum (SAF) in 1995. Since 1998, the ISU has had permanent observer status with the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS). The French Ministry of Education formally recognised the ISU as an institute of higher education in 2004. In 2010 the ISU was awarded the Sir Arthur Clarke Award for International Achievement and in 2012 the biennial Herbert Curien Award. On the back of its success comes a pioneering new partnership with I4IS that brings to the world the first-ever dedicated interstellar MSc projects.

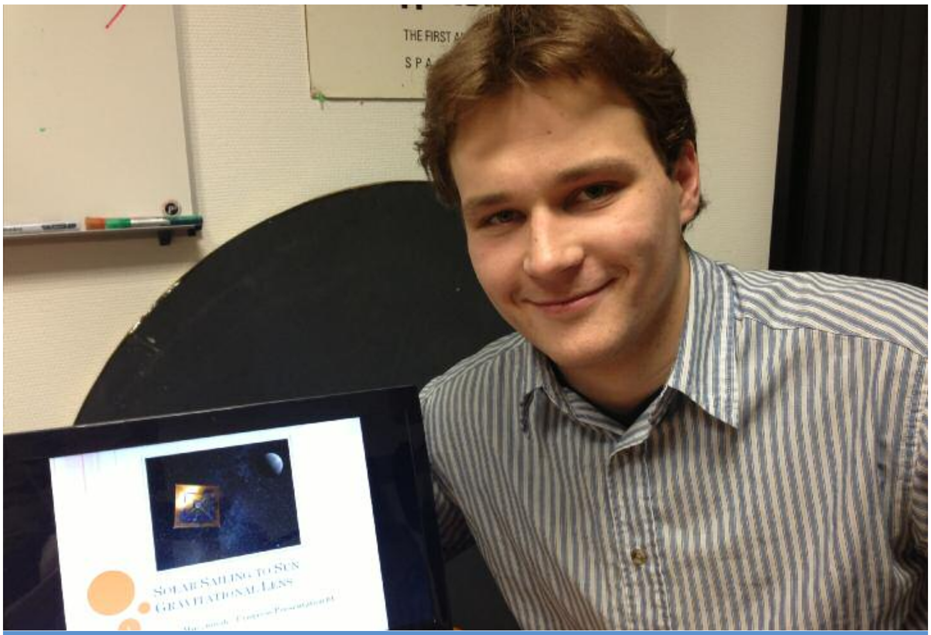
I4IS team-up

During the 2012–13 academic year, I4IS Executive Director Kelvin Long is lecturing on Interstellar Propulsion in Strasbourg. At the same time, I4IS has offered a range of research topics suitable for individual MSc student projects that are supported by I4IS technical advisors.

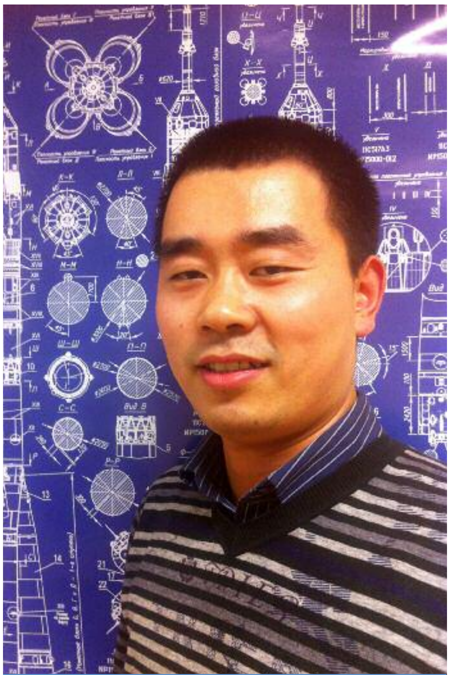
The Space Pioneers Hall inside the ISU.



James Harpur is working on the project of designing an interstellar probe with a 100 kilogram payload.



Piotr Murzoniak is studying the design of an interstellar pre-cursor mission with the ISU and I4IS.



Wang Wei is looking at how to decelerate an interstellar voyager once it reaches its target destination.

Erik Franks is studying the feasibility of large-scale space-based agriculture – essential for large colonies and worldships.

For us at the ISU, we find that the range and scope of the challenges presented by interstellar exploration match well with the ISU's forward-looking, interdisciplinary approach to humanity's future in space. On every level – academic, professional and personal – the ISU is very pleased to be working with I4IS.

There are four I4IS projects currently being undertaken. Piotr Murzoniak from Canada/Belarus is carrying out the preliminary design of an interstellar precursor mission to undertake the study of exoplanets using gravitational lensing, and is being advised by Dr Greg Matloff. "I think that solar sailing is clearly the future for outer Solar System exploration," says Piotr.

Irish student James Harpur is being advised by Kelvin Long as he investigates the design of an interstellar probe with a 100 kilogram payload, while Wang Wei from China takes as his topic a review of deceleration options for robotic interstellar spacecraft arriving at another solar system, and is advised by Dr Ian Crawford. The fourth project is investigating the feasibility of large-scale space agriculture and is being carried out by US student Erik Franks, as advised by I4IS Academy Director Rob Swinney. After starting the projects in October, the four students have completed the initial research phase and have produced their project plans, which are now being implemented with the culmination of the projects taking place at the end of April.

