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PRINCIPIUM

The Newsletter of the Initiative for Interstellar Studies

Issue 14 | August 2016

www.i4is.org

Scientia ad sidera

Knowledge to the stars

Editorial

Welcome to Principium 14, our quarterly newsletter about all things interstellar. Our *Guest Introduction* this time is by Paul Gilster of the invaluable Centauri Dreams blog and the Tau Zero Foundation. He muses on the relations between Science Fiction, space advocacy, exoplanets, SETI and increasingly well funded projects for interstellar probes. Paul is one of our foremost "rational dreamers" and we look forward to more Centauri Dreams. His thoughts will always be very keenly welcomed in Principium.

Interstellar News this time reports on the Andromeda probe project. We report from Charterhouse, the annual British Interplanetary Society (BIS) Space Conference with i4is contributors and the unveiling of Terry Regan's Daedalus model, soon to appear in the BIS headquarters. Two of our regular and highly valued artists have been honoured by the BIS and by a pair of influential SF organisations. Adrian Mann was honoured with the BIS Patrick Moore medal. David Hardy gave the principal address at the joint AGM of the British Science Fiction Association and the Science Fiction Foundation; we report from Imperial College. BIS and i4is will be contributing to science television in Japan, we report from BIS HQ.

We have more schools outreach happening in London. We'd love to help the interstellar community to inspire the rising generation UK-wide, across Europe and worldwide. Please get in touch via contacts, at the end of this editorial.

Kelvin Long, Executive Director of i4is, is a long established collector of space art and memorabilia. He remembers, *Cosmos: A Personal Voyage*, the pioneering television series by Carl Sagan and shows us some of the original art work for the series which he has acquired from the original artist.

Terry Regan completes a saga of detailed model making stretching over several years in *The BIS Daedalus Model - the last lap*. More pictures of how it was done and an engrossing account of the mishaps and triumphs on the way to his completion and it's unveiling.

The i4is two-week elective for masters students at the International Space University is reported in *Interstellar Studies at the ISU*. This was a very substantial piece of work by i4is people and associates from industry and academe and the account in this issue is no more than a taste of what was delivered in Strasbourg.

Last November the i4is delivered a two-day *Starship Engineer* course at BIS HQ in London. Kelvin Long and Rob Swinney give us an outline of its content. This is the first of a series of technical courses at several levels which i4is is planning.

The front cover illustration this time is a "blueprint" of the thermonuclear Orion spacecraft as envisaged for the Cosmos series.

For our rear cover we have an image we spotted on Paul Gilster's Centauri Dreams website. No obvious interstellar connection but the beauty of the image bowled us over!

Look out for the latest issue of our academic education journal, *Axiom*, out soon, and for opportunities to help us achieve our interstellar goals, *Working towards the real Final Frontier*, towards the end of this issue. You don't have to be a rocket scientist!

Comments on i4is and all matters interstellar are always welcome. Write to me!
John I Davies, Editor, Principium
john.davies@i4is.org

PS Look out for the STOP PRESS at the end of the account of Starship Engineer 2015 announcing Starship Engineer 2016 - Weekend of 12-13 November, BIS London. This is a revised and updated version of the course with a more work-friendly timing. Contact info@i4is.org for more details.

Keep in touch!

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

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.

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

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

Shaping the Interstellar Imagination

Writing and editing Centauri Dreams over the years, I've talked to numerous scientists and engineers in universities, space agencies and the commercial sector. They're my primary sources and they often take the time to answer questions and write for the site. But I'm always struck by the number of non-technical people who weigh in to discuss the prospects of reaching another star. Curiosity among the public is rampant, and we in the interstellar community need to nurture it. Fortunately, a number of trends are converging that make this easier.

Let's start with science fiction, because the field has proven enormously productive in enlisting new enthusiasts no matter what their backgrounds. Science fiction writer and critic Adam Roberts, whose recent novel *The Thing Itself* (Gollancz, 2015) is a new and richly developed take on the Fermi paradox, likes to talk about science fiction as a genre that keeps alive our facility for what he calls 'imaginative play,' something that we're pretty good at as kids and tend to lose all too quickly among the pressures of adult jobs, families and other responsibilities.

Imaginative play is something I try to engage in everyday. As does the interstellar community, which is in the interesting position of straddling the line between science fiction and science fact. We talk about concepts that have yet to be confirmed and discuss possibilities of engineering that are well beyond what is currently attainable. People who hear about some of these notions through movies like Interstellar or Avatar take note when they realize that there are serious people who think there are genuinely possible futures that involve star-flight.

So let's talk about what we are doing to engage the imagination in fiction and in fact. Much of this is happening through the ongoing development of space missions. We can thank William Borucki (NASA Ames), principal investigator for NASA's Kepler mission, for his herculean efforts at getting the stupendously successful exoplanet hunting space telescope to fly. And among thousands of confirmed exoplanets that are the result of this, we're beginning to find a few worlds that let the imagination soar because of what they imply about our future.

Long Journey to Earth 2.0

While we dream of places like Pandora, Avatar's utterly unlikely setting (gas giants around Centauri A and B have been ruled out), or imagine evocative worlds like Robert Silverberg's Majipoor, we're also hoping to close the circle by detecting a real Earth-like world.

About 1,200 light years from Earth in the direction of the constellation Lyra, Kepler-62f is a world with a radius 40 percent larger than Earth's, which puts it below the 1.6 RE demarcation line that is increasingly thought to define the difference between Earth-like worlds and planets that are more like Neptune. Thus we're probably looking at a rocky planet here. It's also a planet that orbits its K-class primary at a distance that could place it in the outer regions of the habitable zone (as defined by the possibility of liquid water on the surface).

New work on this world examines the planet's atmosphere to consider scenarios that could produce habitability. A team led by Aomawa Shields (UCLA), working with Rory Barnes, Eric Agol, Benjamin Charnay, Cecilia Bitz and Victoria Meadows (all at the University of Washington) modelled climate possibilities using several different methods — the Community Climate System Model and the Laboratoire de Météorologie Dynamique Generic Model. Informing the climate modelling was the use of another computer model called HNBody, which was used to analyze and adjust the planet's orbital parameters. Out of all this, we get this from Shields:

> "We found there are multiple atmospheric compositions that allow [Kepler62f] to be warm enough to have surface liquid water. This makes it a strong candidate for a habitable planet."

Habitability is a thorny issue, and all too often we look deeper into the composition and characteristics of distant worlds only to find that the likelihood of liquid water on their surface is slim. In many cases the planet may not be a rocky terrestrial world at all. But Kepler62f passes most of our tests and remains a seriously intriguing candidate, even if to house liquid water, it would need an atmosphere with a great deal more carbon dioxide than we find in Earth's atmosphere to keep the surface from remaining in a deep freeze. By adjusting carbon dioxide levels in their atmospheric models, the researchers learned that given various orbital configurations, there were circumstances where habitability was possible.

Just how Earth-like is Kepler62f? Not very. There is a chance that with CO2 levels like the Earth's, the planet could experience melting of ice sheets on an annual cycle. This would depend on a high degree of axial tilt, or obliquity — the angle between the planet's rotational axis and its orbit. The Earth's obliquity is 23 percent. An axial tilt of 60° or higher, coupled with summer solstice at a given hemisphere occurring at the planet's closest approach to its star, could produce this effect, allowing surface conditions that were at least periodically habitable.

This is where we are today. We'd like much better results, but unambiguous habitability is something we're finding hard to confirm anywhere.

Even so, the future is bright, what with the TESS (Transiting Exoplanet Survey Satellite) mission due for a launch next year in a quest to survey nearby stars for planets, and the European Space Agency's PLATO (PLAnetary Transits and Oscillations of stars) planned for 2024. Unlike Kepler, missions like these won't be limited to a fixed field of generally distant stars. Having documented exoplanet populations statistically, we're now about to start populating the local neighborhood around M-dwarfs, K-dwarfs and G-class stars much like the Sun.

