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PRINCIPIUM

The Newsletter of the Initiative for Interstellar Studies

Issue 13 | May 2016

www.i4is.org

Scientia ad sidera
Knowledge to the stars

Editorial

Our Guest Introduction is by Kieran Twaites, a student in year 9 at Reigate Grammar School, UK. His thesis is "Warp drive is possible". Kieran has been interested in Interstellar Studies since 2012 when he was 10 years old. And he's been studying well beyond the school curriculum, as you will see.

Interstellar News this time reports on the latest Tennessee Valley Interstellar Workshop (TVIW), the last few weeks of the Cosmonauts at the London Science Museum and perhaps the biggest news of the year 2016, Project Starshot. We also report new work of interstellar interest by both our own team and others and welcome new volunteers helping i4is do a better job of advancing the Interstellar cause.

Our big feature this month is a meditation, both positive and negative, on the prospects for human interstellar flight, titled the *1,000 Year Starship*. Stephen Ashworth is a well known commentator on matters interstellar. He has written numerous papers for the Journal of the British Interplanetary Society. His blog at www.astronist.co.uk is usually thought-provoking, often controversial and always readable.

In this issue, I conclude my own musings on reaching the stars as Digital Persons, *Sending ourselves to the stars?* Looking at the philosophy of Other Minds and wrapping up with some of the most thought-provoking ideas in this area from SF writers.

Our i4is team member, Terry Regan, has now completed his 1:450 scale model of the BIS Daedalus starship design. This time we have a photographic taster, ahead of the formal unveiling of the model at the BIS Charterhouse conference later this year.

As regular readers will know, Daedalus was the first major design study for an interstellar spacecraft. Its successor, *Project Icarus*, is a cooperative project of the BIS and our friends in Icarus Interstellar. In this issue we feature an introduction to this work by Peter Milne, BIS, and Rob Swinney, i4is.

The front cover illustration this month is by our old friend, artist and musician Alex Storer. It is a modern visualisation of an Enzmann starship, *Demesne*.

Here is a vision of this vessel from Alex's website www.thelightdream.net, quoted with the permission of its writer Richard Hayes -

A vast spaceship stands out against the infinity of the interstellar void. It has the distinctive design of an Enzmann starship, the huge front globe holding the deuterium propellant that powers its nuclear fusion drive, with living quarters extending behind. Many lighted windows show that it is crewed, and several generations may live and die on board before it reaches its destination. Its name stands out proudly – Demesne – and it might indeed be the sole domain of these travellers for many years, possibly even centuries.

The engines of this spectacular craft achieve speeds to a significant percentage of the speed of light, but they are now silent. We think that it might have already achieved its cruising velocity, except for the existence of a smaller spacecraft which is approaching under power – such a hazardous transfer is unlikely during the voyage. No, this starship is stationary, probably before the start of its journey.

We question the purpose of the coming rendezvous between these vessels. A portal is opening in the side of the starship, so the smaller craft is welcome. Perhaps the final members of the crew are arriving before their epic voyage begins, anticipating the challenge of what awaits them – and their descendants.

And with lasers so much in our thoughts we have a beautiful laser spectrum diagram for our rear cover,

John I Davies, Editor, Principium
john.davies@i4is.org

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Join in the conversation by following the i4is on our Facebook page www.facebook.com/InterstellarInstitute

You can also become part of our professional network on LinkedIn www.linkedin.com/groups/4640147

And take a look at the i4is blog, The Starship Log www.i4is.org/the-starship-log

Follow us on Twitter at @I4Interstellar

And seek out our followers too!

Contact us on email via info@i4is.org.

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

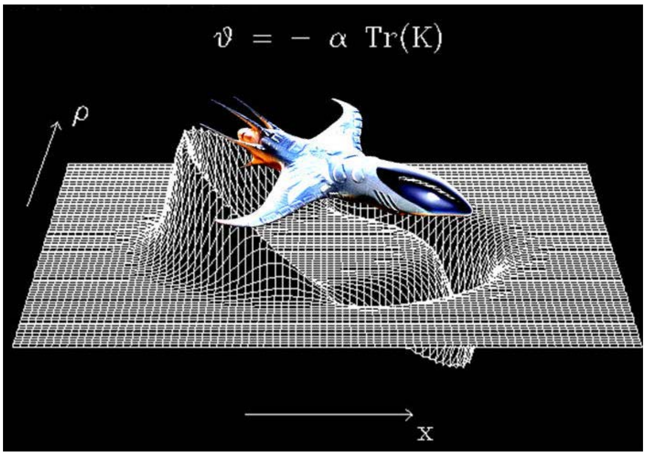
INTRODUCTION Kieran Twaites

Warp drive is possible

If you'd like to know how then please read on…

There have been many apparently unbreakable barriers that we have crossed. They said Man could not fly but the Wright brothers built the first aircraft. They said the sound barrier could not be broken, we built supersonic and even passenger jets that do it. We set ourselves the target of landing a man on the Moon and returning safely. Travelling faster than light is just the next of these "impossible" barriers to be breached.

How will this be done? Please read on to find out.



1) How an Alcubierre drive would work

Everyone's seen Star Trek, when Captain Kirk says to Sulu 'warp factor 9', and the Enterprise goes zipping across the Galaxy, but how much fact is there in this fiction? The most popular and widely accepted warp drive mechanism is something known as an Alcubierre drive, named after the scientist who first theorised it, Miguel Alcubierre. Simply put, space time in front of the star ship is compressed, and space time behind it is expanded a bit like an escalator. It works because the star ship itself is not moving, it is merely the space time it is sitting on is moving. All the Physics works, and the Maths is sound, however there is one problem I've always had with this theory; the energy required is enormous, not just in normal energy, but also in negative energy, a substance that has opposite properties to normal matter (note: this is not to be confused with antimatter; which simply has a negative charge to their corresponding particles in the standard model of particle physics, as far as we know so far), such as being repelled by a gravitational field rather than attracted to a gravitational field, and travelling away from an object when it is attracted to it. This produces a negative energy density around the spacecraft, which prevents the whole thing from collapsing into a black hole. We have created extremely small quantities of what we think to be negative

My name is Kieran Twaites. I am 14, mad keen on Cosmology, Quantum and Temporal Mechanics, and hope in the future to change the way we look at space, time, and the inner workings of the Cosmos.

I have been a member of i4is for 4 years and first became involved when I met Kelvin F Long, Executive Director of i4is, at the Starfest astronomy convention in 2012. Although I was only 10 years old at the time, I had many burning questions about liquefaction of space time and interstellar travel. Kelvin was very gracious and patient, answering all my questions, however daft they must have seemed to him. He then set me some questions about travel times to Pluto using different forms of propulsion.

Kelvin kindly gave me a copy of his book entitled "Deep Space Propulsion" and we kept in touch by email. He continued to answer my questions as kindly as ever and we discussed my new thoughts on faster than light propulsion, most of which included science which was very much unproved at the time, such as the Higgs field or negative matter.

I was invited to join i4is by Kelvin and jumped at the chance to get more involved. This led to me being asked to take the Interstellar Minimum paper last year. It was very difficult with many new concepts for me to grasp. Kelvin's book was an invaluable guide and I was lucky enough to pass the exam and was awarded my certificate by Rob Swinney at Starfest 2015.

I try to keep up with all the latest developments and discoveries in Science. I regularly attend lectures at both the Royal Institution and Royal Society and have been lucky enough to chat with many eminent leading scientists. They, like Kelvin, have taken all my questions seriously and given fantastic answers. These people, of which there are far too many to list, have inspired me to seek a career in Quantum Mechanics, Cosmology, and interstellar travel. I am very focused and driven in my desire to succeed in everything I attempt. Who knows what I can achieve with the help of others for the benefit of mankind?

matter in the lab using something called the Casimir effect, where 2 plates are drawn together by a larger pressure outside (created by quantum fluctuations, where matter – antimatter pairs are created and destroyed) on the plates than between them, forming a negative pressure between the plates, and there is other evidence to suggest the existence of negative energy up in the cosmos. Dark energy is a mysterious repulsive force that is sending all the galaxies in the universe away from each other. If this ‘dark energy’ does turn out to be negative energy, it would outweigh normal matter 14 : 1. To propel an adequately sized star ship for human travel, we are supposed to find the equivalent negative energy as the mass of Jupiter, which doesn’t sound too bad, however you can’t exactly just ‘scoop’ it up, and it is extremely difficult to manufacture in any sort of quantity.

So it seems then that if we want to achieve Gene Roddenberry's dream of having warp drive by 2063, we might have to take a look at some other options.

Tachyons are theoretical particles outside of the standard model that travel faster than the speed of light. These act in a rather odd sort of way, as they accelerate, they approach the speed of light, slowing down, and also gain energy as our personal time moves forward. This is made possible by their imaginary mass. But how can a mass be only imaginary?

To travel faster than the speed of light, a tachyon’s squared mass $m^2 < 0$. This indeed appears to be the case, as the tachyon’s energy has to be real, and-

$$E = \frac{mc^2}{\sqrt{1-\frac{v^2}{c^2}}}.$$

When a particle travels faster than the speed of light, the denominator must be the square root of a negative number, so it is imaginary. To balance the equation and make the energy real, the numerator must also be imaginary. Travelling faster than the speed of light has very strange effects, such as gaining energy as time passes (from the point of view of the observer). This is because as you approach the speed of light, your personal time slows down. To help explain this I’m afraid I’m going to have to use another equation $dx+dy+dz+dt=c$. This means that if I am not moving in any of the 3 spatial dimensions (i.e. standing still), I am travelling through time at 186,282 miles per second (c). However if I then start running at 1 mile per second (and yes, I know that’s probably not physically or biologically possible, but please suspend your disbelief for this bit), to balance out the equation, I would then travel through time at 186,281 miles per second, -

$$c - 1\frac{mi}{s}$$

- and so on. So logically, if your speed in the 3 spatial dimensions exceeds the speed of light, your speed through time must be negative to balance the equation. But doesn't this gaining energy and things that tachyons do sound like what negative matter would do? How is imaginary mass different from negative mass? Well, it’s not all that different, imaginary mass is just negative mass squared.

So what if you could use these particles to exceed the speed of light yourself? Unfortunately for us, probably not, as -

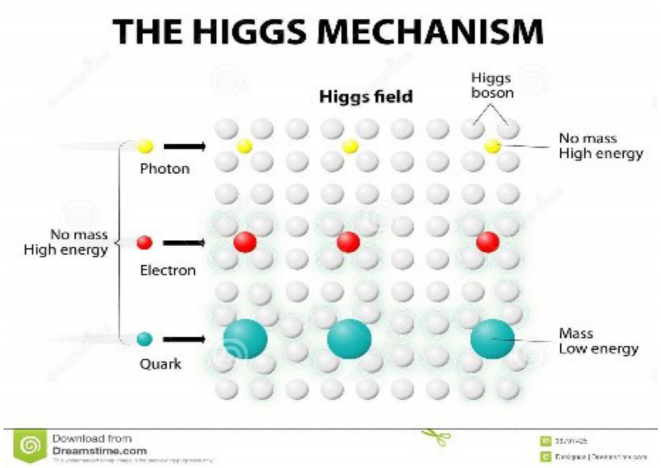
a) we’ve never found any proof for their existence, and most scientists don’t think they exist at all, and

b) a substance that has imaginary mass is very unstable, and is commonly called an ‘instability’ rather than a particle. So it seems then that we might have to forget negative mass altogether.