More details about the ISU and its programmes can be found on its website, www.isunet.edu. The deadline for application to the MSc programme in any given year is at the end of the preceding June, although earlier application is strongly advised for those seeking scholarships or financial support.

About the author

Professor Chris Welch is the Director of Masters programmes at the International Space University and a visiting lecturer in spacecraft propulsion at Cranfield University, UK.

He also acts as the Deputy Chair for the I4IS Senior Advisory Council.

Retrospective: The Bussard Ramjet

Scooping up interstellar hydrogen gas and using it as nuclear fuel may be the secret to travel between the stars.

It goes without saying that there are no gas stations in space. Instead, interstellar voyagers are faced with carrying all the fuel they need for the entire journey with them. When the British Interplanetary Society designed the Daedalus starship (see issue one), they set aside 50,000 tonnes for the 30 billion pellets of deuterium and helium-3 that the onboard fusion reactor would require to propel the starship towards Barnard's Star 5.9 light years away. Daedalus was designed to be a one way trip; if you wanted to come back, the round trip would require a lot more fuel.

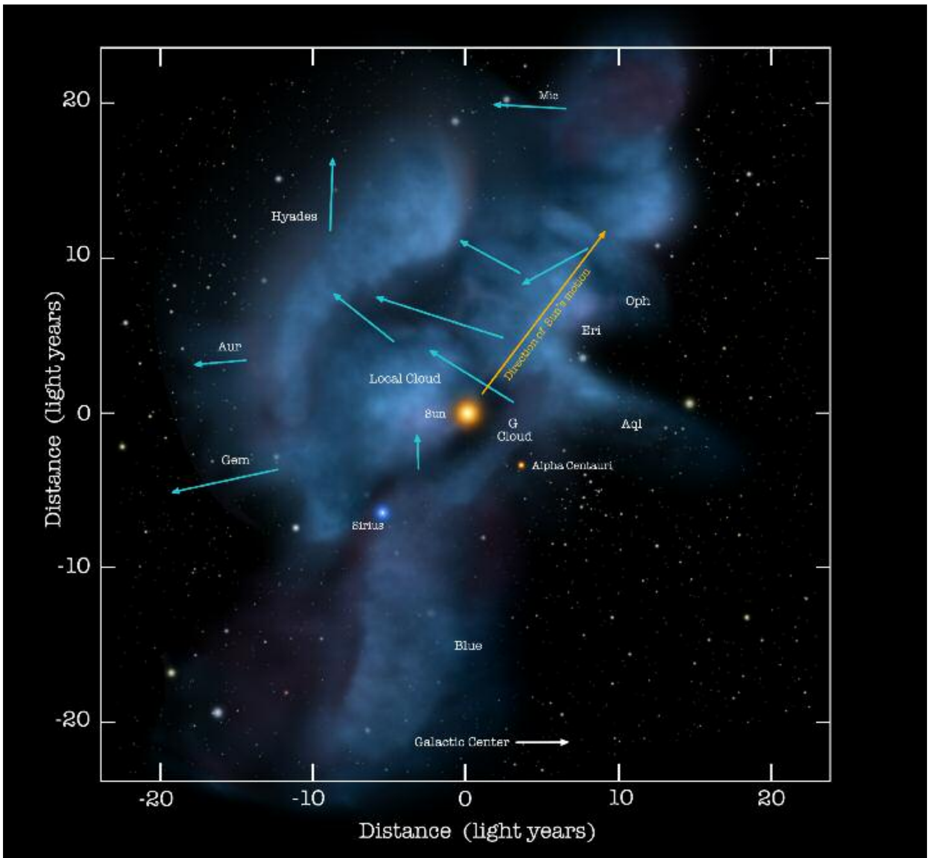
All that mass needs a lot of energy to push it up to even a few percent of the speed of light. To reach those energies you need a lot of fuel, which brings the mass up even higher, consequently causing the energy requirements needed to push all that extra mass to become even greater, and on and on in a vicious circle. Daedalus alleviated the problem somewhat by having multiple stages; when one stage had exhausted its fuel load, it was jettisoned, bringing the mass down.

There may, however, be another way and, as crazy as it sounds, it doesn't necessarily require carrying any fuel at all. It's the brainchild of a nuclear physicist who worked at the Los Alamos National Laboratories in the United States in 1960, where he wrote a revolutionary scientific paper describing a new type of starship, one that finds its fuel lying untouched in its path through space. His name? Robert Bussard.