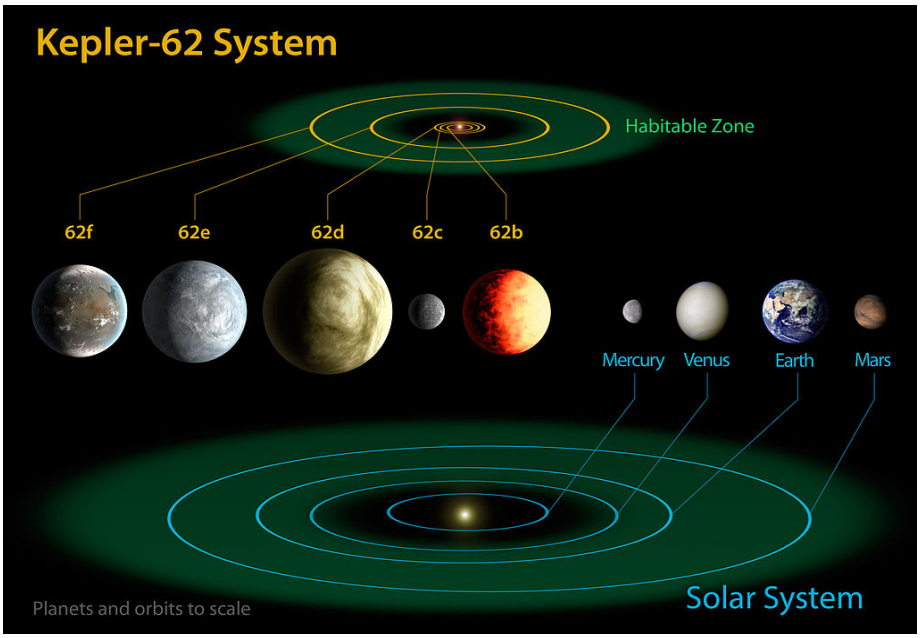


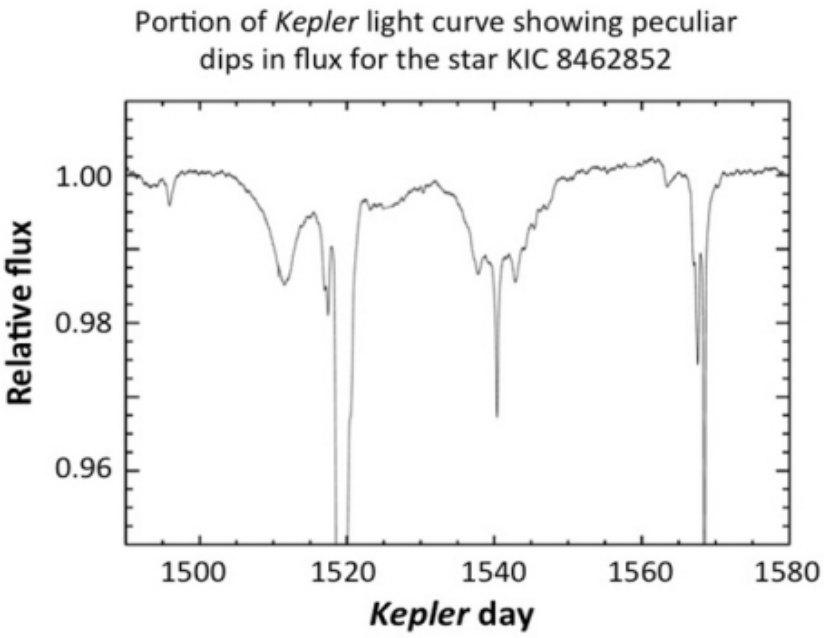
Image: The Kepler62 system, with Kepler62f at the very outskirts of the habitable zone. Note the contrast with our own Solar System's habitable zone. Credit: NASA Ames/JPLCaltech.

Couple this with the James Webb Space Telescope, which is on track for a 2018 launch, and we can begin drilling down to smaller worlds as we study planetary atmospheres. There is an exciting possibility of a starshade, a specialized occulter far from the parent telescope, to complement the upcoming WFIRST (Wide Field Infrared Survey Telescope), which should launch in the mid-2020s. This would give us our best view yet of a rocky world around another star. Can analysis of such a planet's atmosphere in search of biosignatures be far behind?

The SETI Overlap

As exoplanet detection becomes increasingly refined and we start peering into small planet atmospheres, we may just make some anomalous detections with SETI implications. KIC 8462852 is an F-class star whose lengthy designation belies the fact that it is what Penn State's Jason Wright calls 'the most mysterious star in our galaxy'. Coming from Wright, this is especially noteworthy, as he heads up a project called GHAT, standing for Glimpsing Heat from Alien Technologies. Wright, along with co-investigators Steinn Sigurðsson and Matthew Povich (Cal Poly Pomona) are seriously engaged in studying what kind of infrared signature a high-level civilization might put out. Richard Carrigan (Fermi National Accelerator Laboratory) may come to mind here. He was an early proponent of looking for possible Dyson spheres.

We have a hard time wrapping our heads around the engineering that could build a cluster of solar power stations around a star to such an extent that the starlight might actually begin to dim, much less an actual sphere (far less likely, it's thought, because of stability issues) around such a star. But if we grant advanced civilizations the powers they might well possess, we can't rule such things out. And now we have KIC 8462852, an anomalous star that, unlike Kepler's other relatively straightforward transits, shows a transit light curve of unusual proportions.



Just what is out there around KIC 8462852? If it were a single planet, we would see a dip in the star's light followed by a recovery, all of this occurring in ways that would allow us to learn a great deal about the planet in question, including its mass and likely composition.

But have a look at KIC 8462852's light curve, which is like nothing that has previously been found.

We have no idea what is causing these light curves, though various natural explanations have been offered, such as an unusual swarm of comets. But likewise interesting from our perspective as interstellar advocates is the social media and crowd-sourcing of ideas and resources that has accompanied this story. Tabetha Boyajian (Yale University), for whom the star often called 'Tabby's Star' is named, heads up a project called Planet Hunters that puts Kepler data in front of the general public. This is a good idea because even the best algorithms sometimes miss things that the human brain's pattern recognition abilities can see.

It was a civilian effort citizen scientists that found the anomalies surrounding KIC 8462852, and it was Boyajian's paper that discussed possible natural causes of the phenomenon. A carefully modulated paper from Jason Wright and team mentioned the possibility of extraterrestrial engineering, launching wild media speculation that in no way reflected his group's careful approach. Furthermore, Tabetha Boyajian followed up with a successful Kickstarter campaign to support a year-long further investigation of KIC 8462852 using the automated instruments of the Las Cumbres Observatory Global Telescope Network.

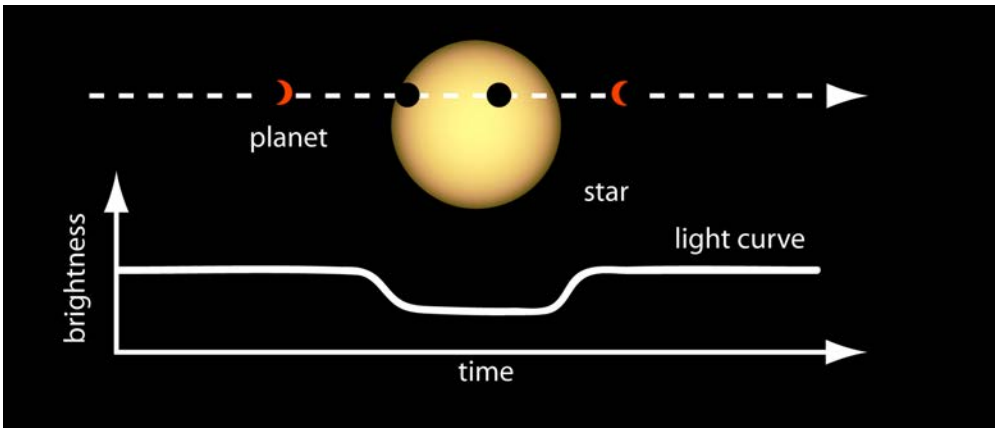


Image: A transiting planet usually leaves a well behaved light curve, reflecting the dip in starlight as the planet moves across the face of the stellar disk. Credit: NASA.