In 2012, the Higgs Boson was discovered at the LHC (Large Hadron Collider) in Geneva Switzerland. As Peter Higgs proved, this new particle gives other particles mass by having them pass through a field known as the ‘Higgs Field’.

This got me thinking ‘if a photon, which has no mass, can travel at the speed of light, then why not just take away the Higgs Field from around the space craft?’ I later discovered that this would fail for two important reasons.

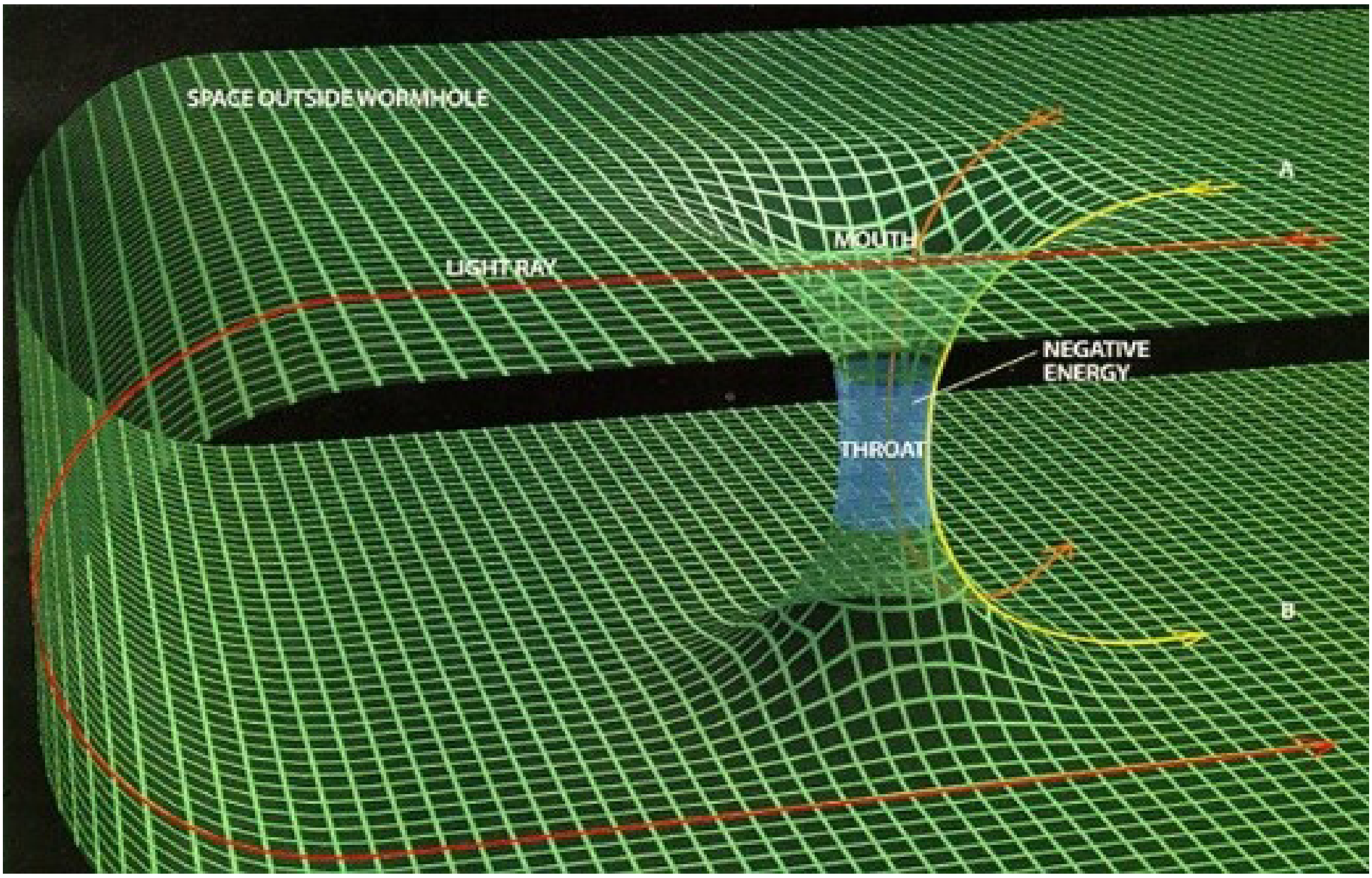
1) Thinking that I was onto something, a couple of years ago I attended the Cheltenham Science festival, where Peter Higgs himself was present. Knowing that putting matter and antimatter together resulted in a total conversion from mass into energy, I thought that if you could somehow surround the ship in an anti-Higgs field, the result



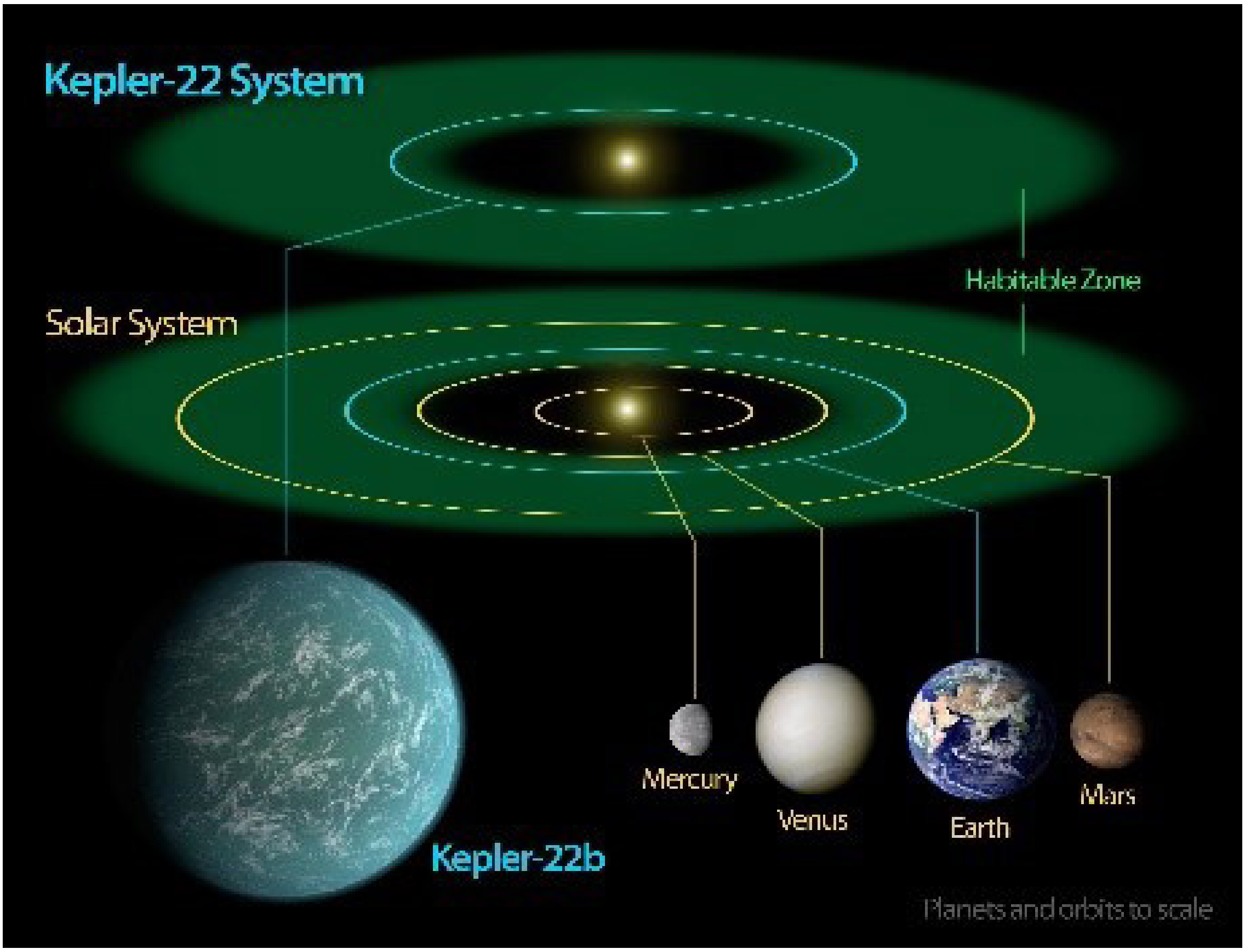
2) Analogy for the Higgs Mechanism Credit: [www.dreams-time.com](http://www.dreamstime.com)

would be an eradication of the Higgs Field surrounding the ship, allowing it to travel at speeds greater than c. However on asking Prof. Higgs, he explained to me that the Higgs Boson is its own anti particle, a fact I didn't fully appreciate at the time. But there is another reason why this would be more 'come and spend your life in the void of space' than Star Trek.

2) And it is a simple one. Even if we could find a way to shield a spacecraft from the effects of the Higgs Field, we would still only be able to travel at the speed of light. At first glance, this doesn't seem like much of an issue, but even with this immense speed, it would still take 6 years to get to Sirius, and 600 years to reach Kepler 22b, one of the most Earth-like planets ever found.
So then, yet again, it seems we might have to forget Quantum Mechanics, and move on to the (slightly) more normal realms of General Relativity.
In 1905, Albert Einstein gave us Special Relativity, and, 10 years later, General Relativity. These two theories completely revolutionised our understanding of the Universe. From explaining Mercury's weird orbital path to foreseeing time dilation effects in satellite-operated GPS systems, relativity solved everything. However it was this which gave us the cosmic speed limit of c, and it all comes down to light travelling faster than itself. What?! Let me explain.
Imagine I am driving a car at relativistic speeds (say, 99% of c - and yes, I know you'll have to suspend your disbelief here again, but please bear with me), and I flash my headlights. Since light has no mass, it can travel at c, but no faster. At normal speeds, velocities just add. For example if I threw a tennis ball at 10mph out of a car straight travelling at 70mph, the tennis ball would be travelling at 80mph. However, in the headlight analogy, $c+(v<c)=(v>c)$. In other words, the light coming out of the headlights would be travelling at speeds greater than the speed of light, impossible! Therefore, the speed of light must be constant. Do you remember $dx+dy+dz+dt=c$? This is why time is affected by motion: because c cannot be altered.
A couple of years ago, I had a sudden flash of inspiration whilst (predictably) waiting for a science lesson to begin. I went off the idea of the Alcubierre drive. I thought 'if it takes too much energy to bend and warp space, why can't you just rip straight through it to get to where you want to go?' I thought this was a fantastic idea at the time, for the following reasons -



4) 3d representation of a Wormhole. Credit: Jean-Pierre Luminet & shutterstock.com



3) Comparison of Kepler 22b and Earth, credit: NASA/Ames/JPL-Caltech

1) In theory, you could travel at infinite velocity, as if you are ripping through space time you aren't actually travelling through space time and therefore not travelling through time, so you are travelling a finite distance in no time.