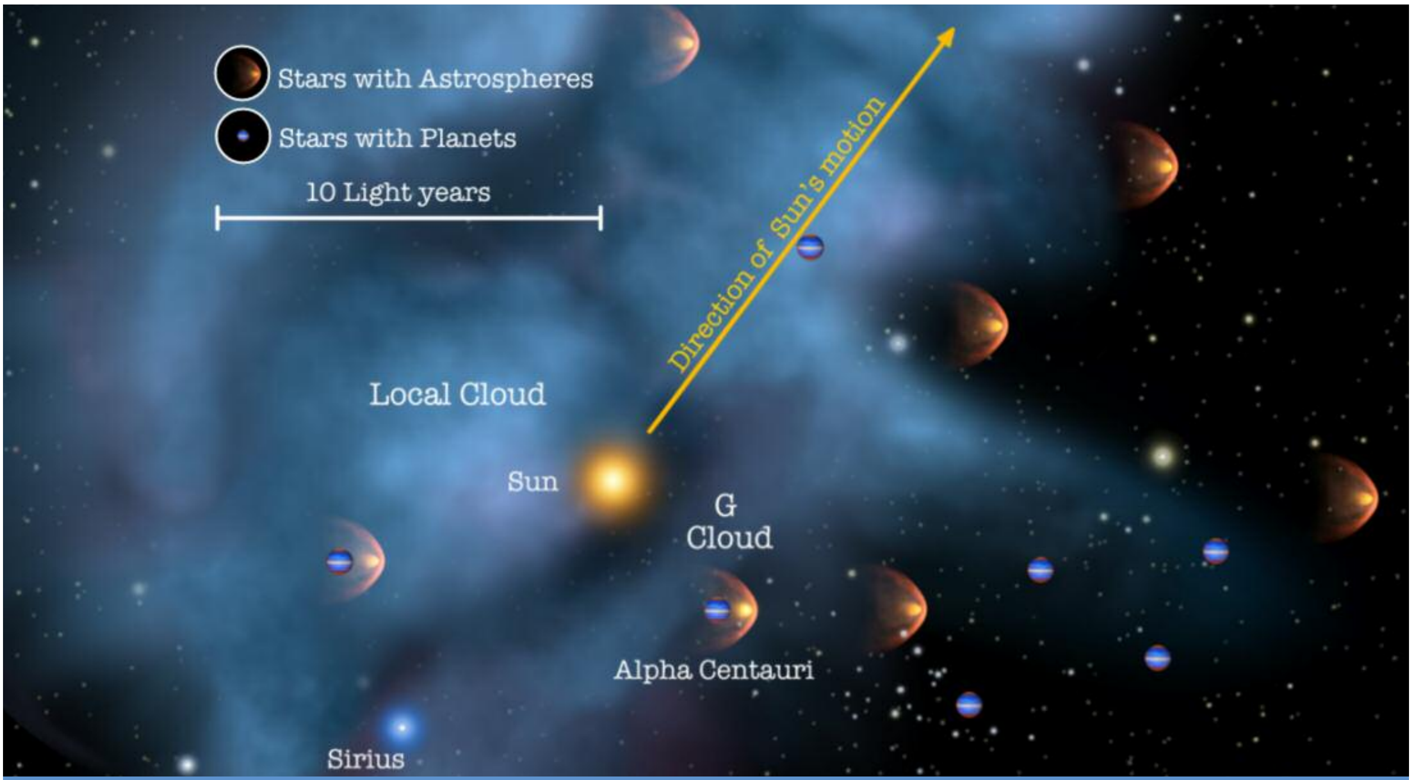
Space is not empty. It is filled with a tenuous mist of atomic nuclei, molecules and electrons known collectively as the interstellar medium. Mostly it is hydrogen gas, the most common substance in the Universe. Bussard figured that if you could somehow collect this hydrogen gas it could be used in fusion reactions inside a starship to provide energy. He imagined an enormous magnetic scoop that could sweep up the ionised (i.e. charged) gas in its path, funnelling it into the ship, analogous to an air-breathing ramjet. Inside the ship the magnetic fields compress the gas to such a degree that temperatures and pressures reach that required for nuclear fusion. The extent of the magnetic 'ramscoop' would need to be enormous to collect enough gas from the diffuse interstellar medium: if the mass of the starship were a mere 100 tonnes then the magnetic scoop would need to be 1,400 kilometres in diameter, with a surface area of ten trillion metres square – that's larger than many moons. In essence, the ship would be just a big cosmic vacuum cleaner and, the faster it travels, the more gas it sucks up and the greater the acceleration. Alan Bond calculated in the 1970s that at two percent the speed of light, a ramjet reaches only fifty percent efficiency. A decade later and Robert Frisbee was slightly more pessimistic, expecting a ramjet efficiency of fifty percent at six percent of the speed of light.