Steady eyes on this star are important because we don't know what its light curve is going to do next, and in any case the Kepler mission, now in its K2 extended observation cycle, can no longer view the star. That we can now proceed is owing to the Internet, which has gifted us with the capability of funding a serious scientific project solely through the efforts of curious citizens. That SETI is a driver for this interest is unmistakeable. In fact, the Allen Telescope Array has already had a quick look at Tabby's

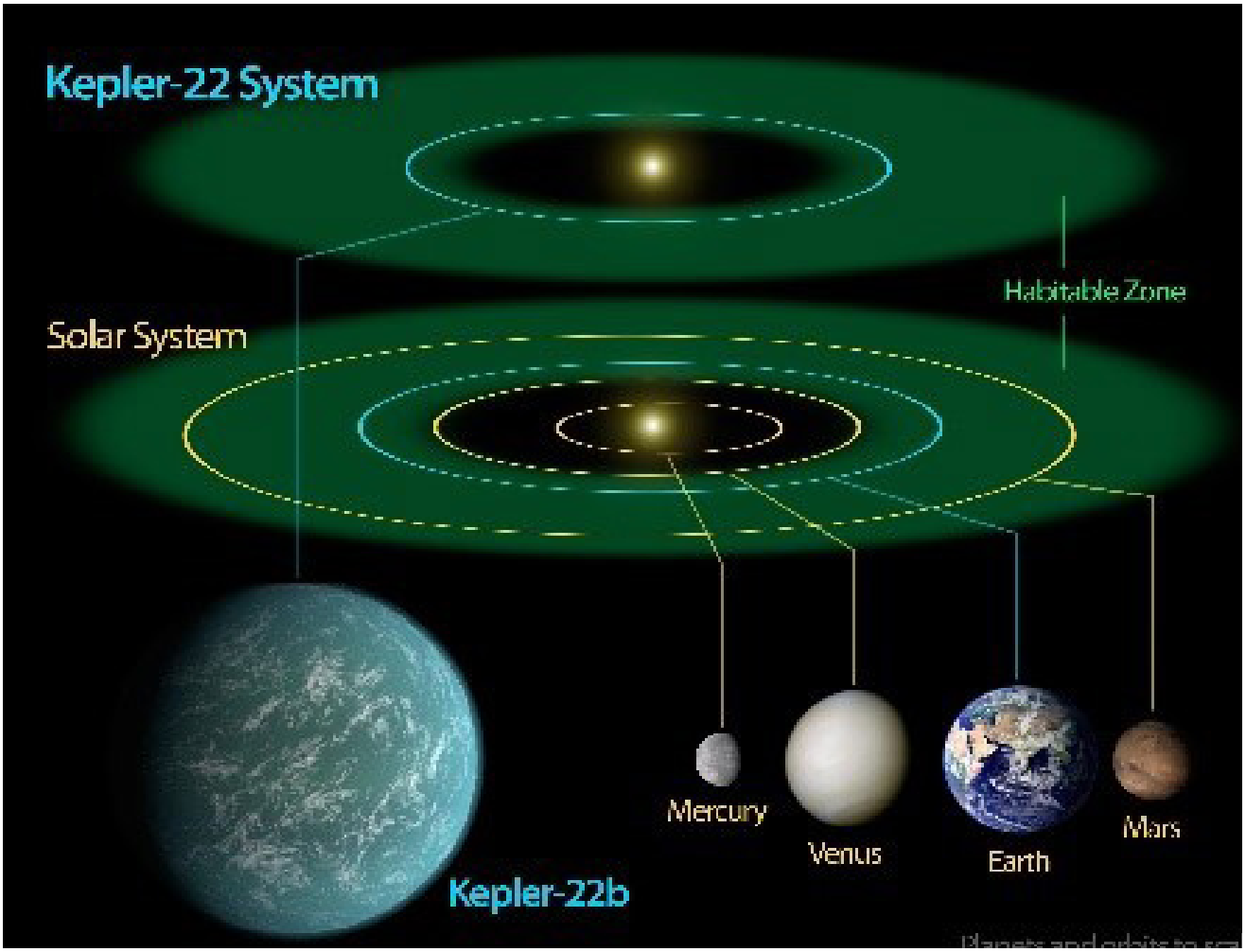


Image: The Kepler62 system, with Kepler62f at the very outskirts of the habitable zone. Note the contrast with our own Solar System's habitable zone. Credit: NASA Ames/JPLCaltech.

Star just in case microwave beaming might be going on there by way of furnishing power to an ongoing mega-engineering project. Although the ATA found no sign of such beaming, the short observation period allows us to draw no real conclusions about what may be happening at longer time-frames.

SETI carries huge fascination for people who have been raised with science fiction in their magazines and on their TVs and cinema screens, the film Contact being an obvious referent. But SETI is all about destinations, the home worlds of whatever civilizations we eventually encounter. It is the emergence of the exoplanet menagerie (over 3,200 and counting, with tens of thousands more on the way) that has provided a glimpse of such places. If Kepler62f offers a potentially habitable canvas for the imagination, KIC 8462852 now gives us a mystery to solve.

Breakthrough Starshot: Memories of Heinlein

Imagination, mystery, distant worlds, all are fodder for renewing public interest in space. What the interstellar community has also needed, though, is a driver for serious research into the kind of technologies that can make an actual mission possible. 2016 saw the emergence of just such a vision and the money to research it in the form of Yuri Milner's Breakthrough Starshot initiative. Following on the heels of Breakthrough Listen, a SETI program already taking data at Green Bank and the Parkes observatory in Australia, Breakthrough Starshot brings $100 million to the table, funding concept studies toward an audacious goal: Using a phased laser array to push a fleet of miniaturized spacecraft at 20 percent of light-speed to Alpha Centauri.

The time-line for Starshot is 10 years of R&D, 10 years for construction of the System, 21 years transit time for the first sail-craft. The micro-probes (the initiative refers to them as 'Starchips') would enter the Alpha Centauri system in 2057, a century after the first Earth satellite.

If the intention is straightforward, the problem areas are anything but. What Milner, aided by

Stephen Hawking and Freeman Dyson at the New York announcement, put forth is the use of an enormous phased laser array approximately a kilometer to the side, situated perhaps in Chile's Atacama desert, to produce enough laser power to drive small sail-craft up to 20 percent of light-speed with a burst of acceleration lasting two minutes and hitting 60,000 g's. The payload: Miniaturized spacecraft weighing no more than grams, a fleet of which could technically be dispatched to nearby interstellar targets, ensuring against loss along the way.

At a follow-up discussion event in Palo Alto, the core Breakthrough Starshot team ran through the huge questions raised by the prospect, any one of which could be a show-stopper. Can a small sail survive the laser onslaught directed at it, even one only a few minutes long? Can the phased laser array be built to specifications and get the needed power to the sail? Can a spacecraft the size of a smartphone or smaller return data from 4.3 light years away? The list keeps going: What about interstellar dust? Cosmic ray damage? Political and regulatory issues?

One big 'if,' of course, is the target. We have no information about Alpha Centauri planets other than to note, as Xavier Dumusque himself pointed out at the Palo Alto event, that the earlier evidence for an Alpha Centauri Bb has now been shown to be an artefact in the data. Dumusque was on the original team behind the Centauri Bb announcement, so I think we can let that particular planet go even as we delve into much more intriguing possibilities in this system.

Much of the time at Breakthrough Discuss was devoted to the problems and possible solutions for detection of planets around Centauri A and B. The good news: as seen from Earth, the two stars are about as close in their orbits as they can get, and at an angle that makes untangling radial velocity signals hugely problematic. In coming years, that situation is going to ease.

We also have the potential for an interesting find at Proxima Centauri, the small red dwarf that is about 15.000 AU from the primary Alpha Centauri stars. The Pale Red Dot project,

Image: Yuri Milner presenting the Breakthrough Starshot concept in New York in April 2016.

Who's in the picture

Yuri Milner, Stephen Hawking FRS, Freeman Dyson FRS and Professor Avi Loeb, Harvard University, Chair of the Advisory Committee, Breakthrough Starshot Initiative

under the guidance of Guillem Anglada Escudé (Queen Mary University, London), has finished taking data at the European Southern Observatory's La Silla Observatory. Nothing precludes an Earth-sized planet around Proxima Centauri, although many scenarios for larger worlds have been ruled out. If we find an inviting target at Proxima, Breakthrough Starshot will have one more option.

The common thread that runs through all this is the public imagination, which must be galvanized to support any large space mission. If $100 million sounds like a lot of money, remember that it's just for a conceptual study. Actually putting Breakthrough Starshot into a working mission ramps us up into the multi-billion dollar range, rivalling the Large Hadron Collider. What could drive the public to support such a mission would be the discovery of a truly Earth-like world around one of these stars and the prospect of other forms of life.

When he published *Time for the Stars* in 1956, Robert Heinlein envisioned a private foundation funding a manned interstellar mission. The Heinlein of those days is worth quoting. Here he describes the foundation through the eyes of one of the identical twin protagonists:

> "Its coat of arms reads: "Bread Cast Upon the Waters," and its charter is headed: 'Dedicated to the Welfare of Our Descendants.' The charter goes on with a lot of lawyers' fog but the way the directors have interpreted it has been to spend money only on things that no government and no other corporation would touch. It wasn't enough for a proposed project to be interesting to science or socially desirable; it also had to be so horribly expensive that no one else would touch it and the prospective results had to lie so far in the future that it could not be justified to taxpayers or shareholders. To make the LRF directors light up with enthusiasm you had to suggest something that cost a billion or more and probably wouldn't show results for ten generations, if ever … something like how to control the weather (they're working on that) or where does your lap go when you stand up."