2) Even though this would require masses of energy, it would require no negative matter, as this is basically what black holes do and they only use 8.897676269494494636 x10^36 MJ (OK, so it's a fair amount, but that's beside the point)

However, as usual, there is a fundamental problem with this: gravity is simply a 'well' in the fabric of space time. However, with a black hole, because over the event horizon it has infinite gravity, it has an infinitely long well, so it's plausible that black holes must 'rip' space time. This is where our knowledge of black holes ends; beyond here is theory and speculation. As you are, in effect, travelling inside a black hole here, we have literally no idea what would happen to the spacecraft other than it would probably be quite unpleasant.

In 1935, Einstein teamed up with Nathan Rosen to come up with a theory to apply general relativity to electrons. The resulting paper "accidentally" showed how to link either 2 black holes or 1 black hole and 1 white hole (even though they had no interest in black holes, but, still). A white hole is simply the opposite of a black hole. In geometric terms, if a black hole is compressing space, a white hole is expanding it. An Einstein-Rosen bridge is basically just a tunnel joining these points together.

So what we're really making is a black hole. So beyond the event horizon it has infinite gravity. At this point nothing, not even light, can escape. For anything unfortunate enough to have mass, a process known as spaghettification occurs, where each individual atom of the object is prised apart from one another, slowly falling into the black abyss. So then, not a good way for a maiden flight to end.

It was looking bleak, but in the November 2014 issue of the BIS monthly newsletter "*Spaceflight*", there was an article entitled "*The Tachyon World*". This got me rather excited, and began to read. But there was one paragraph that stood out above all the rest:

> *"Then at this point, an object no longer has a limit, it has no more need to accelerate or decelerate. It is now, without inertia but 370,000 times the speed of light, in a non-inertial state relative to our side of the 'universe', without mass or even momentum, on the other side of the grand Event Horizon, in reverse time. It is a Tachyon Particle and is thus tunnelling. At this velocity, now unmeasurable and unobservable to us, it has travelled 100 light years in under 2.5 hours and is 100 years in the past."(*5)

Summarised, the article is investigating the idea that our observable universe might just be one layer of a much larger picture, and that there may be other Universes out there where particles are superluminal, and time travels backwards.

However, as always, there is a problem: even if you could find a way to traverse into this alternate reality, you would be going backwards in time, and then if you tried to then get back to this side of the pond, you'd encounter all kinds of causality problems. So not the best solution, and I certainly don't think we'll be able to achieve this by Gene Roddenberry's deadline of 5th April, 2063

But at least it does show us that there are limitless options to bending the rules of the universe, some of which only have technological issues, others of which have more fundamental flaws. I hope this has inspired you to look at the Universe in a new light, so next time you look up at a star just wonder "will we get there?"

Image and Quotation References:

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3. Dr Tony Philips (2016). Kepler-22b. Available: en.wikipedia.org/wiki/Kepler-22b Last accessed 7th Feb 2016.
4. Credit: Jean-Pierre Luminet & shutterstock.com.
5. Robert B Cronkhite. The Tachyon World. BIS Spaceflight Vol 56 No 11 November 2014.

Kieran Twaites receiving his certificate of completion of the Interstellar Minimum paper from Rob Swinney, Deputy Director of i4is, credit:i4is

About the Author

Kieran Twaites is a student in year 9 at Reigate Grammar School, Surrey, UK. He is currently studying Physics, Chemistry, Biology, Maths, Statistics, English Language, English Literature, Computing, Product Design, Geography and Latin at IGCSE level and aims to study Maths, Physics, Chemistry and Computing at A-level, before moving on to university to complete a first degree in Physics. He envisages a career in Theoretical Physics, Cosmology or Interstellar science / technology. He successfully completed the i4is Interstellar Minimum paper in 2015. He is the youngest person, by some margin, to achieve this so far.

Interstellar News

John Davies with the latest interstellar-related news.

Project Starshot

As you may have noticed, the Breakthrough Initiative recently announced Project Starshot (breakthroughinitiatives.org/News/4). This is a $100 million research and engineering programme that aims to develop a proof of concept for light beam-powered nanocraft and laying the foundations for an eventual launch to Alpha Centauri within a generation. Under the leadership of -

- Yuri Milner
- Stephen Hawking
- Pete Worden

- we expect great things in the fairly near future! i4is was involved in Project Starshot before the announcement and three i4is people are on the Management and Advisory Committee of the Project -

- Freeman Dyson, FRS, a member of our own Advisory Committee
- Kelvin F Long, our Executive Director,
- Greg Matloff, chair of our Advisory Committee

Our old friend Paul Gilster has summed up the importance of this -

> *Breakthrough Starshot is an instrumented flyby of Alpha Centauri with an exceedingly short time-frame.*
> *Milner is putting $100 million into the mission concept, an amount that dwarfs what any individual, corporation or government has ever put into interstellar research. A discipline that has largely been the domain of specialist conferences — and in the scheme of things, not many of those — now moves into a research enterprise with serious backing.*

More at www.centauri-dreams.org/?p=35402

There will, of course, be more about Project Starshot in future issues of Principium.

TVIW 2016 - left to right - Kelvin F Long (i4is), Robert Kennedy (TVIW Chair), Angelo Genovese (i4is), Stefan Zeidler (i4is), and Rob Swinney (i4is) at the Chattanooga ChooChoo hotel

TVIW

Perhaps the most established of those "specialist conferences" Paul Gilster mentions is the Tennessee Valley Interstellar Workshop (TVIW). The 2016 event took place in Chattanooga, Tennessee (28 Feb - 2 Mar) with the theme *From Iron Horse to Worldship: Becoming an Interstellar Civilization* and a wide ranging agenda, *www.tviw.us/tviw-2016-agenda*. Many of the most prominent researchers in our subject were present, as usual, and we will be looking at some of the papers in future issues of Principium.

Rob Swinney and Kelvin F Long of i4is were there and Kelvin gave the after-dinner speech. Other speakers included Lt. Gen. Steven Kwast (USAF), Jim Benford, Robert Kennedy, Eric Hughes, Bruce Wiegmann (NASA), Jason Cassibry, Gerald Cleaver, Al Jackson, Rex Ridenoure, Philip Lubin, John Lewis, Ken Roy, James Schwartz and Cameron Smith - plus our own Greg Matloff and Angelo Genovese - and I haven't mentioned the parallel tracks! More in the TVIW newsletter, *Have Starship, Will Travel* (www.tviw.us/sites/tviw.us/files/TVIW_Newsletter_N09_Compressed.pdf).

Rob and Kelvin also visited JPL, NASA Ames, the Planetary Society, visited Griffith Observatory and the City University New York as part of their US tour.

It's been a long time...

The Cosmonauts exhibition at the London Science Museum ended in March. The reminders of what was achieved in human spaceflight in the 1960s by Soviet cosmonauts and engineers, closely

Tsiolkovsky 1911 quotation from Cosmonauts exhibition

The exhibits were striking but perhaps the spirit was best conveyed by a quote covering a wall at the exit
Source: Science Museum, Picture: John I Davies

followed by US counterparts, were contrasted with our more recent steady but slower progress by Stephen Ashworth. Stephen contributes elsewhere to this issue but a recent post by him, *55 years of men and women in space* reminds us that the first human in Earth orbit now dates back before many living memories. His survey produces some sobering conclusions. Most strikingly - *since the retirement of the Shuttle the numbers flying to space annually have been extremely low, less than a quarter of their 1985 peak* just before the Challenger disaster. More at www.astronist.co.uk/astro_ev/2016/ae124.shtml

Some notable recent papers

Andreas Hein, Deputy Director, i4is, working with Nikolaos Perakis of Technical University of Munich (TUM) have published *Combining Magnetic and Electric Sails for Interstellar Deceleration, Andreas Hein on Interstellar Deceleration* (hal.archives-ouvertes.fr/hal-01278907/document). Following on work by TUM as part of i4is Project Dragonfly they show that a magnetic sail is most effective at high velocities and an electric sail at lower velocities. If we wish to decelerate an interstellar probe, and thus study our target system at length, then this looks like an attractive combination.

We also noticed a fascinating piece by Swedish and American Astronomers *Terrestrial Planets Across Space And Time* (arxiv.org/pdf/1602.00690v1.pdf). It's a very detailed analysis of where we might expect terrestrial planets looking at star classes, galaxy types and the distorting effects of seeing the universe through what we might call "historical binoculars" given the finite speed of light.

i4is at the International Space University

The Initiative for Interstellar Studies delivered a 2-week elective to the students on the Masters of Space Studies course at the International Space University, Strasbourg, 2-13 May 2016. The course modules were delivered by Professor Chris Welch of the International Space University, Professor Ian Crawford of Birkbeck College, University of London and, from i4is, Robert Swinney, chair of our Eduction Committee, who organised the event and delivered several of the modules, Angelo Genovese, Andreas Hein, John I Davies, Kelvin F Long, Marc Casson, Sam Harrison and Stephen Ashworth. Several of our i4is contributors are from leading European companies and institutions. We aimed to broaden and deepen students' knowledge of starship design and technology. We also covered philosophical, social and economic issues in interstellar studies. We'll be reporting back in more detail from Strasbourg in the next issue.

Welcome to i4is

The i4is team has recently been joined by new volunteers who are helping with our support technology and our outreach. So please say hello to -

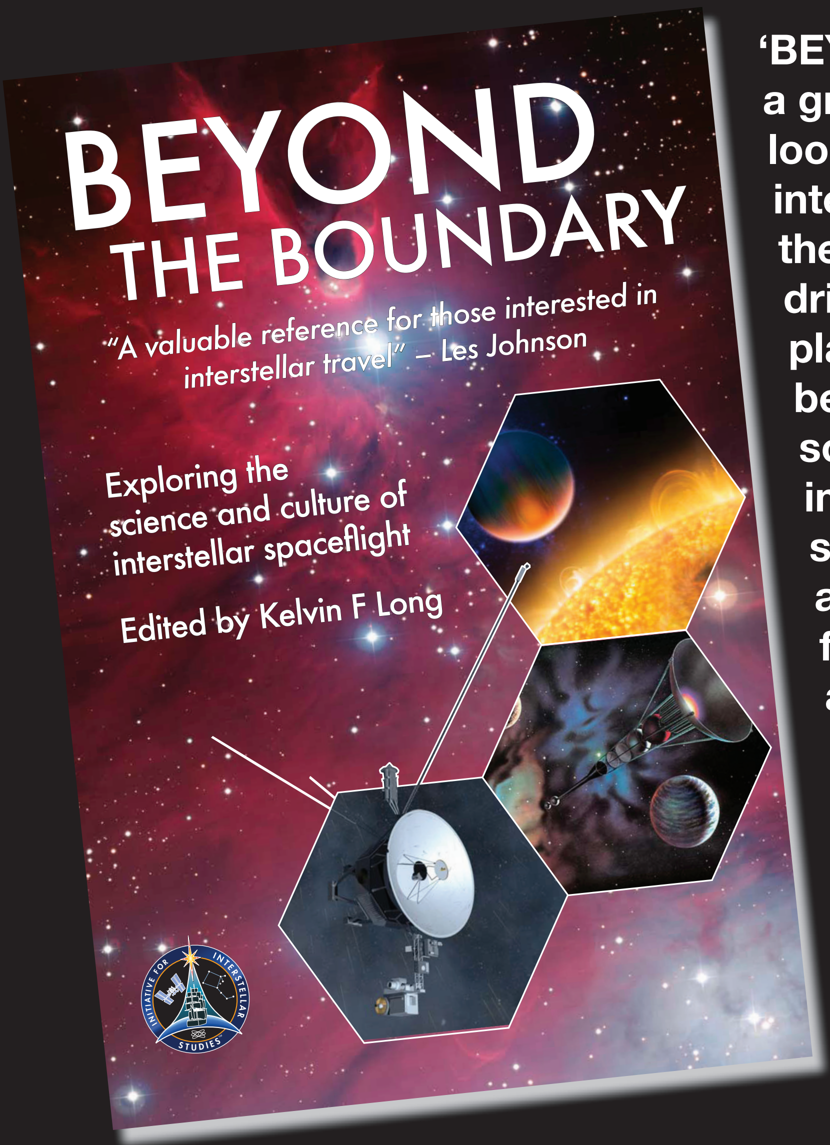
- Michael Grant, IT consultant and Project Manager
- Bill Skopelitis, Media Consultant
- Yannis Argyropoulos, Software Engineer

All are based in London, UK

The 21 students on the 2 week Interstellar elective at the International Space University, Strasbourg with Professor Chris Welch (black shirt), ISU, and Kelvin F Long (white shirt), i4is.