Extra oomph

Bussard ramjets come in a range of configurations sandwiched between two extremes. At one end is the scenario wherein the vessel carries no fuel onboard at all, while at the other extreme is a concept known as the Ram-Augmented Interstellar Rocket (RAIR). It works similar to air being sucked into a rocket – the interstellar gas is accelerated by an electric field generated by the fusion reactor and used to dilute the propellant, giving the exhaust more oomph. In a way,



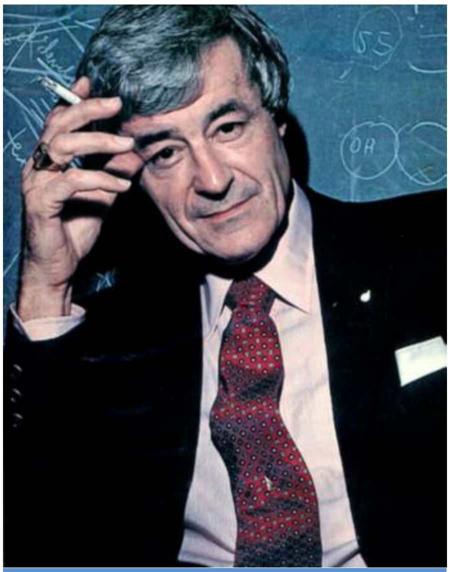
A map of the local interstellar environment, based on measurements provided by NASA's IBEX satellite. The arrows indicate the direction of motion of the clouds. The Sun appears to be close to the edge of the 'Local Cloud'. Nearby stars such as alpha Centauri and Sirius are labelled. Image: NASA/GSFC/Adler/University of Chicago/Wesleyan.



A close-up look at some of the nearby stars in the 'Local Cloud'. Stars with known exoplanets and stars with known astrospheres (magnetic bubbles like the Sun's heliosphere, which protects from cosmic rays – see *Principium* Issue Two) are indicated as potential locations of habitable environments and destinations for a starship.

it is a nuclear-powered version of an ion drive, such as the one currently operating on NASA's Dawn spacecraft to the asteroids, which accelerates ions to provide a gradual build up of thrust; only in the ramjet's case, it packs a much bigger punch.

Although Bussard neglected to delve too deeply into the engineering challenges of such a vessel in his paper, *Galactic Matter and Interstellar Flight*, the Bussard ramjet would lighten the load considerably; without the need for carrying fuel, a starship could mass hundreds or a few thousand tonnes, rather than tens of thousands of tonnes. It all sounds too good to be true: free fuel, free energy, lower mass, higher velocities. Iain Nicholson, in his classic 1978 book *The Road to the Stars*, was sufficiently impressed to describe the ramjet concept as "such an elegant one that it would be tragic if it could not be developed to allow the possibility of completing major interstellar flights within a human lifespan."



Dr Robert William Bussard, 1928–2007.

Hydrogen inadequacies

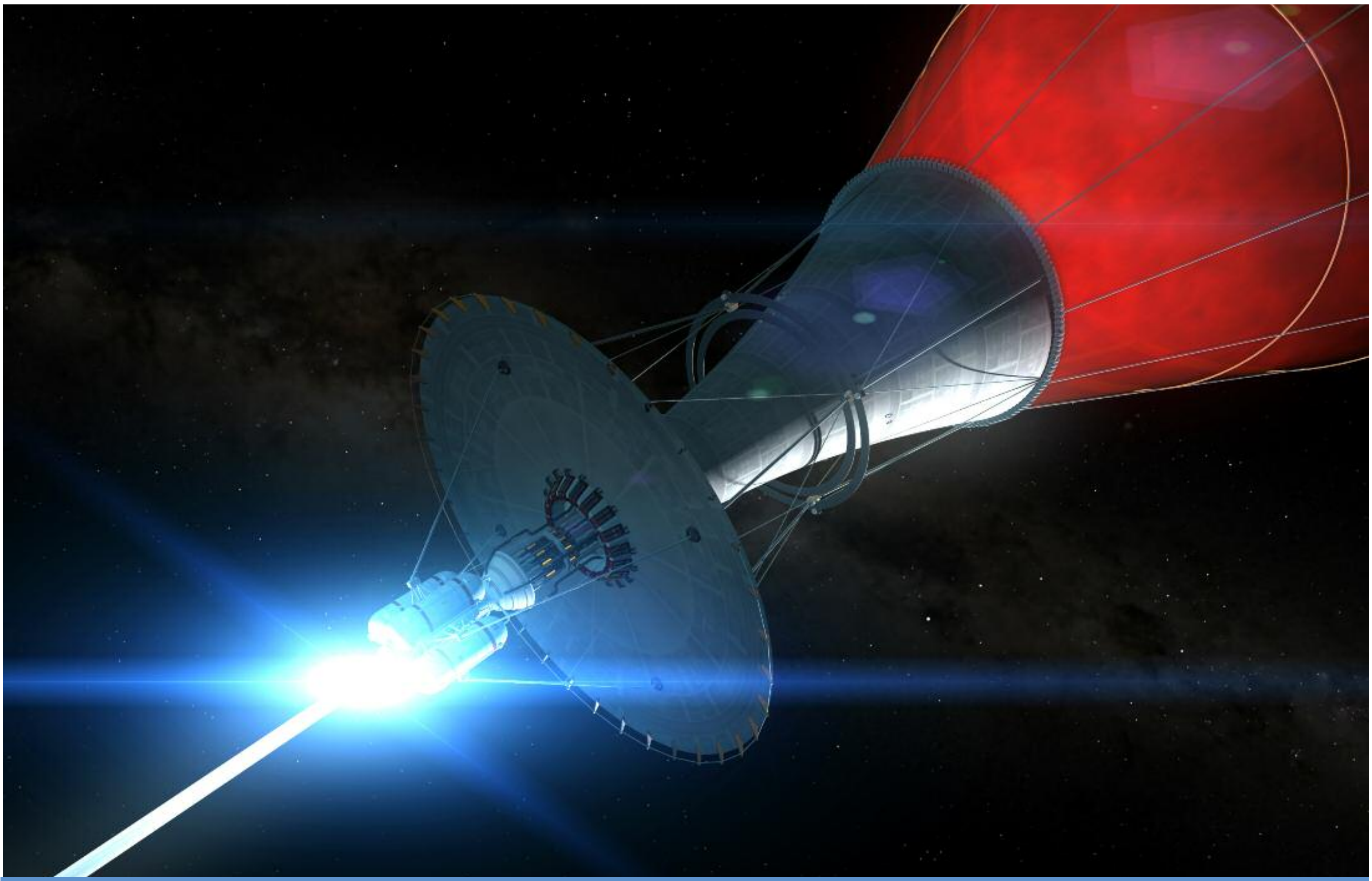
So what are the possible show-stoppers? The interstellar medium is more rarefied than Bussard thought, with around one atom per cubic centimetre of space on average, (although the densest patches can be 1,000 times more concentrated). It's also pretty patchy – a void could cause the ramjet engine to stall. Furthermore, in order to sweep up the required number of atoms, the spacecraft has to already be ploughing through space at high velocity, so it will be essential to carry at least enough fuel onboard to get up to speed. Plus, not everything in the interstellar medium is of use – only charged particles interact with magnetic fields, so neutral hydrogen atoms cannot be captured by the magnetic scoop, although a laser could be used to shoot ahead and ionise them.