In Heinlein's novel, the Long Range Foundation pays off, developing a number of exploratory starships called 'torch-ships' that can reach a substantial percentage of the speed of light.

Picking up the Heinlein thread, Allan Steele recently looked at a private, star-minded foundation in his novel *Arkwright* (Tor Books, 2016) which tells of an organization created through the estate of the fictional science fiction writer of the title to perform much the same service. Here the premise is that building a nearby infrastructure can become the driver for deep space:

> "It was hoped, though, that the Galactique Project would bootstrap a new era of space exploration. Aside from brief missions to Mars and the Moon and small-scale efforts to mine near Earth asteroids, humankind was still largely confined to its native planet. The foundation believed that Galactique would demonstrate the viability of beamships and thus prompt private industry to use the project's beamer to send manned missions to the outer planets."

Technologies could be offered for lease to commercial space companies interested in sending spacecraft to Mars and beyond, thus fuelling future deep-space initiatives. The idea is bold and energizing, but can it be done? Is it possible that the first true interstellar mission will be created and then built by private funding in a kind of civilization-wide deep space Kickstarter?

No one can know at this point, but I think we can make one confident assertion. Whether or not Breakthrough Starshot puts a payload through the Alpha Centauri system decades from now, we'll still have learned a great deal about the beamed propulsion and sail technologies necessary to do the job someday. Good science is going to come out of this $100 million commitment, a level of funding that interstellar studies has never before experienced.

The ensuing ideas continue the synergy of science fact and imagination that drives science fiction but also spark the kind of public engagement that has repercussions in support and funding. In an era of commercial space and citizen science, we're all the beneficiaries.

About the Author
Paul Gilster is author of Centauri Dreams: Imagining and Planning Interstellar Exploration (Wiley, 2005), and author/editor of the website by the same name (www.centauridreams.org). He is one of the founders of the Tau Zero Foundation.

Interstellar News

John Davies with the latest interstellar-related news.

The Andromeda probe project

We told you in the last Principium about the Breakthrough Initiative Project Starshot, launched by Yuri Milner with $100m support and the backing of Stephen Hawking, Mark Zuckerberg and Freeman Dyson. What we could not tell you at the time was that i4is experts had already contributed a 40 page report to the Breakthrough Initiative discussing the physics, engineering and mission architecture issues relating to an interstellar probe propelled by beamed energy. This work was carried out across multiple time zones in the US and Europe and at short notice. A small team within the Initiative for Interstellar Studies was assembled. The time constraints were significant - this was a three day study! A set of questions was asked by the Breakthrough Initiative related to the mission. The team were tasked with describing solutions to these questions. This report, in its entirety, was initiated and delivered in the required time frame. The requirement was for a probe to be sent to Alpha Centauri propelled by lasers or microwaves with a total mission duration of 50 years travelling at a cruise speed of 0.1c (i4is Executive Director Kelvin Long had met with Brigadier General Pete Worden, Chairman Breakthrough Prize Foundation, when he was in California during early 2016).

Andromeda mission patches, Credit: K F Long

Kelvin commented in the delivered report "Although we may not have adequately addressed all of the technical issues, due to time constraints, we hope that this work demonstrates the confidence and capability of our team, and the positive attitude to make it happen – Ad Astra!"

We'll be reporting in more detail on this in subsequent issues. Our contributors will be identifiable when you meet them by their Andromeda mission patches!

BIS at Charterhouse

The annual British Interplanetary Society (BIS) Space Conference happened at Charterhouse, a public (in UK parlance) school in Surrey near London from 21 to 23 July 2016. There were two interstellar contributions -

- Kelvin Long, Executive Director of i4is, on Interstellar Flight: Advanced Concept Solutions
- Rob Swinney, Education Director of i4is, on Academic Opportunities in Interstellar Studies

We also heard reminiscences and history going all the way back to Mir and further to cordite rockets in the first half of the 20th century. Wider aspects of the space future were considered by Gerry Webb (BIS and Commercial Space Technologies Ltd), Richard Osborne (BIS and i4is), Mark Hempsell (President, BIS) and Alan Bond (founder of Reaction Engines and co-leader of the BIS Daedalus project).

Alan Bond congratulates Terry Regan on his model of Daedalus for BIS HQ
Left to right - Vix Southgate, Gerry Webb, Mark Hempsell (BIS President), Terry, George Abbey, Alan.
Credit: Richard Osborne

Adrian and partner with the BIS Patrick Moore medal
Credit: K F Long

spaceflight both solar system and interstellar, will recognise the name of Adrian Mann (www.bisbos.com). His art and video has helped almost everyone one in space and interstellar advocacy for many years and he is also responsible for the images and videos used by Reaction Engines Ltd (www.reactionengines.co.uk/image_library.html and www.reactionengines.co.uk/video_gallery.html).

Adrian is now the proud holder of the BIS Patrick Moore medal, in recognition of his contribution over the years. Kelvin Long, of both BIS and i4is, was able to deliver the medal in person to Adrian in Hungary where he has lived for many years with his partner.
David Baker, editor of BIS *Spaceflight* tells us he will be featuring Adrian strongly in an imminent issue. We at i4is salute Adrian as one of three generations of artists who have supported our cause with their imagination - David Hardy (see elsewhere in this News), Adrian and the youngest Alex Storer (www.thelightdream.net), who you will remember contributed our cover illustration last time. And on the other side of the Atlantic, Jon Lomberg (www.jonlomberg.com) has contributed both in Principium and elsewhere.

And Charterhouse saw the final unveiling of the new BIS model of the Daedalus starship. This magnificent work of art and craft was executed by Terry Regan of BIS and i4is. The model was financially sponsored by i4is. More about it elsewhere in this issue.

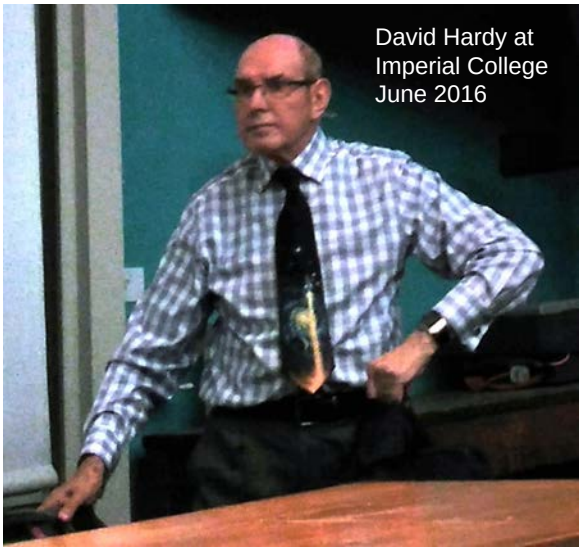
Schools Outreach

Since the last issue John Davies, i4is, has given talks on the Tsiolkovsky rocket equation and its significance for interstellar travel and on his own career in space technology, computer communications and mobile data at William Perkin School in Greenford, London.

Rob Swinney and John Davies are working with STEMnet London on a major new interstellar project for London schools which we also hope to roll out across the UK and beyond.

BIS Medal for Adrian

Regular readers of Principium, and just about any source on



David Hardy at Imperial College June 2016

David A Hardy

Our old friend, the "grand old man" of space art, David A Hardy, was chief guest speaker at the joint AGM of the Science Fiction Foundation (publishers of *Foundation, the Review of Science Fiction*) and the British Science Fiction Association (BSFA) at Imperial College, London, 25 June 2016. He showed and explained his art from the 1950s to this year (see www.astroart.org)

NHK television at BIS

Rob Swinney, Education Director of i4is, and Mark Hempsell, President of the British Interplanetary Society (BIS) were interviewed at BIS HQ, London, in June. NHK (Japan's national public broadcasting organisation) are making *Cosmic Front; Interstellar Travel*. Mark and Rob were able to tell NHK about work from the BIS in the 1950s and 1970s (Project Daedalus, see elsewhere in this issue) and about more recent work in Project Icarus and Project Dragonfly. The programme will include interviews with several other space and interstellar experts. We have several readers in Japan so it would be good to hear how the programme turns out.