The Initiative for Interstellar Studies

presents



'BEYOND THE BOUNDARY' is a ground-breaking new book looking at the possibilities of interstellar flight, including the technology that will drive our starships, the planets and stars that will be our destinations, the sociological basis and impact of becoming a space-faring civilisation and how our interstellar future is depicted in art and culture.

- 448 pages, hardback edition
- Featuring 21 chapters written by i4is' interstellar experts
- Topics as diverse as propulsion technology, exoplanets, art and SETI

www.i4is.org

The completed model
Credit, model and image:
Terry Regan

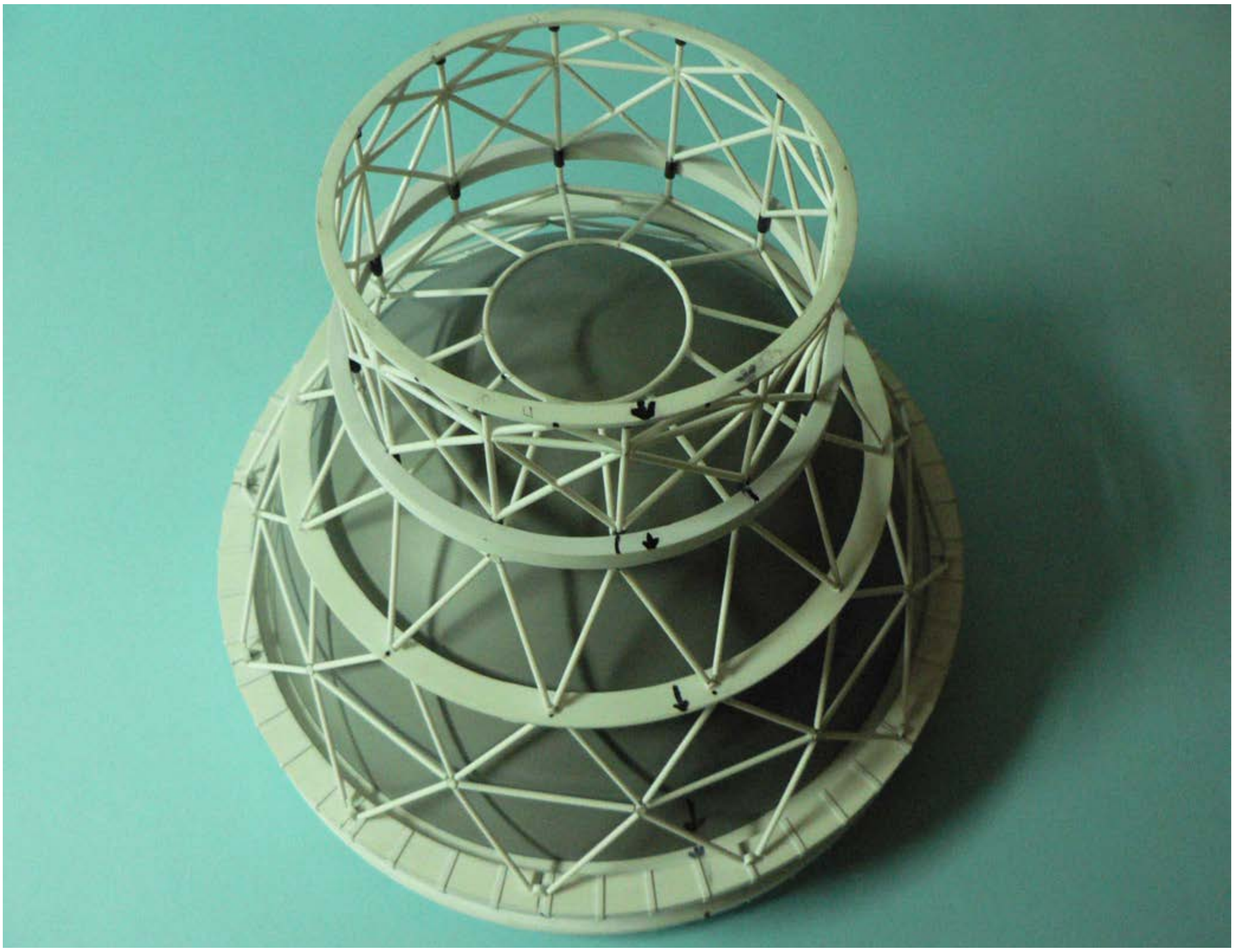
A scale model for BIS

John Davies presents pictures of the completed work.

Terry Regan, of the Initiative for Interstellar Studies and the British Interplanetary Society, has been working on this model of the craft, envisaged by a BIS team led by Alan Bond and Tony Martin, for a number of years. You may recall it on the BIS stand at the 2014 SF Worldcon. It's entirely scratch built and it's approximately 1:450 scale being 0.42m high versus the vessel itself, which would measure 190m from shield to the rim of the reaction chamber.

Terry will follow up this photo-feature which with a fuller account of the final stages of the work- complementing the piece you will find in Principium 8, on his early work and plans.

This really is a labour of love! We look forward to a formal unveiling at the BIS Charterhouse conference later this year, 21-23 July 2016.



Completed first stage support structure

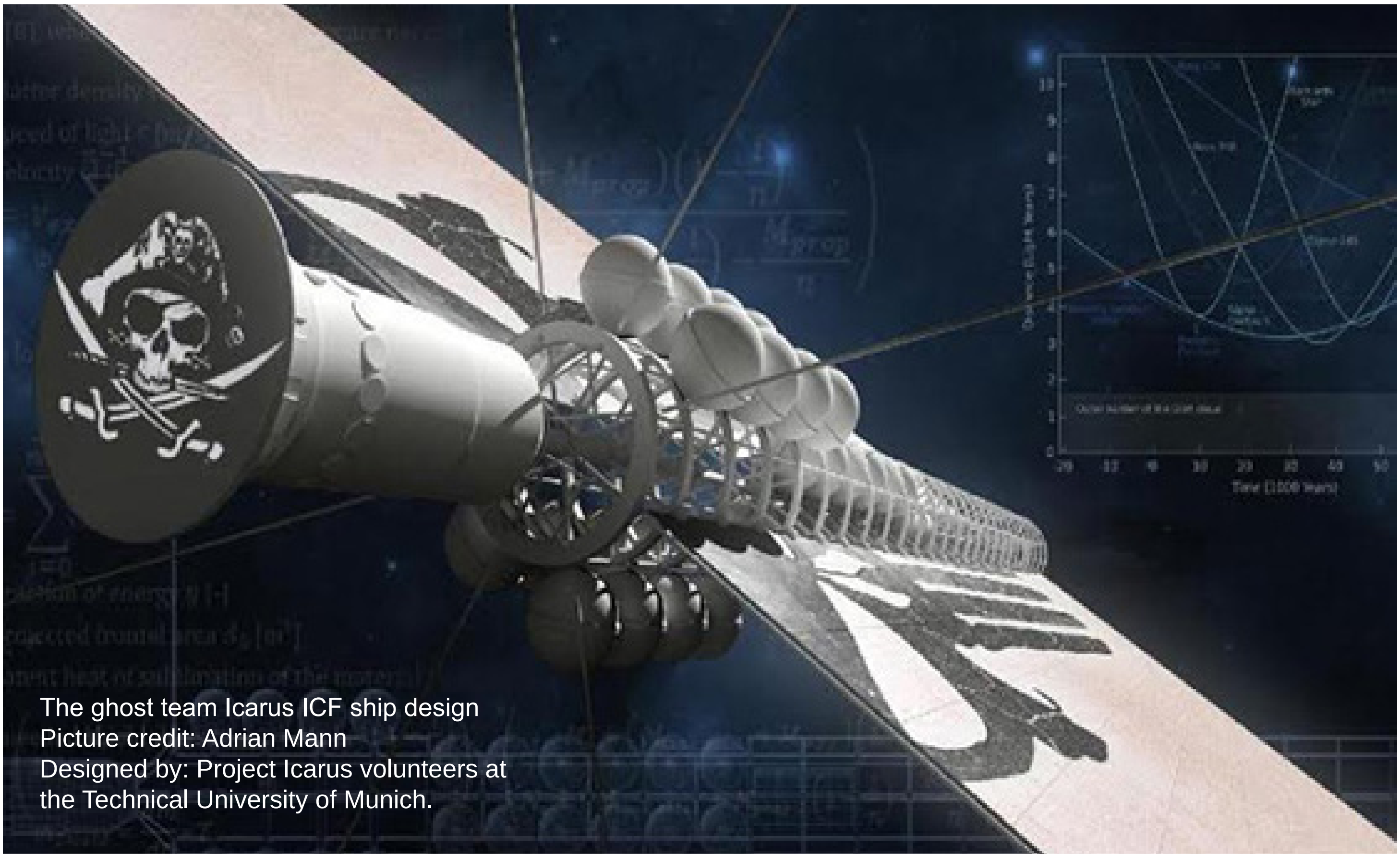
Construction of the first stage support structure

Second stage along side first stage to give size comparison

Full stack Daedalus with a good old English pint glass for scale

Project Icarus

Peter Milne & Robert Swinney outline this joint project of the British Interplanetary Society and Icarus Interstellar.



The ghost team Icarus ICF ship design
Picture credit: Adrian Mann
Designed by: Project Icarus volunteers at the Technical University of Munich.