Then there is the assumption that we can construct a suitable fusion engine. Suffice to say, a fusion reactor that produces a net profit in energy has not yet been constructed, although hopes are high that this landmark will be achieved by the end of this decade, possibly by ITER (International Thermonuclear Experimental Reactor) being built near Marseille, France, or the National Ignition Facility at the Lawrence Livermore Laboratories in California. Additionally, hydrogen isn't the best fuel for fusion reactions, which is why terrestrial reactors tend to use deuterium, helium or tritium. However, the so-called CNO cycle, wherein carbon, nitrogen and oxygen are used as a catalyst for hydrogen fusion at a much higher rate than the standard proton-proton chain (a proton is a hydrogen nucleus), may solve this problem.

Starflight is a drag

Suppose we are one day able to construct a ramjet starship with an efficient fusion reactor and that we are able to locate a course filled with ionised hydrogen for it to fly through. It won't be plain sailing because, now that we are underway, another problem rears its head to quite literally become a drag.

When charged particles are accelerated as they spiral in a magnetic field like that of a ramscoop, they emit radiation (anything from microwaves to gamma-rays, and is known as either cyclotron or synchrotron radiation depending upon the energies of the particles). As the radiation



A Bussard Ramjet-powered unmanned probe collects hydrogen fuel using a collosal magnetic field, and fuses it to provide thrust as it travels vast interstellar distances. Image: Adrian Mann www.bisbos.com