SPACEUP:UK

The 2016 SPACEUP:UK was in June at Kings College, University of London. The

main theme was the human body in space, especially the effects of microgravity. A report from Kings College researchers was especially interesting. They are developing a suit to counteract the ill-effects of microgravity. There was time for a couple of short presentations on interstellar themes. John Davies of i4is asked the delegates when they thought interstellar would be achieved. Most thought a robot probe would happen within 50 years and there were even a few optimists who gave it 10 years or less. Most were students and postgrads with only a sprinkling of oldsters like your editor so this bodes well for the interstellar cause. Dr Alfredo Carpineti, Astrophysicist and Science Communicator, of IFLScience (www.iflscience.com) told us about *Crazy Ways to Reach the Stars* - including a few I had not heard of - the Diametrical Drive (which creates a "Gravitational Curl" to produce an unbalanced force), the Disjunction Drive (which separates matter from the gravitational field), the Bias Drive (which changes the Gravitational Constant in front of the craft, producing a 'Gravitational Pressure') and the Differential Sail (which creates a pressure imbalance in Dark Energy). I haven't asked the i4is experts about these yet so I don't know how exotic they are but intriguing certainly. Thanks to Sam Harrison of i4is for his input to this report.

The Institute of Isolation

i4is was invited to the launch of *Beyond the Lab* at the London Science Museum in July. Our friend Lucy McCrae had the premier of her short film "The Institute of Isolation" at the show. It's about the acclimatisation of the human body to space, especially microgravity (echoes of SpaceUp:UK, also reported in thus News). The central scenes, of Lucy in a horizontal treadmill simulating weightless running, are integrated into evocative images (spot Kew Gardens!).

Along with the "citizen science" in *Beyond the Lab* it is showing at other European venues -

From 6 July in Bonn at the LVR LandesMuseum
From 7 July in London at the Science Museum
From 14 July in Warsaw at the Copernicus Science Centre
From 16 August at the Tehnološki park Ljubljana

More at www.sparksproject.eu/article/event/opening-sparks-exhibition.

TVIW

i4is people have always had a close relationship with the Tennessee Valley Interstellar Workshop and we'll be expanding that relationship in future. For a regular update on their work take a look at their quarterly newsletter *Have Starship Will Travel* (www.tviw.us/resource/newsletter).

Kelvin delivers the Patrick Moore medal to Adrian

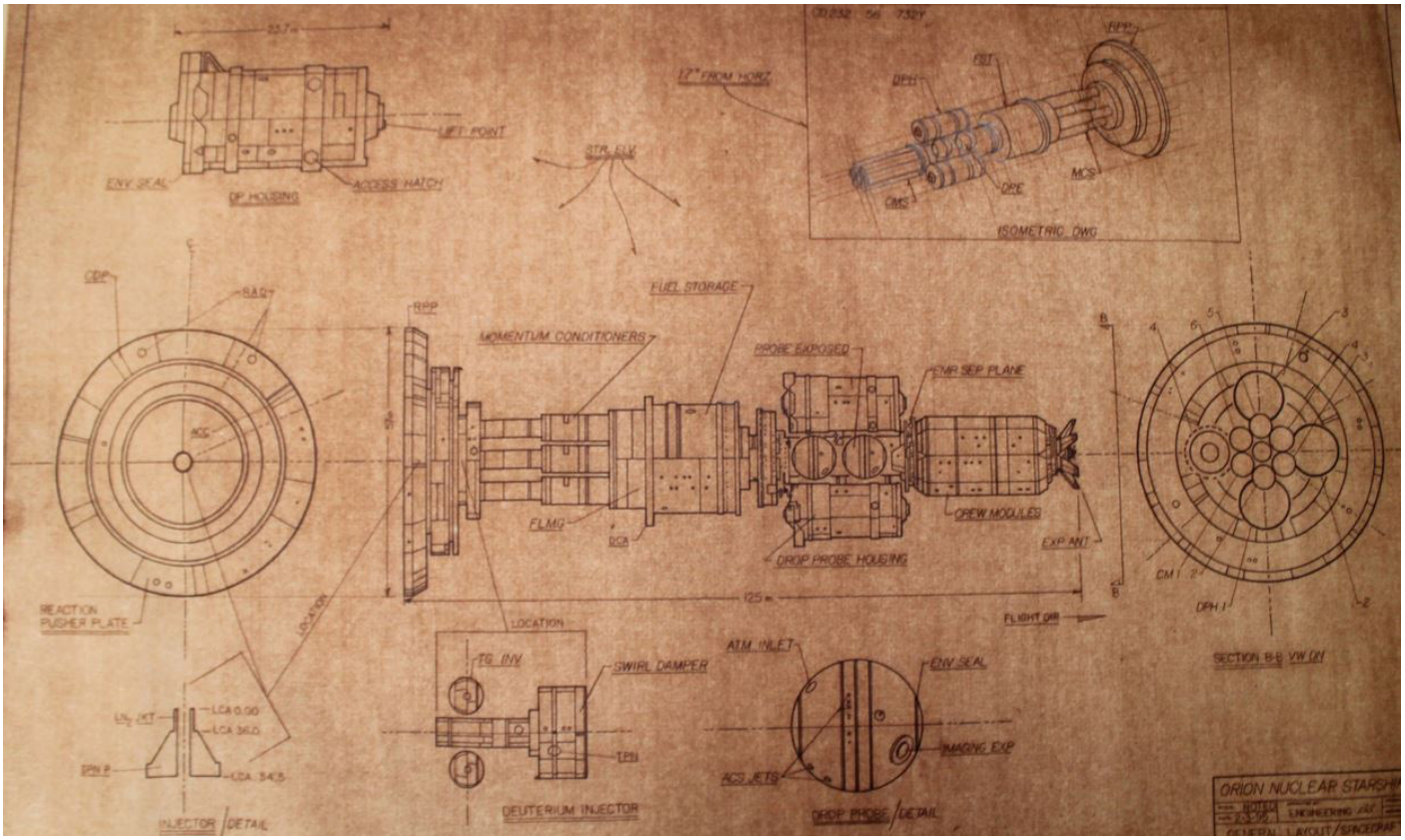
COSMOS: A PERSONAL VOYAGE

A Daedalus interstellar spacecraft using laser or electron beam fusion propulsion Credit: Rick Sternbach / K F Long collection

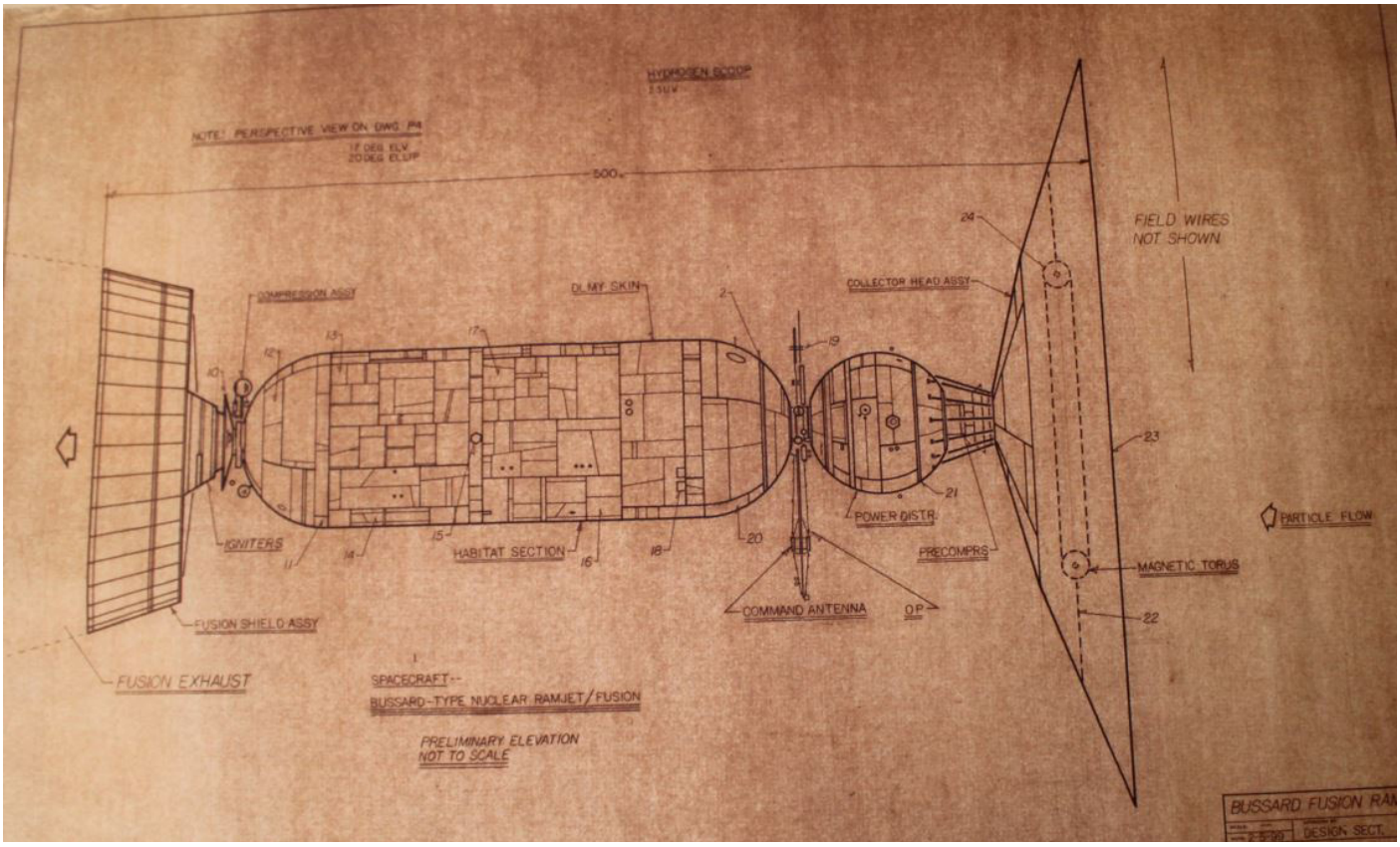
i4is Executive Director Kelvin F. Long hymns the work of Rick Sternbach, Carl Sagan and the Cosmos team