As regular readers of Principium will know, the British Interplanetary Society (BIS) undertook a study into the design of an interstellar spacecraft in the 1970s, Project Daedalus. The Daedalus mission was a flyby of Barnard's Star, some 5.9 light years away from Earth. No deceleration was planned. The aim of the study was to show that, with then current technologies or reasonable extrapolation of near-future technologies, interstellar travel was feasible, and this was indeed accomplished. Daedalus is still thought of as the most comprehensive engineering design for an interstellar probe, although some weaknesses in the design were revealed later.

Project Icarus, now a collaboration between BIS and Icarus Interstellar in which a number of i4is members are also involved, was established to update the Daedalus concept after several decades of technological advance. The Daedalus propulsion system was based on Inertial Confinement Fusion, in which relativistic electron beams ignite cryogenic Deuterium and Helium-3 pellets, and the resultant plasma exhaust propels the vehicle, in two stages, to around 12% of the speed of light. Icarus does not advocate fusion as the only solution, or necessarily the most likely to achieve interstellar travel, but aimed to create a design that is feasible and credible using current or near-future technologies, and also to act as a comparison with the original Daedalus design. As a result, all Icarus designs are based on some form of fusion as the basis for propulsion.

Briefly, chemical, ion and plasma cannot conceivably meet the needs for interstellar travel, and antimatter drives are out of "near future" reach. Any sort of warp drive, or other faster than light technique, is seemingly beyond reality if not theoretical physics. Nuclear fission might be a precursor, or sails/beamed sails credible alternatives for small payloads. The advantage for fusion is that the high energy available permits a high exhaust velocity, which closely determines the achievable cruise velocity, and the physics is fairly well known.

A new target star system was selected for Project Icarus; Alpha Centauri. This star system is slightly closer to Earth, and is also more interesting scientifically as a binary system which may even include an exoplanet. A third star, Proxima Centauri, may also be bound to this star system, but at a large distance. Instead of a flyby mission, the Icarus spacecraft requirement is to decelerate and launch probes to explore the star system.

The original aim of Project Icarus was to complete the study by 2015, but several issues prevented this. Some results have already been published in the Journal of the British Interplanetary Society (JBIS), and further papers are anticipated through 2016, following a critical review of designs and papers undertaken at the end of February.

For the first few years, team members carried out significant research into various aspects of science and technology required for an interstellar probe. In 2013, we completed different Project Icarus concept designs, based on different fusion propulsion systems; Inertial Confinement Fusion (ICF), both laser ignited shock ignition and fast ignition variants; Z Pinch; ultra dense deuterium laser driven fusion; and Plasma Jet Magneto Inertial Fusion (PJMIF).

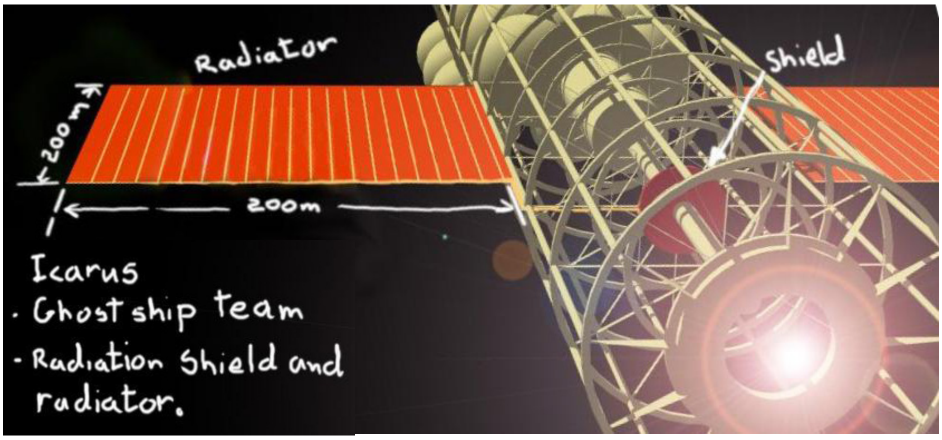
These design solutions are huge by normal standards, as was Daedalus, because of the fuel required and no apparent way to shrink the heavy fusion propulsion system and because of the cooling systems required to remove waste heat. All of the designs are hundreds of metres long with a mass of many thousands of tonnes, of which a significant proportion is the fusion fuel. The typical cruise speed is around 5% of the speed of light, which was well within that thought theoretically possible for fusion and partly because of the need to complete the journey in a “reasonable” time – set at 100 years to reach Alpha Centauri. Because of the inherently large propulsion system, Icarus can carry a significant payload of 150 tonnes, which includes the sub-probes, other scientific equipment to explore and study the three stars of this system and any potential planets and moons, and the materials to construct a large communications antenna to enable high data rate communications with Earth.

The project team continues to refine the designs, and papers describing four of them should be published soon. Indeed, an abridged version of the Z Pinch design, known as Firefly and primarily the work of Icarus Interstellar designers Robert Freedland and Michel Lamontagne, has already been published in a recent issue of JBIS (volume 68, number 3/4) in September 2015.

In general, the fusion technologies investigated by the project Icarus team suggest that it will be possible to make a 100 year journey to Alpha Centauri sometime in the near future, although still some decades away.

About the Authors:

Peter Milne is a Chartered Engineer and Chartered Physicist, and has worked in the satellite industry for over 40 years.
Robert Swinney is a Chartered Engineer and retired Squadron Leader from the Royal Air Force, where he was an Aerosystems Engineering Officer. Rob was one of the founders of the Initiative for Interstellar Studies, where he is now Deputy Director, Finance Director and Chair of the Educational Academy Committee. He is also a Director and Project Leader at Icarus Interstellar.
Both are Fellows of the British Interplanetary Society.



from "A Plumber’s Guide to Starships" (www.icarusinterstellar.org) showing the main elements of the cooling system.
Credit: Michel Lamontagne, Icarus Interstellar

Sending ourselves to the stars?

Sending our physical bodies to other worlds looks very difficult. Could a solution be to send our digital selves? John Davies considers more issues which arise from this proposition.

Resumption

In the February 2016 issue of Principium I introduced the concept of Artificial General Intelligence, as distinct from the specialised AIs which can drive cars or translate languages. Inspired by my i4is colleague Andreas Hein (Transcendence Going Interstellar, www.centauri-dreams.org/?p=30837), I explained both bottom-up routes to AGI, building artificial nervous systems, and top-down routes, simulating human behaviours. I finished with the highly speculative idea of developing an intelligence as "part of the family", perhaps by instrumenting a familiar childhood toy, a Teddy Bear. And another look at Turing's Mind paper (cited last time) reveals that he envisaged educating a "child computer", although he assumed it would not have arms and legs.....

In this second and concluding set of musings I discuss how we should treat Digital Persons, if and when they exist. I describe how Artificial General Intelligence (AGI) has had some "false dawns". And I wrap up with a mention of just a few of the more thoughtful examinations of the possibilities of AGI in science fiction.

The status of Digital Persons

One of the oldest problems in philosophy is the Other Minds problem[1]. What entitles us to our belief that other human beings have inner lives? A commonsensical (and philosophically respectable) view is that this is the best explanation of their behaviour. But some philosophers disagree and it may fail the refutability test[2] and thus be dismissed as "not science" by many.

Concentrating on the specific case of a transcendent or digital person - How can we know that such a transcendent "person" is a real person? If s/he is a real person (within whatever definition we choose to use) then are they the same person as the original biological person from whom they may have been derived? Even if we have managed to copy the original non-destructively, how can even the original human know that the copy is identical to him/her? Clearly any digital person starts immediately to have different experiences (that's the point if we are going to send her/him to the stars). Will it ever be certain that we have made a "good enough" copy? If we raise and educate a digital person, rather than copying or emulating an existing biological person, then how do determine their "personhood"? And with all that uncertainty, how will we feel that the human race has actually visited another stellar system?

But perhaps it's not unlike the knowledge that most Europeans had of the USA or Australia before the era of mass air travel. My cousin sailed to Australia in 1960 with her new Australian husband and I didn't see her again for 30 years. A digital person will be able to visit the Alpha Centauri system with a round trip time of around 8 years - and will be effectively immortal so will be able to tell us all about it several times over - even in our own short lifetimes.

Superintelligence
Paths, Dangers, Strategies
Nick Bostrom
Paperback: April 2016
ISBN: 9780198739838

Migrants to Australia in 1954
Credit: Australian National Archive

Looking at a wider picture, what is it to be human? Recent and even some contemporary cultures are known to define some other members of the species Homo Sapiens as less then human. Philosophers and moralists have tried to determine the human status of embryos, persons in various forms of coma and even some "higher" non-human species such as apes and whales. The status of digital persons seems suitable for the same sort of analysis, probably equally inconclusive. And some speculators on our interstellar future imply that the stars are the province of some sort of machine intelligence rather than a biologically based one. Another of my i4is colleagues, Dr Rachel Armstrong[3], studies how a convergence of biology and computing can work on earth and in our interstellar future. It may be "both" rather than "either".

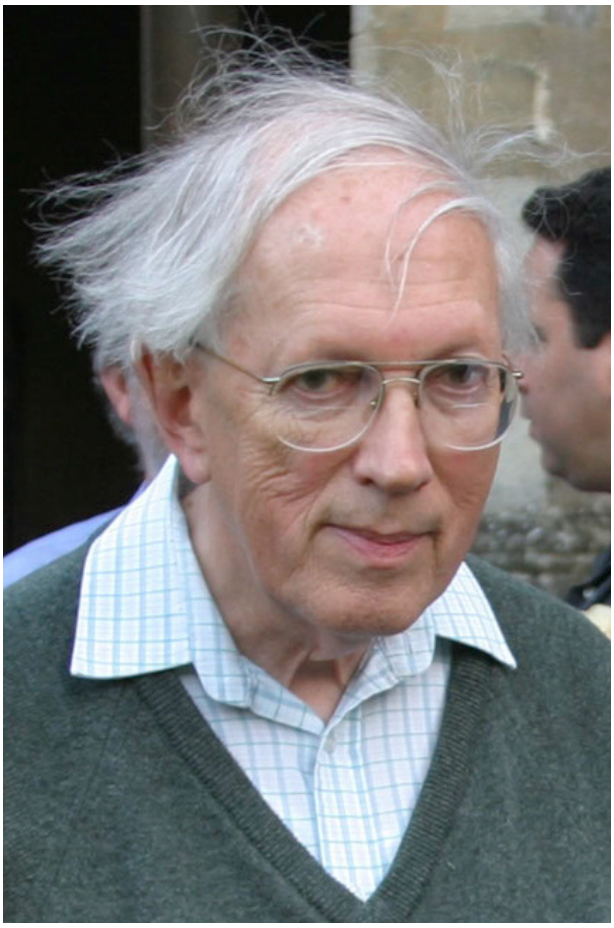
A wise old bird, Oswald Hanfling[4], used to ask "How do you know that Ossie Hanfling is not a parrot?". The answer, of course, was based on his behaviour. If I met a parrot (or an AI) as smart as Ossie then I hope I would be as polite to it as Alan Turing recommended.

The "False Dawn" of AGI and evaluating future possibilities

AI in the AGI sense has a reputation of being always 10-20 years away (There are depressing parallels for interstellar researchers in the predicted and achieved development of fusion power).

Early on, the optimism of the 50s and 60s evaporated when the Lighthill report[5] formed the basis for the decision by the British government to end support for AI research in all but three universities.