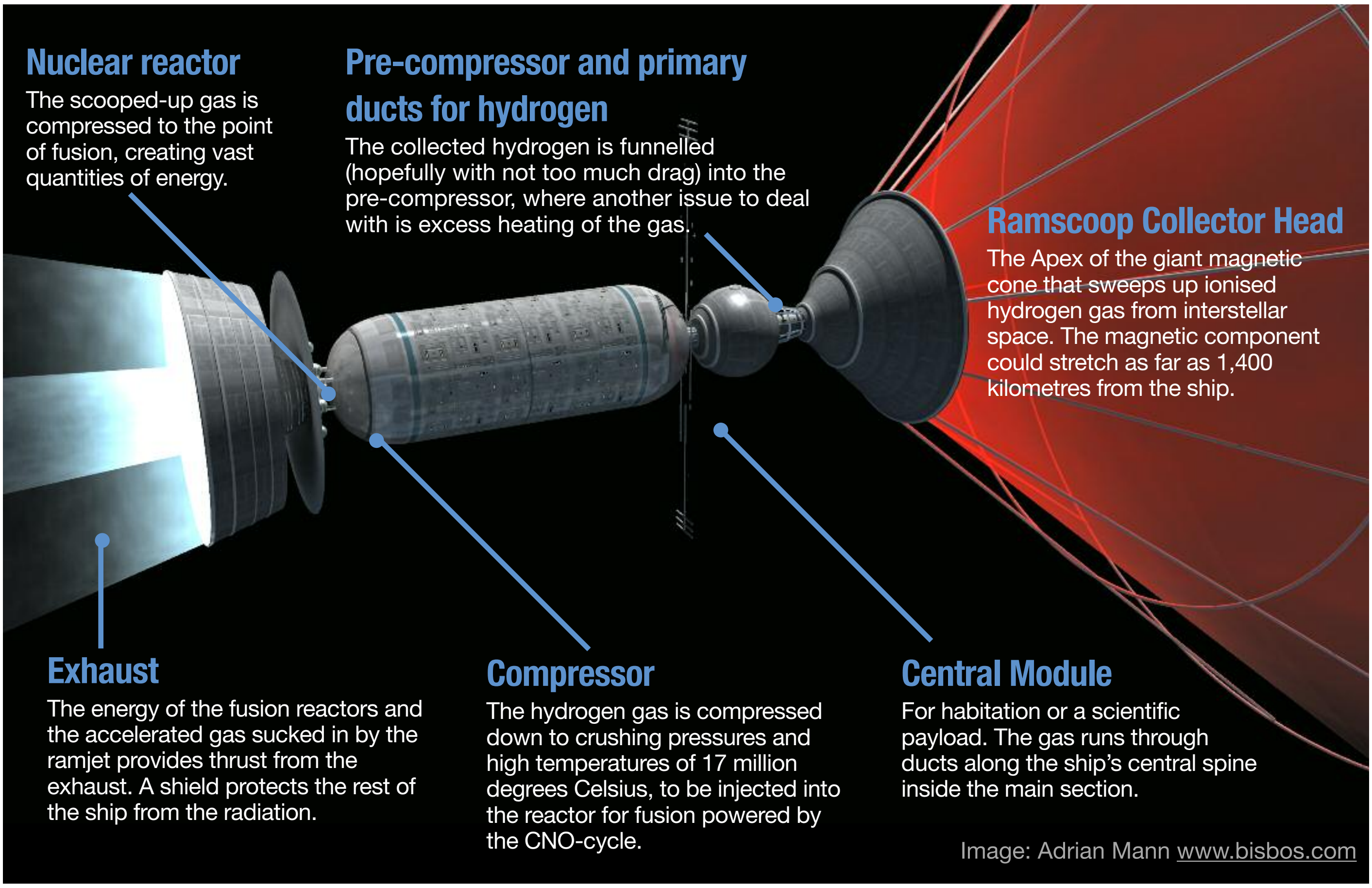
is released, it steals some of the momentum from the scoop, imparting a drag on the vessel that will hinder attempts to reach the highest velocities. To be truly successful any ramscoop design will therefore have to limit the spiralling motion of the charged particles as they are swept up by the magnetic scoop. Furthermore, as the magnetic field converges and begins to compress the gas to the point of fusion, the gas heats up and the thermal emission steals even more momentum. Consequently, ramjets will have a limiting velocity where the thrust and drag are balanced, because without drag a ramjet could, in theory, reach astonishing speeds up to 90 percent of the speed of light.

Such immense velocities would come about in the following way: as the ramjet accelerates, it scoops up gas at an ever increasing rate (assuming that the density of the interstellar medium is relatively uniform) and, as the velocity climbs ever closer to the speed of light, relativistic effects come into play. Length contraction – the effect that sees rulers decrease in length as witnessed by a traveller moving at high percentages of the speed of light – means that distances in space seem to become ever shorter from the point of view of the speeding starship, allowing the ramscoop to gobble up even more gas and consequently experience runaway acceleration. Although in practice this is never going to be possible, efforts to minimise drag will increase the performance of the ramjet and permit velocities to a decent fraction of the speed of light.