In 1980 the American Astronomer Carl Sagan took part in one of the best television documentaries ever seen on the subjects of evolution, space and astrophysics, Cosmos: A Personal Voyage. This thirteen-part programme was co-written by Sagan and Ann Druyan and Steven Soter, and Sagan also featured as the main presenter. The show was so popular that a book was also published to accompany the series. The series was one of the most widely watched programmes in history and went on to win several awards. It is alleged to have been seen in more than 60 countries and by over 500 million people. Episode eight of the series was titled "Journeys in Space and Time", which contained ideas about time and space from Albert Einstein's special theory of relativity, discussions on red shift and blue shift relevant to the measurement of distance and speed for interstellar objects.

The episode also took Carl Sagan to Italy. Here he discussed the astonishing works of the Renaissance man Leonardo da Vinci. It was in this context that he also discussed the British Interplanetary Society (BIS) lunar lander and then went on to a discussion of interstellar travel. This included the different speeds we may be able to travel at, and the implications for time travel, and even circumnavigation of the entire universe. The key starship designs discussed by Sagan included the BIS Project Daedalus (nuclear fusion propulsion), the US Air Force and General Dynamics Project Orion (nuclear bomb propulsion) and the Robert Bussard concept for an Interstellar Hydrogen/Helium ramjet (nuclear fusion propulsion). When discussing the potential for travelling close to the speed of light, Sagan mentioned the possibility of travelling to the centre of the galaxy in only 28 years, or the edge of the Andromeda Galaxy in only 30 years – all ship time of course. Sagan had discussed similar ideas in his paper "Direct Contact Among Galactic Civilizations by Relativistic Interstellar Spaceflight" (Planet.Space Sci, Vol 11, pp.485-498, 1963). For this reason, and others, Sagan is an important participant (and pioneer) in the subject of interstellar studies and SETI, and did much to promote the subject, and its positive benefits to human kind. Today he is best remembered by the



Engineering drawing of Orion spacecraft, produced for the Cosmos series. Based on the work of the Orion project team. Credit: Rick Sternbach / K F Long collection



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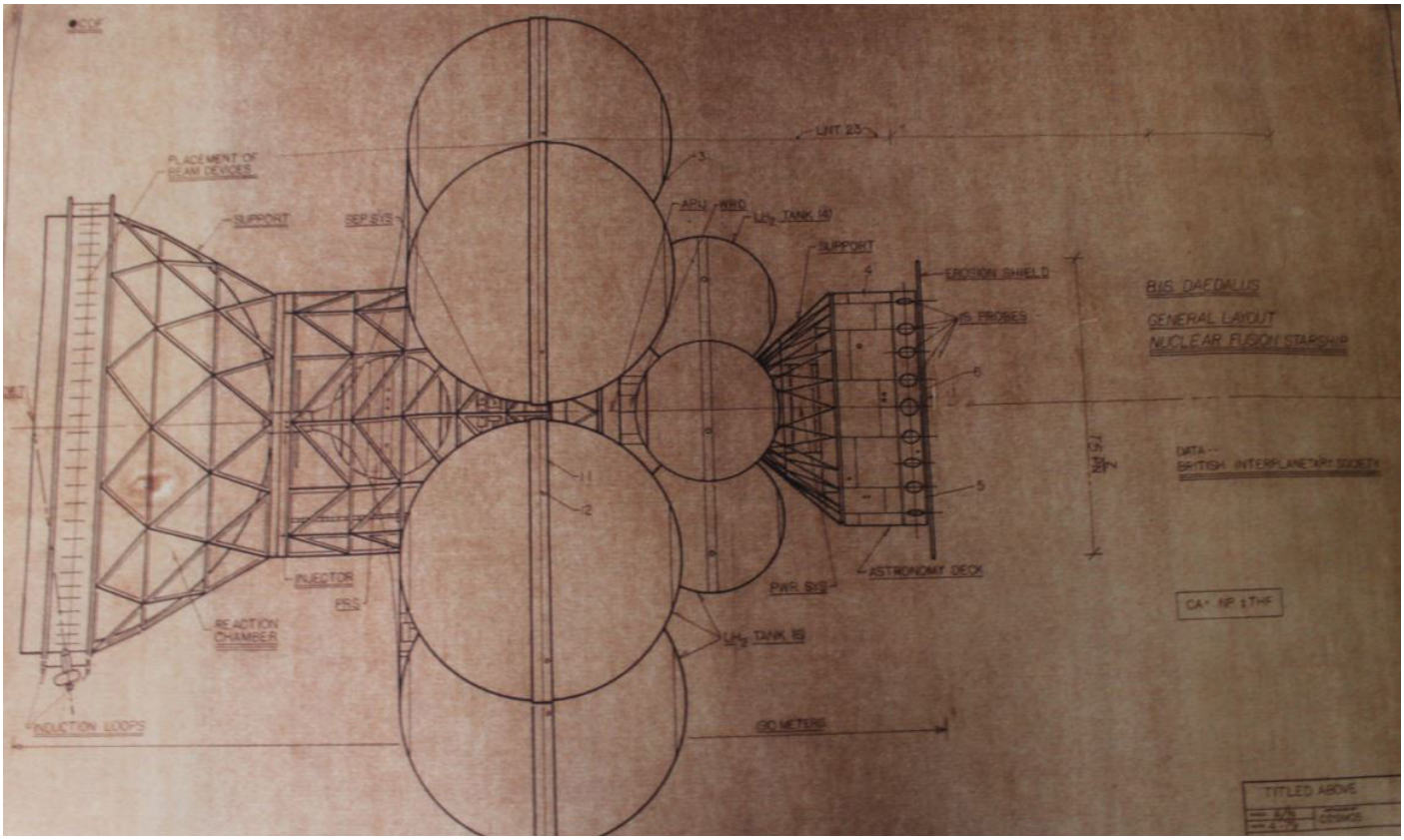


Engineering drawing of Daedalus spacecraft, produced for the Cosmos series. Based on the work of the Orion project team. Credit: Rick Sternbach / K F Long collection

work of the American Planetary Society, of which he was a co-founder.