In the USA the report of the "Automatic Language Processing Advisory Committee" in 1966[6],



Not a parrot?
Oswald Hanfling, Philosopher, at the British Society of Aesthetiticians, 2005 Credit: Dr. Ian Ground, University of Hertfordshire, Department of Philosophy

gained notoriety for being very sceptical of research done in machine translation so far, and emphasising the need for basic research in computational linguistics; this eventually caused the US Government to reduce its funding of the subject dramatically.

In general, AI developments in the last 50-60 years have promised much and delivered only glimpses so far. How may we evaluate proposed AI technologies in the future? Falsifiability is an important, though not uncontested[7], test for scientific respectability. Sandberg and Bostrom's Whole Brain Emulation (WBE) roadmap says -

"Brain emulation is currently only a theoretical technology. This makes it vulnerable to speculation, "handwaving" and untestable claims. As proposed by Nick Szabo, "falsifiable design" is a way of curbing the problems with theoretical technology".

Szabo[8] says "We lack a good discipline of theoretical technology." and suggests "falsifiable design" as a means of evaluation.

How much needs to be emulated to achieve effective WBE? Sandberg & Bostrom (2008, cited above) consider "scale separation". For example, you don't need to emulate the analogue electronics underlying a computer system to emulate the computing behaviour of the system. There is scale separation between the analogue and digital levels of the system. If WBE can apply scale separation at some intermediate level then the computational demands may be less onerous, though clearly substantial.

One of the most pessimistic assessments of the problem comes from mathematical physicist and philosopher Roger Penrose. In The Emperor's New Mind (1989)[9] and later works, he suggests that consciousness may have quantum mechanical foundations. If this suggestion from a very distinguished scientist is correct then any digital representation of a human brain is very much more difficult and may even be computationally infeasible.

But recall Clarke's First Law "When a distinguished but elderly scientist states that something is possible, he is almost certainly right. When he states that something is impossible, he is very probably wrong"[10]. Just a "rule of thumb", of course, but one to bear in mind.

Science Fiction examples

Most of the fictional references to interstellar travel via some digital representation of a sentient being, human or otherwise, involve some biological or very advanced mechanical body. This is dramatically valuable since it results in a "person" with whom the reader can empathise. It is clearly not necessary to achieve interstellar transmission and instantiation. If we could load a human equivalent consciousness into a "ship brain" then we probably would. Iain M Banks' "ship minds" in his Culture novels are, in effect, the ruling intelligences of his Culture. But he does not use this fact to provide for interstellar travel, good old-fashioned space warps suffice for Mr Banks!

Another interstellar artificial intelligence is Salo, the "robot" from Tralfamadore in *The Sirens of Titan* by Kurt Vonnegut. Vonnegut's usual black humour has this AI as the descendent of a long line of races of artificial beings. Each of these races, back to and including their biological ancestors, had sought their purpose in the universe, found it not worth pursuing, created a race of robots to fulfil that purpose and promptly died out. Let us hope this is not prophetic of any of our own artificial descendants!

Another cautionary example is, of course, HAL in *2001: A Space Odyssey* but I assume there is no need to explain what goes wrong in that case! Clarke explains that HAL stands for Heuristic Algorithmic. So HAL uses both heuristic (i.e. strategies derived from experience with similar problems) and algorithmic (conventional computing) methods. Clarke explains -

> "HAL stands for Heuristic Algorithmic, H-A-L. And that means that it can work on a program's already set up, or it can look around for better solutions and you get the best of both worlds. So, that's how the name HAL originated."[11]

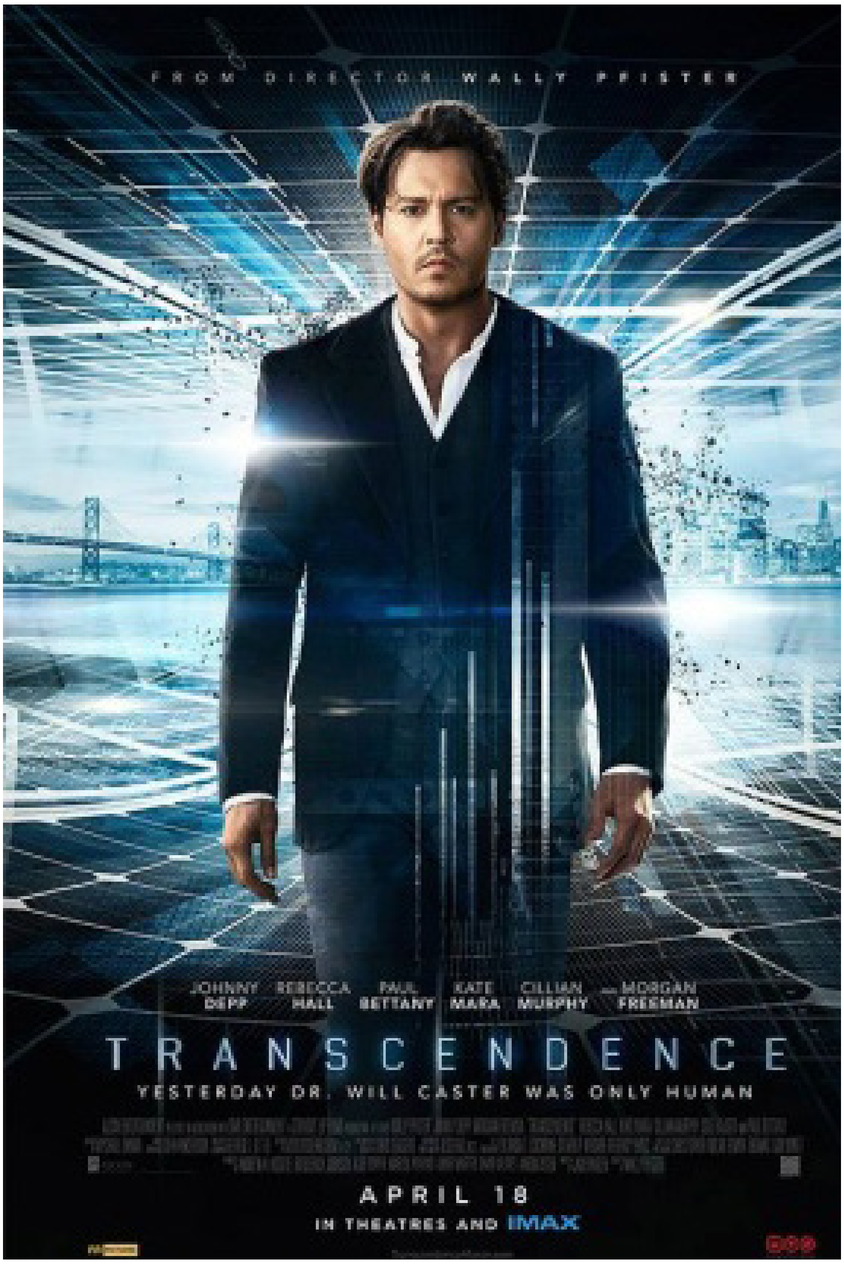
Charles Stross at UK Eastercon 2012
The slogan relates to a spat with Chris Priest about the Arthur C Clarke SF awards that year

Clarke was hedging his bet here. HAL was educated heuristically (as in the example of neural networks in the section above - Top Down - simulation of human behaviour) and programmed algorithmically, like a conventional computer.

Turning to actual transmission of intelligence over interstellar distances, Greg Egan is one of the deeper theoreticians of science fiction. *Incandescence*, for example, builds its plot on this assumption and the consequences or interaction between very advanced sentient beings that differ widely in their technology levels and their response to the possibilities arising from being, in effect, digital persons. His *Permutation City* eerily imagines how it might feel to be a Digital Person.

Most recently Charles Stross' novel, *Neptune's Brood*, has characters transmitted and installed in "soul chips" which are then plugged in to waiting bodies like SIM cards in mobile phones. Some bodies even have multiple SIM slots, just like some mobile phones! Stross is a former computer programmer who has been articulately sceptical about interstellar travel so perhaps he is simply satirising the idea of Digital Persons. His other writings (which I recommend) suggest he is a serious joker.

And back to the inspiration for this piece, "Transcendence going Interstellar", much cited above, also considers the use of FTL communication through very small wormholes as means of transmitting digital persons. These appear as a means of viewing distant and past scenes



Film poster for *Transcendence, Credit: Warner Brothers and Wikipedia*

in *The Light of Other Days*, by Arthur C Clarke and Stephen Baxter. Curiously enough, Clarke and Baxter don't include interstellar use of this technology. They are mainly concerned with terrestrial applications, with echoes of Bob Shaw's short story *Light of Other Days* (1966), *Burden of Proof* (1967) and his novel *Other Days, Other Eyes* (1972).

Conclusion

This has been a tour of just a few topics arising from Andreas Hein's "Transcendence going Interstellar" and it now may be the time to go back to Andreas' excellent piece (www.centauri-dreams.org/?p=30837) which I hope I have been able to decorate with a few interesting baubles. The topic of Interstellar by Transmission of Intelligence presents tremendous scope for research, design and speculation - both realistic and fictional.

Some topics deserving of immediate expansion based upon Andreas' firm foundation include Mind Uploading and the required Transmission Technologies at various levels of scale separation and thus volume of data required. Mind downloading to either a digital humanoid or a biological one may not be a first-generation requirement but would contribute to that feeling of humanity having actually reached the stars. I hope that I or others will be able to visit these topics in future issues of Principium.

There is a lot of controversy about when and if Digital Persons might be feasible. Some believe it is forever impossible in some fundamental sense. Roger Penrose seems to be close to this view. At the other extreme are Ray Kurzweil, who believes that The Singularity is Near[12] and a whole movement, Singularitarianism[13].

My own, entirely amateur, view is that Digital Persons in some form will exist in the future but I'm not sure how soon. Nor am I sure if they will ever "replace" biological humans, though I think they will surpass us in ways that we ourselves will acknowledge. Again, much scope for further discussion in Principium, in Axiom (The Journal of the Initiative for Interstellar Studies), and in interstellar studies generally. We have a vital interest in this area of work - we will inevitably engage with it. Some of our largest and newest companies are devoting investment not just in self-driving cars but in AGI[14] .

Thanks to Stephen Ashworth, Andreas Hein, Kelvin Long and Professor Austin Tate for their thoughts on this subject. None of my views above should be attributed to them and I am in either "violent agreement" or disagreement with more than one of them.

The first part of this set of musings had an “Overture” – a brief fiction illustrating how an electronically-cloned Digital Person might relate to a clone twin returning from a mission to the Epsilon Eridani system. May better writers challenge us with visions like this and help us to prepare for the challenging experiences which will inevitably arise if we succeed in Sending Ourselves to the Stars.

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About the author

John I Davies is a retired software engineer and mobile telecommunications consultant. More about his brief spell in space technology in the first part of this article. He retired in 2008 and has been active with the Initiative for Interstellar Studies since soon after its foundation in 2012. He is a career-long member of the British Interplanetary Society and has dabbled in philosophy via the UK Open University and latterly, the University of the Third Age.