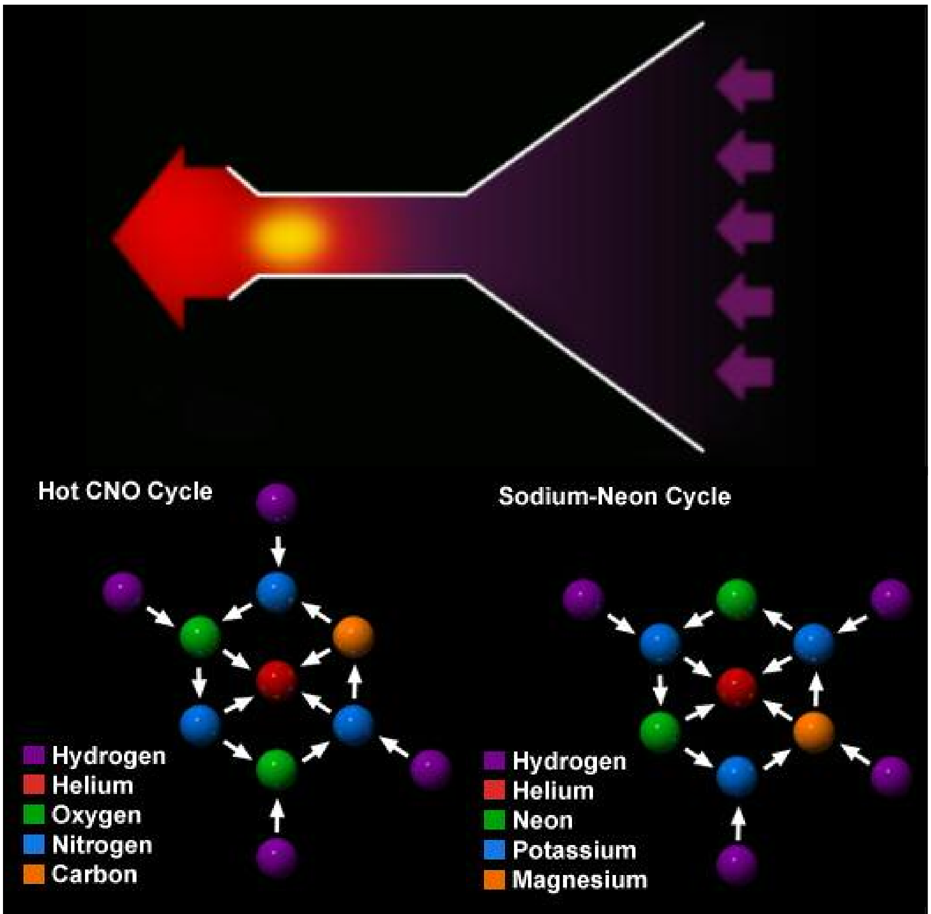
That, however, assumes that the hydrogen gas – in particular ionised hydrogen – is sprinkled liberally and uniformly across the cosmos. In truth it appears patchy, although we certainly haven't been able to fully map it. A starship with a ramscoop that passes through one of the more rarefied voids could risk stalling and the loss of power could result in the starship shutting down. NASA's Interstellar Boundary Explorer (IBEX), an Earth orbiting, particle-detecting satellite, measures particles entering our Solar System from beyond, sampling hydrogen, helium, oxygen and neon amongst other gases. From this IBEX has been able to produce a map of the interstellar medium for a few light years around the Sun. It shows that the Solar System as a whole is currently inside a tenuous hydrogen cloud nicknamed the 'Local Cloud', but that we are close to its edge and will pass over into a void in a few hundred years. A ramscoop starship leaving the Solar System during that time won't find much gas to run on.

Parachutes

Let's say everything works flawlessly – enough interstellar gas is found, the drag is minimised, and the engine works efficiently. Once the ship reaches its destination, how does it stop? Switching off the engine won't help because the vessel will have built up enough velocity that it will just coast through its target system unless something else intervenes. Here again, however, we can illustrate the magic of the ramscoop. All the while throughout the journey it has been attracting the positively charged protons of ionised hydrogen; just switch the polarity and all of a sudden it deflects those self same particles, in the process shutting down the engine. Again, this exerts a drag, but when you're wanting to slow down, that's a very good thing. For an analogy think of the drag as like a parachute and the ship as aerobraking. It won't bring the ship to a complete halt, for as the velocity decreases the usefulness of the ramscoop also decreases, but it will slow things down enough for some sort of retro-rocket to work, perhaps by rotating the ship and then firing the main engine (using stored fuel – remember the ramscoop is no longer operational at this stage) in the opposite direction of travel.



Bussard himself wasn't blind to the challenges. In his famous paper of 1960 he wrote, "The engineering effort required for the achievement of successful short-time interstellar flight will likely be as much greater than that involved in interplanetary flight as the latter is more difficult than travel on the surface of the Earth." However, Bussard's paper came only three years after Sputnik 1 and with still a year to go before Yuri Gagarin's name became immortal; only four years earlier, Astronomer Royal Richard Woolley had decried space travel as being far too expensive, describing it as "utter bilge." And yet here we are – we've landed on the Moon, sent probes to the distant corners of the Solar System and slowly but surely begun to populate Earth-orbit. While space travel is not yet as pedestrian as travel over land, and will likely take some time to reach that stage, the opening of the space lanes to private industries (see the *Advances* section this issue) will surely set us down that path. As I4IS undertakes a project to research the history, physics and engineering of the Bussard ramjet, in an attempt to identify potential solutions to some of the obstacles to using the the interstellar medium itself to venture across the cosmos, we will take our first steps down that path to the stars.

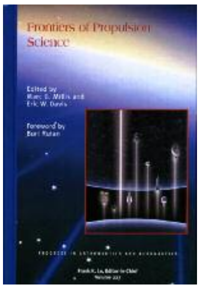


Hydrogen scooped from the interstellar medium by a vast magnetic field created by the vehicle undergoes cyclic reaction in a fusion reactor to convert four hydrogen atoms into one helium atom, releasing energy in the process. Two possible cycles are illustrated here although neither is yet possible using known technology. In each case the 'catalyst' atoms remain in the reaction to repeat the process.