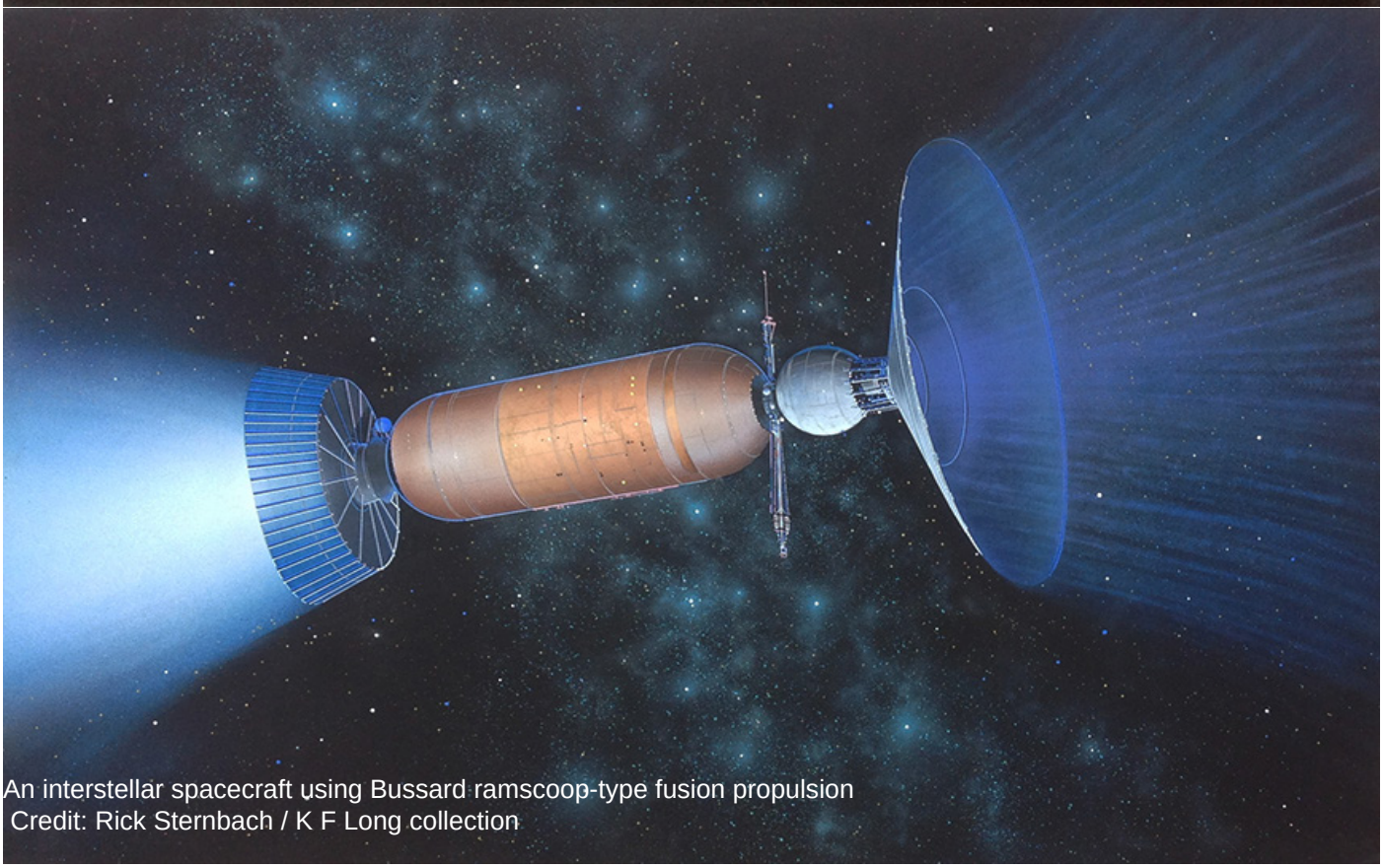
I had not watched the original television series when it first was shown and I only watched it when the DVD collection came out many years later. Suffice it to say, when I watched episode eight, I was quite taken aback by the inspirational visions that were shown of the starships, and also in the highly appropriate context of Leonardo da Vinci. After some investigations, I managed to locate the artist responsible for the art work shown by Carl Sagan, and it turned out to be Rick Sternbach, who had also produced a lot of illustrations for the Star Trek television series. Later on I would also work with Rick (and also the artist Don Davis) in the construction of a paper for the Journal of the British Interplanetary Society titled "The Enzmann Starship: History and Engineering Appraisal" (JBIS, 65, PP.185-199, 2012, A. Crowl, K. F. Long, R. Obousy).

So I contacted Rick and asked him about the drawings and the paintings, and it turned out that he still had them. So, over several years, I gradually purchased them all from Rick and they were sent in large parcels from some place called Hollywood, Los Angeles, California.

The pictures are now displayed on the walls of my home for all to see. But, when the Initiative for Interstellar Studies has our own headquarters, we do plan to run the occasional art exhibition and the pieces will be displayed for that purpose so that the general public can also enjoy the marvellous work by Rick Sternbach, and also be inspired by the optimistic visions of Carl Sagan. As a space art collector, I also own work by David A Hardy, Adrian Mann, Clive Burrows, Gavin Mundy, and Jackie Burns. My ideal space art to collect would be by John Berkey. All of these artists have in common that they are able to communicate the visions of interplanetary and interstellar space flight, and help the public to imagine what the future can be, if we continue to work towards it. This has been a long tradition in the space sciences, stemming from some of the original artists such as American Chesley Bonestell and Briton Ralph Smith. It is wonderful that Carl Sagan also recognised this tradition and its importance. Today, many of these artists are represented by the International Association of Astronomical Artists (IAAA) of which I am an associate member (www.iaaa.org).

The three Cosmos paintings are

An interplanetary spacecraft using Orion-type propulsion
Credit: Rick Sternbach / K F Long collection



An interstellar spacecraft using Bussard ramscoop-type fusion propulsion
Credit: Rick Sternbach / K F Long collection

original acrylic creations, done by hand for the Public Broadcasting System miniseries Cosmos in 1978-1979 and used in production of the program and published in the companion Cosmos hardcover book. The various engineering drawings or 'blueprints' are also artwork for the same three vehicles and are known as

About the Author
Kelvin F Long has been a leader in Interstellar Studies for many years. He is one of the founders of the Initiative for Interstellar Studies and is currently its Executive Director.

The BIS Daedalus Model - the last lap

Terry Regan

The two stages of the completed model - note the small human figures at the base of the first stage
Credit: Terry Regan

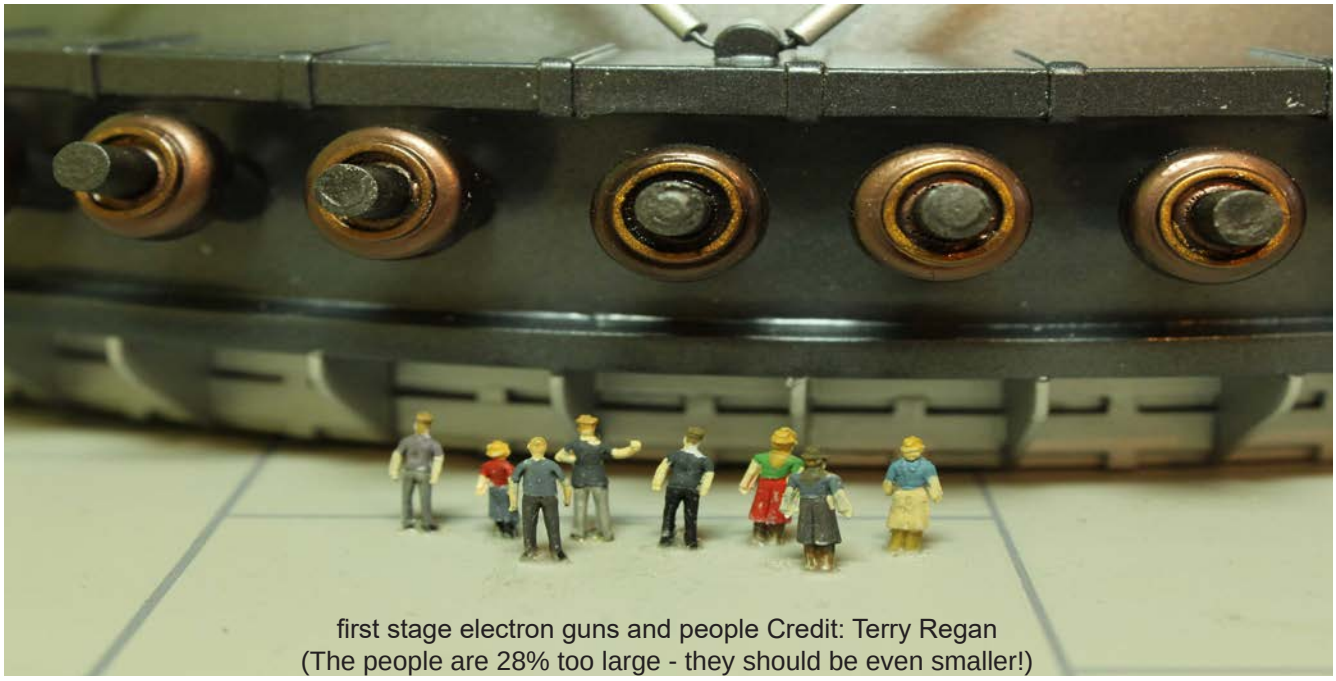
Following on from the photo feature in the last Principium, Terry Regan, of i4is, BIS and the North Essex Astronomical Society tells us about the final part of his construction of a 1:450 scale model of the BIS Daedalus starship. This is a personal account of around 700 hours work. That's about 100 working days or nearly 6 months solid work. And Terry has a day job too! The Initiative for Interstellar Studies salutes our most skilled model builder and looks forward to seeing the model at the British Interplanetary Society headquarters in London in the near future.