Project Starshot – chips to the stars

Project 'Starshot' (breakthroughinitiatives.org/News/4) is a $100 million research and engineering programme that aims to develop a proof of concept for light beam-powered nanocraft and laying the foundations for an eventual launch to Alpha Centauri within a generation. The Initiative for Interstellar Studies has been working in technical support of the Breakthrough Initiative before its launch and will continue this support of 'Starshot' into the future. See Interstellar News in this issue for more about this.

If we can get people into chips, as discussed in this article, and we can get chips to the stars, as the Breakthrough Initiative plans, then at least one route to the stars will be available to our species.

One of the AGI-optimists at KurzweilAI, Giulio Prisco, www.kurzweilai.net/giulio-prisco, has already envisaged this "Uploaded e-crews for interstellar missions" www.kurzweilai.net/uploaded-e-crews-for-interstellar-missions

The Thousand-Year Starship

Stephen Ashworth

A prolific writer on matters interstellar considers a recent controversy and adopts an optimistic view - though with some scepticism on timescales.

Interstellar controversy

Kim Stanley Robinson, author of the recent SF novel *Aurora*, blogged in January 2016:

> "Going to the stars is often regarded as humanity's destiny, even a measure of its success as a species. But in the century since this vision was proposed, things we have learned about the universe and ourselves combine to suggest that moving out into the galaxy may not be humanity's destiny after all. […] All the problems [of an interstellar voyage] together create not an outright impossibility, but a project of extreme difficulty, with very poor chances of success." [1]

Robinson specified three preconditions for interstellar travel to become a reality:

- Sustainability for industrial civilisation on Earth;
- At least some space colonisation within our own Solar System ("a great deal of practice in an ark orbiting our sun", Robinson wrote);
- Interstellar probes aimed specifically at identifying Earth-analogue planets for human occupation.

Of these three, the first two are obvious and uncontroversial. The third is made unnecessary by virtue of the second, for if human life is comfortable and sustainable in at least one space colony orbiting the Sun, and of course in the worldship itself, then the same lifestyle will be equally acceptable at the destination.

The preparation itself, wrote Robinson, is "a multi-century project". Not everybody agrees. The 100 Year Starship organisation, led by former NASA astronaut Mae Jemison, is focused on the timeframe of a single century. It states on its website: "We exist to make the capability of human travel beyond our solar system a reality within the next 100 years" [2]. Meanwhile the *Starship Century* book and website reads like a Who's Who of the interstellar community [3].

So the "100 year starship" meme has entered the culture, and even influences work at the International Space University (ISU). A recent worldship study was undertaken by a team of 22 postgraduate students at the International Space University (ISU) and supported by the Initiative for Interstellar Studies (*Principium* 12, p.6). Their study, now published as the *Astra Planeta Final Report*, is based on the initial assumption that manned interstellar travel will prove to be easy enough that it is safe to specify a launch date just 100 years in the future [4]. The 100-year timeframe is justified within the terms of reference of this study because it allows a focus on the use of near-future technology (p.3).

So what are our prospects of developing an interstellar civilisation? Is it realistic to expect the first literal astronauts, the first star-sailors, to depart by the early 22nd century, and does it matter what we think of it now?

Our own Solar System first

While attempting to predict the future growth of technology is a hazardous game, some constraints on what the future might hold can be sensibly discussed.

The general theme of manned interstellar travel is dominated by three major questions, the first of which is whether and how quickly our currently global industrial civilisation will spread out into the Solar System.

Whatever humans may do in our local extraterrestrial environment – living permanently away from Earth, mining and using local resources, constructing infrastructure and vehicles on other worlds and in open space – interstellar travel will demand an extreme version of it. Because the distances between neighbouring stars are around five orders of magnitude greater than those between neighbouring planets, the endurance of any interstellar vehicle, its reliability and self-sufficiency and the energy and power of its propulsion system will need to be orders of magnitude greater than would be acceptable for, say, a flight from Earth to Mars.

One can confidently state, therefore, that interstellar travel will not become possible until interplanetary travel and colonisation have been thoroughly mastered. This has a historical precedent: the space age could not begin until global exploration and settlement had been brought to a high level of sophistication.

How quickly might the process of Solar System settlement take place? When talking about permanent human life away from Earth, what is envisaged is a new kind of life-support system quite different from the one we use at present. A hierarchical progression of such life-support systems can be sketched:

(1) The hunter-gatherer-scavenger-beachcomber lifestyle of all our tribal ancestors up to around 10,000 years ago;
(2a) Agriculture and a settled village life, beginning independently in Mesopotamia and in several other regions around the world at the end of the last ice age;
(2b) Alternatively the nomadic pastoralist life typical for a time in Central Asia;
(3) Urbanisation developing out of village life, but with the majority of the population employed in the agricultural hinterland;
(4) Industrialisation from the 18th century onwards, causing a flow of population from the countryside to the cities; the agricultural hinterland still exists as the cities' life-support system, but is itself industrialised.

This is where we are at present. Living on Mars, however, or in a space colony, the agricultural space has to be constructed together with the residential and industrial space, along with all air, water, organic and inorganic recycling facilities which on Earth are taken for granted as part of the pre-existing global environment. This requires the creation of a new kind of city, fully self-contained in so far as all routine life-support, manufacturing and recycling functions go.

While being developed for Mars, where it will be essential for anything more than a temporary scientific base, the self-contained city would also see application back on Earth. It could enable the colonisation of regions which at present are only sparsely populated. More importantly, it would allow existing developed areas to become progressively more sustainable over long timescales, a process which has already begun with high-intensity greenhouse agriculture. Extraterrestrial colonisation is therefore intimately linked with the sustainable consolidation of industrial civilisation on our home planet. An optimistic

Biosphere 2, Credit: www.flickr.com/photos/drstarbuck, Creative Commons future scenario involves the two proceeding in parallel.

But the timescale will inevitably be a long one, and for two reasons.

Firstly, creating such novel self-contained cities away from Earth will involve the solution of many interlocking problems in organic and inorganic recycling, food production, microbiology, low-gravity physiology, embryology, social organisation, mining and manufacturing in an unfamiliar environment, skill shortages, spare part shortages, and so on[5, §1]. A life-support system on a planetary scale with huge buffers of air and water must now be miniaturised to function within the walls of a single artificial structure.

The closest attempt so far was the Biosphere 2 project, in which eight volunteers lived for two years in a sealed building containing the wherewithal to grow all their own food and replenish all their air and water [6]. They did not, however, have any ability to manufacture replacement clothing or other hardware items. And even their supplies of oxygen and food turned out to be only marginally sufficient, with an occasional boost necessary from outside.

The cost of that project and the problems encountered show how much more there is to be done before settlers will be ready to live permanently away from Earth even at a neighbouring location in the Solar System, let alone in interstellar space or in orbit around another star.

Secondly, given the high cost of access to space, extraterrestrial colonisation will clearly suffer from a bottleneck effect in which infrastructure and population grow, not as a function of their totals on Earth itself, but from a relatively small founder population which is slowly added to over time. While growth on Earth must inevitably slow down as it approaches the carrying capacity of the planet, there will, according to a paper now due for publication in 2016, inevitably be a hiatus of several centuries before extraterrestrial infrastructure and populations become large enough to resume the upward growth trend[7].

Thus I must agree emphatically with Robinson that the preparation for interstellar travel will certainly require many centuries, while equally strongly disagreeing with him as to its ultimate prospects of success.

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The limits to technology

A second major question affecting our views on interstellar travel is where the limits to technological capabilities might be found. Will it, for example, be possible to build ships which can travel faster than light at an affordable power cost, or are slower-than-light propulsion systems in conjunction with already known physics for their energy source the best that can be achieved?

Clearly, there are diverging views on this, and a fundamental revolution in basic physics could change the way we see interstellar travel. But that revolution has not happened yet, and until it does, I think the only intellectually defensible position is to assume pro tem that it will not, but at the same time to stay aware of new developments in physics and keep an open mind.

As it happens, magical technologies (in Clarke's sense) are not necessary for interstellar travel: it is already well understood that with nuclear fusion as an energy source, a spacecraft could be accelerated to a few per cent of the speed of light, and decelerated at its destination. Basic physics is not in question; rather we are looking at questions of engineering development and economics. More powerful engines will reduce the necessary journey time, longer endurance for the vehicles and their occupants will raise the permissible journey time, and when these two development curves cross for some interstellar destination then the starship becomes technically feasible[4, §5].

Why not assume that by then some kind of warp drive will be possible, or that power will be drawn at will from the quantum vacuum? Firstly, because any precise engineering study with such nebulous concepts is impossible, and any vehicle based on them is little better than pure science fiction. But secondly, because the trend at present is not favourable to such devices. The great strides in technology of the past 200 years – steam power, electricity, the internal combustion engine, the jet engine, the rocket, nuclear power, the information revolution – have all respected certain absolute theoretical limits: the laws of energy conservation and thermodynamics, the uncrossability of the speed of light, the quantum uncertainty principle.

Science has moved into the study, not so much of the fundamental processes underlying nature, but rather of the behaviour of highly complex systems in cosmology, biology, microbiology, climatology and planetology. The fundamental physical theories of gravity and quantum electrodynamics have resisted unification. Technological progress has hit a curve of diminishing progress, with the slow progress towards controlled nuclear fusion and large-scale space travel two obvious indicators of the trend. Intelligent machines are not yet with us, consciousness has not yet been uploaded, and the medical problems of senile dementia and the wasting illnesses of old age have not yet been solved. Meanwhile the continuing development of civilisation on Earth throws up new problems of complexity in society and politics as countries with incompatible cultures are thrust together by the pace of globalisation.

So all the signs at present are that just getting to a fusion-powered worldship is going to take a major effort over a number of centuries. This could change at any time, and we should keep an open mind to revolutionary possibilities, but while fundamental revolutions in physics and in managing complex systems are not yet certain we should be equally on our guard against seductive but ultimately empty hype.

Energy and power

Assume, however, that the Solar System has been settled, that nuclear fusion is a mature technology for rocket propulsion and electrical power supply, that mining and manufacturing from primordial materials in a dusty microgravity vacuum is well established, and that rotating space colonies are spreading outwards to progressively more remote locations – the main asteroid belt, the Jupiter trojans, among the satellites of the giant planets, the centaurs, the Kuiper belt – coming progressively closer to worldship performance in their self-sufficiency and reliability. Multiple human generations have reproduced in space, and the biological and social problems encountered in this most delicate and complex of processes have been discovered, addressed and solved.

There remain issues connected with the energy and power required to send a vehicle large enough to carry a human population to the stars. These are fundamental physical considerations, independent of the actual technologies used. A small robotic probe can escape them by using the power of sunlight as its propulsion system, but this is only possible because a robot can tolerate the high accelerations that would be experienced when unfurling a light sail close to the Sun. People require gentler treatment, and solar sailing is unable to accelerate a manned ship to an interstellar speed greater than about 940 km/s, in Greg Matloff's latest design, which takes 1400 years to reach even the closest nearby star[8].