Reviews

Frontiers of Propulsion Science

Editors: Marc G Millis and Eric W Davis



Ramscoops, nuclear fusion, microwave beaming – these are all considered ‘conventional’ forms of spacecraft propulsion despite none having got off the drawing board yet. The difference between, say, the Bussard ramjet and the Alcubierre warp drive, however, is that no new physics has to be discovered to make the ramjet a reality, whereas the warp drive currently only exists on the tentative fringes of our scientific knowledge.

It’s the gaps in our knowledge at the bleeding edge of physics that this book aims to start trying to plug. It’s a hefty tome, split into 22 chapters across five areas: ‘Understanding the Problem’, ‘Propulsion Without Rockets’, ‘Faster-Than-Light Travel’, ‘Energy Considerations’ and a concluding ‘From This Point Forward’.

Readers should be forewarned that the treatises inside this book are highly technical and often at graduate level, but for those with a technical background and an interest in advanced propulsion this is an essential book.

The editors are world-leading researchers in advanced propulsion. Eric Davis is a physicist at the Institute for Advanced Studies at Austin and a former contributor and consultant to NASA’s Breakthrough Propulsion Physics Project. Meanwhile, Marc Millis is the founder of the Tau Zero Foundation and led the Breakthrough Propulsion Physics Project at NASA's Glenn Research Center between 1996 and 2002, and many of the essays within this book are based on work conducted during that time, in such esoteric topics as the Casimir effect, anti-gravity effects from superconductors, the Alcubierre warp drive, quantum entanglement, zero point energy, Mach’s Principle, tachyons and wormholes.

A forward from X-Prize winner Burt Rutan kicks things off, swiftly followed by Robert Frisbee’s superb look at how far conventional propulsion can be taken before unconventional theories are required to take things to the next, relativistic level. Things could easily get out of hand, with wild claims and fanciful science, but the editors should be given credit for keeping things on the ground and not being afraid to describe experimental failures or null results, or explaining where previously established physical principles have been misunderstood in unfamiliar settings. The editors and authors hope to show that we can learn something from these failures and misunderstandings in order to focus future research.

As a primer on this speculative but pioneering field, *Frontiers of Propulsion Science* really does the topic justice. Book-ended by highly readable pieces on the history of advanced propulsion research by Centauri Dreams' Paul Gilster and how we should approach the subject in the future by Millis, the concepts discussed within really make the reader think that perhaps interstellar travel will be possible one day.

Publisher: American Institute of Aeronautics and Astronautics

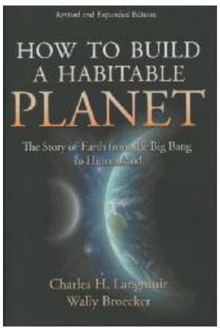
ISBN: 978-1-56347-956-4

Price: £94.50 (Hb) 739pp

Find this book on Amazon via our Interstellar Index website.

How To Build A Habitable Planet

Authors: Charles H Langmuir and Wally Broecker



If the Solar System was unique and our eight worlds and accompanying dwarf planets were the only planets in the Universe, would we yearn as greatly as we do to take that interstellar leap? Fortunately, it’s a moot point; with over 860 exoplanets discovered, thousands more candidates identified and billions more suspected, we’ve got destinations a plenty to go to. More uncertain is the number of habitable planets, but if we can understand why Earth is habitable, perhaps we can better understand what the chances are for other habitable (as we know the term) worlds.

Consequently this book is the story of our planet, from its formation, through the evolution of the land, sea and atmosphere, and the properties and feedback cycles that permit conditions for life. It’s actually the second edition of this title, substantially revised and expanded from its first edition in 1984, when it was written solely by Earth scientist Wally Broecker of Columbia University. For the second edition Broecker is joined by Harvard’s Charles Langmuir and together they make a formidable team, for this is the definitive tome on the evolution of our planet.

They start at the beginning – the very beginning with the big bang – and describe how the elements that built our planet came into being, followed by the formation of the Solar System. It’s a complex, weaving narrative that develops towards explaining the processes that make Earth habitable, as authors’ expertise really comes to the fore. One eye-catching facet is the importance of plate tectonics on maintaining Earth’s habitability, helping to regulate climate and recycle carbon and indeed, several chapters are devoted to tectonics.

Towards the end of the book, Langmuir and Broecker determine that we have now entered the Anthropozoic era, where human actions are shaping the destiny of our planet and, in many cases, are having a deleterious effect. The authors offer hope by suggesting ways that we can reverse the ecological and environmental damage, but if we cannot then perhaps humanity’s only hope will lie in colonising other planets. So while *How to Build a Habitable Planet* is Earth’s story, we may discover one day that it could also be another planet’s story, one that provides safe haven for those of us who may venture to the stars.

Publisher: Princeton University Press

ISBN: 978-0-691-14006-3

Price: £27.95 (Hb) 718pp

Find this book on Amazon via our Interstellar Index website.

Mission Statement

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

Vision Statement

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 Statement

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.

The Carina Nebula, imaged by the VLT Survey Telescope at the European Southern Observatory in Chile. Image: ESO.

We'd love to hear from you, our readers, about your thoughts on Principium, the Institute or interstellar flight in general.

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