For a vehicle driven by any kind of engine or artificial beam, questions arise concerning the cost of the energy used, and the cost of building infrastructure which can deploy that energy at sufficient power to accelerate the vehicle within a reasonable period of time. In brief, an assumption that society would devote greater energy and power resources to an interstellar worldship than it uses for its own domestic purposes is not credible. Given the enormous values of energy and power required, a civilisation of a certain minimum size is required, far larger than could be maintained on Earth alone, thus bringing into play estimates of how fast future growth might be.

My own conclusion is that the earliest date when we could realistically expect a manned starship to be launched will be at some time in the second half of the current millennium, at least 500 years in the future, and more plausibly 750 to a thousand years or more[5, 7]. This is especially so when one considers the bottleneck effect which will constrain future growth for some centuries after it has topped out on Earth.

The sort of ship I have in mind here is a cruiser worldship, thus one whose accommodation resembles that of a cruise liner or a housing estate on Earth. It would have a zero-propellant mass of around a million tonnes, sufficient for perhaps one to two thousand occupants, and its cruising speed of 8000 km/s would carry it to Alpha Centauri after 170 years of flight, or to Tau Ceti in 450 years. It is quickly seen that the energy cost of such a ship would be 200 ZJ (one zettajoule = 10^{21} joules), equivalent to an amount of energy that would maintain our current global industrial civilisation for about 400 years.

Towards an *Astra Planeta 2*

How might a future generation of students at the ISU develop the *Astra Planeta* worldship in such a way as to address these quantitative issues?

The study shows an artist's impression of the concept design (Fig.12 on p.21), consisting of ten stacked tori for habitation with an engine and propellant tank in the middle. But the all-important figures for ship mass, propellant mass and exhaust velocity have not yet been provided. Without at least rough estimates of these key variables, an engineer cannot gain any overall feel for what is being

discussed, and the validity of the starting assumptions cannot be assessed.

It is stated that some sort of nuclear fusion (or possibly fission) rocket propulsion should be used (p.24), and a cruising speed in the region of 0.005 light speed (*c*) is implied (p.53). This speed would fix the journey time to Alpha Centauri at around 900 years, and that to Tau Ceti at well over two thousand years, assuming that acceleration and deceleration were completed within a small fraction of the total trip time. A table showing journey times to a range of nearby stars would be interesting.

A population of at least 100,000 is specified, and their per person floor space allowance is discussed in detail (p.11-15). A minimum mass of 230×10^6 kg is mentioned (p.17), but no source for that figure is provided. A future generation might decide that a mass of 2.3 tonnes per occupant would be too small. For comparison, the International Space Station – lacking radiation shielding, artificial gravity or onboard food or spare parts production – has a mass of over 60 tonnes per person.

All things considered, for multi-generational occupation I would prefer a mass of at least 500 tonnes per occupant, though a wide range of values have been suggested by other authors[9]. The extremely slender tori shown in the illustration of the completed worldship suggest a structure which is inefficient in its use of mass, particularly if passive radiation shielding is used, driving up the mass per person to a higher value, and this factor could also be re-examined. But, staying with the per capita figure of 500 tonnes, the stated minimum population size requires a zero-propellant mass of at least 50 million tonnes.

An exhaust velocity of 10,000 km/s (the same as the value produced by the *Daedalus Report*[10]) is mentioned as possible for nuclear fusion (p.22). Using this value, a mass ratio of 1.35 is required. The propellant load is then 17.5 million tonnes and the energy cost comes out to 875 ZJ, or 1750 times current global industrial energy production of around half a zettajoule. This figure should be increased by whatever inefficiencies occur during the conversion of the released energy into rocket thrust.

If the main engine fires at low thrust for a total period of acceleration plus deceleration of, say 100 years, then that engine needs to have a power of around 300 terawatt (TW); if the total engine burntime is reduced to around a single decade then the power needs to be up in the petawatts. The current aggregate power of global industrial civilisation on Earth is around 16 TW.

The questions may then be asked: is it reasonable to expect growth in industrial energy capacity over the next 100 years to reach the point where a project which consumes 875 ZJ of high-tech fusion fuel on a single flight is likely to be affordable? Is it plausible to project that economic and technological growth will allow a single engine (or cluster of engines mounted on a single vehicle) to operate at a power level two to three orders of magnitude greater than that of the entirety of civilisation only a century earlier?

At the same time it is also necessary to ask whether 100 years is sufficient to qualify a vehicle for at least 900 years of multi-generational habitation, plus whatever period of time must be spent at the destination before newly built infrastructure can be completed. Don't forget that the occupants would be using a mode of life which has so far only been partially tested once, by Biosphere 2, with mixed results. A fourth critical question would concern the tools and techniques needed for mining and manufacturing with extraterrestrial resources. Can these be matured to a sufficient level of reliability that the occupants of the *Astra Planeta* ship will be able not only to survive, but to grow once they reach their destination?

One may hope that the *Astra Planeta* report will not be forgotten, but used as a basis for subsequent studies which address questions such as these, and so progress the design further towards greater engineering realism.

Robinson: agreement and disagreement

Meanwhile, should one agree with Kim Stanley Robinson, or disagree? As I suggested above: both.

Interstellar travel and colonisation of other stars is perfectly consistent with already known physics, provided that multi-generation ships, travelling at say 1 to 3 per cent of the speed of light, are used, and therefore provided in turn that the mode of living on such objects has been well worked out beforehand by at least several centuries of experience at progressively remoter locations in the Solar System. There will inevitably be mistakes and occasional disasters along the way, and time must be allowed for these to happen and the lessons to be learned.

But there will be time. The energies and power levels required of any manned starship guarantee that interstellar flight will not take place until a civilisation several orders of magnitude larger and more powerful than present-day mono-planetary society has arisen. Similarly, spaceflight itself required a similar degree of progress from the relatively weak and primitive civilisations which sent early terrestrial explorers such as Zheng He, Columbus and Drake on their way. This starfaring civilisation cannot appear overnight, or in a single century.

That is why I think it is more reasonable to think in terms of a *thousand-year starship* development period.

Why does this matter? It matters because we need a realistic idea of where our civilisation is headed, of what the future possibilities are. It matters because we need assurance that the human heritage can be effectively immortal, if that is what we collectively want, and finally because it places our present-day concerns on a far vaster stage.

Looking ahead a thousand years, we can look equally far back and see how far we have come in that brief moment of cosmic time. That perspective should reassure us that, despite the ups and downs of day-to-day or even decade-to-decade world events, and despite the fashionable pessimism about the sustainability of our terrestrial civilisation, long-term progress is possible and technically feasible, and should still be worked towards.

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NB all internet references were checked at 18 May 2016.

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About the author

Stephen Ashworth has been a BIS member since the 1980s, and associated with i4is since its foundation. He has written numerous articles for Spaceflight magazine (most recently one on Mars settlement in the April 2016 issue), and several of his technical papers have appeared in the Journal of the BIS. He is the author of a full-length science fiction novel, The Moonstormers, available online (www.smashwords.com/books/view/260248); a novelette, “Half-way There!”, in the collection Visionary, published by the BIS and available on their website; and a short story, “The Marchioness”, inspired by the recent movie The Martian. He blogs at Astronautical Evolution (www.astronist.co.uk/astro_ev/ae_index.shtml). He works in academic publishing at Oxford University and plays jazz saxophone.

NEXT ISSUE

In the next issue our Guest Introduction will be a reflective piece by Paul Gilster of the invaluable Centauri Dreams blog and the Tau Zero Foundation. We will report more from the ISU Masters 2-week elective module for the students of the Masters of Space Studies course at the International Space University, Strasbourg, mentioned in our News this time. We'll also hope to bring you the final chapter of Terry Regan's account of how he built Daedalus and of its unveiling at the BIS 2016 Charterhouse Conference. And more on Starship Engineering from Kelvin Long, with perhaps some of the original drawings from Carl Sagan's Cosmos programmes.

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Editor: John I Davies
Deputy Editor : Kelvin F Long
Layout: John I Davies

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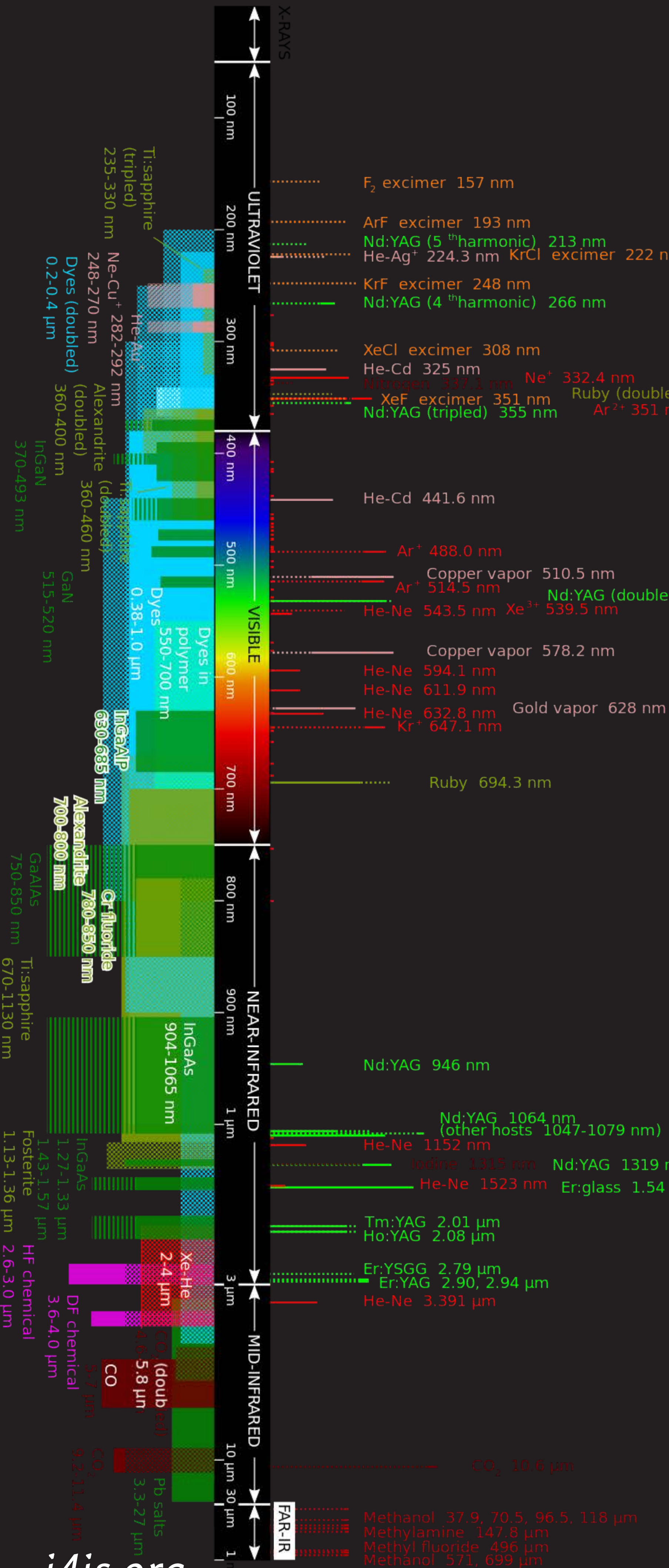

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