Terry gave an account of the early stages of the work in Principium 8 "Building Daedalus: Step-by-Step". This concentrated on the smaller second stage. He takes up the story….

Daedalus The 1st Stage (Engine)

After building the second stage I took a couple of months off and in that time I spent looking around for various parts and bits and pieces to build the 1st stage. I needed a dome of a diameter around 230 mm and as I just could not form a perfect dome by plunge moulding, I came across a dome of 235 mm.

Sitting the dome on the bench I measured up from the bottom 40 mm and made a mark all the way round, then again measured up 15 mm and again marked all the way round. This area was where the electron guns are going to go. Next I need to make two rings, top and bottom, to fit where the two marks that I had made.



first stage electron guns and people Credit: Terry Regan
(The people are 28% too large - they should be even smaller!)

This opened up a few problems. The top ring inner diameter is going to be smaller than the bottom ring and also these rings must be perfectly level otherwise it will spoil the overall look. Below the section that holds the electron guns is the Induction Loop. Having a long thought over this problem I decided to start making the Induction Loop. I cut a length of styrene strip 14 mm wide, not 15 mm, and around a 1 metre long so as to allow for the thickness of the ring sitting on it. I curled the strip round my fingers then offered it up to the dome, trimmed off what was not needed and glued. Next, to cut the bottom ring, I made several templates out of cardboard until one fitted perfectly.

Taking the measurements from the templates I cut out from 2 mm plastic styrene, two discs, outer 245 mm and the inner 222 mm diameter. Glue these two together to make it 4 mm thick and now I have the beginning of the Induction Loop. This ring was not yet glued to the dome as I would need to remove it several times to carry out more work on it.

support structure and second stage with one first stage tank removed Credit: Terry Regan

Now to the electron gun mounting ring, again several templates were made till I found the perfect fit. Looking at Adrian Mann's CAD drawings they show a ridge/trench but not a gap by the dome so I cut one disc, outer at 245 mm and the inner work out at 215 mm, which gave a nice snug fit to the dome. The second disc I cut again 245 mm outer and the inner at 218 mm again using 2 mm styrene card. I now have the ridge/trench look.

Now I had the top ring made I cut a strip of styrene card 22 mm wide and around 1 metre long and again curled it around my fingers to get the ring. Now I had another problem, this ring has got to sit perfectly square all the way round otherwise it will look awful and again spoil the look. So another set of rings were made but with a smaller outer diameter, one to be glued to the top of the Induction Loop and the other to the underside of the top electron gun ring then I glued in the round ring where the guns are going to be fitted. I now had the bottom part of the dome ready for detailing.

Going back to the Induction Loop it needed some detailing to give an engineering/purpose feel to it so I cut a few lengths of styrene strips and added to the loop - going by Adrian's drawings. There are 50 electron guns that are mounted on the dome so I had to make 50 side plates to fit to the Induction Loop. These were cut out of 20 thou (0.020 inches) styrene card and shaped. I used a pair of dividers to get the spaces even, the side plates were glued in and then strips of styrene were added to the top of the electron gun ring to give more detail. The last thing to do was to mark out the centre of each of the fifty bays where the electron guns were to be fitted. More on that later.

The Support Structure

Looking at the plans from Adrian Mann (bisbos.com), there are three sections of lattice work construction forming the main support structure. On the second level there is an induction coil and the bottom of the support structure is mounted on twelve mounting points on top of the electron gun housing. I cut six discs off a 3 mm diameter rod, cut them all in half and drilled a 0.6 mm hole through each one and "super glued" 15 amp fuse wire. These would be the locating pins. The mounting points were glued evenly all the way round the top of the electron gun housing. Using a pack of 2.5 mm styrene rod I cut into lengths of 45 mm and drilled both ends with 6 mm holes so they could lock into the fuse wire. I then cut off twelve 3 mm discs, again drilled a large hole end to end and threaded in two pieces of fuse wire, spread them apart and drilled a hole half way round to take the cross bearers. Next I started to build the support structure placing each rod into the fuse wire but not gluing at this stage as adjustment would be needed. Another set of rods were cut to 45 mm long and again drilled both ends. More 3 mm discs were cut (this time only six) and then cut in half, drilled and fuse wired and then fitted. It's all now taking shape although looking somewhat out of line. I will worry about that later! Now I had the two part lattice work support structure built although nothing at this stage is glued down and all is held together with fuse wire. Next step was the induction coil; this was made out of 2 mm thick plastic card with diameter of 170 mm x 12 mm wide using a compass cutter and detail was added to the ring. Once I was happy with it, I made the third part of the support structure - same again, more support mounts, drilling and fuse wire. It was all assembled to the main dome. A steel ruler was placed on top of the structure in six places and the structure was all out of line. I didn't even have to check the measurements, it looked awful!

Eureka! A broken wine glass Credit:Terry Regan

The Support Structure

All the rods, as I mentioned, weren't glued so the first job was to "tease" the structure into some sort of shape around the dome which took out around 80% of the "misshape" then replace the ruler on top again in 6 places and took measurements. I found 8 rods required shortening by a few millimetres. I rechecked the measurements and found again a few "tweaks" here and there. Another measurement and this time it's spot on. Each piece was taken off glued and refitted.

Vertical Truss

This is the vertical support structure. It goes through the Parabolic Reflector and is the large disc that holds the six large

fuel tanks and the second stage. This would have to be made in two parts. 12 rods were cut in lengths of 55 mm, drilled and pinned, and fitted to the support structure. I hit another problem; the vertical rods went all out of line so I had to make a jig to fit on top of the rods which kept everything in line. Once happy I started to build in the lattice work and it needed yet another Induction Coil so another ring was made, 5 mm deep with two rings cut out for the top and bottom and glued to the truss. A second truss was made to go on top of the Parabolic Reflector but this needed an internal support structure to hold the second stage.

Second Stage Support Structure.

The second stage Daedalus sat inside the top part of the main engine support structure. Emailing Adrian Mann about this I found out there was no documentation on this so I came up with my own idea. So I made four framework structures with an angle guide so, when lowering the second stage, it basically guided itself to rest with electromagnets to hold the second stage in place. The idea behind this is - cut the power, and away it goes! My thoughts were that if explosive bolts, clamping system were used, all you need is one bolt or clamp to fail and the whole mission would be jeopardised. I test fitted the second stage into the truss, took measurements and made the support structures. I pinned and glued the structures in and did a test fit. Disaster! The second stage just didn't fit, I was one millimetre out on my measurements, so removed them, trimmed them all up and refitted - all OK!

Parabolic Reflector

I had to cut a large disc out of 2 mm plastic card. As I don't have a compass cutter big enough I had to make my own cutter and cut a disc to be 360 mm in diameter. Then the next problem was to form the pellet gun funnel. I had been thinking about this for a couple of years and came up with nothing until one evening in the pub, I was enjoying a pint when one of the bar staff broke a stem off a wine glass "Eureka!" there was the answer to my funnel problem. I couldn't use that wine glass as it was too badly damaged, so I bought two glasses and cut the base off the stem in one go, heated up the plastic and plunged the glass in to form the funnel. So I'm sorry to say a wine glass was harmed in the making of this model.

A second disc was cut out and then I cut out the centre and glued the two together to give it some strength. The top half of the truss was then glued on. The whole disc assembly was fitted to the engine and I checked it all was level. Some tweaking here and there and all is fine!

The Fuel Tanks

I needed six tanks of around 140 mm in diameter and searching on the Internet came up with large Christmas "baubles". They were 150 mm but I ordered them. Once they arrived I cleaned off all the glitter and detailed them. Now on to the fuel tank support arms. Going from the CAD drawings from Adrian Mann they were again a lattice work construction. Again I just could not replicate that so, using six square plastic rods, I drilled hundreds of holes and made six locking mounts to fit on the truss and twelve locking mounts to fit on the end of the arms. The tanks were all fitted to check for alignment. Again some tweaks here and there and all is good. Now for the big test, will the support structure take the weight of the fuel tanks and the second stage? The biggest lump of my life came into my throat as I placed the whole assembly, fuel tanks and second stage onto the main engine support structure and stepped back waiting for everything to collapse. It held the weight! I was just gobsmacked. I gave it a good look all over and there were no bulges or bits and pieces breaking away so I left it for a week and all was OK, the panic was over. At this stage I had spent over 350 hours just building the 1st stage so a well earned beer was needed.

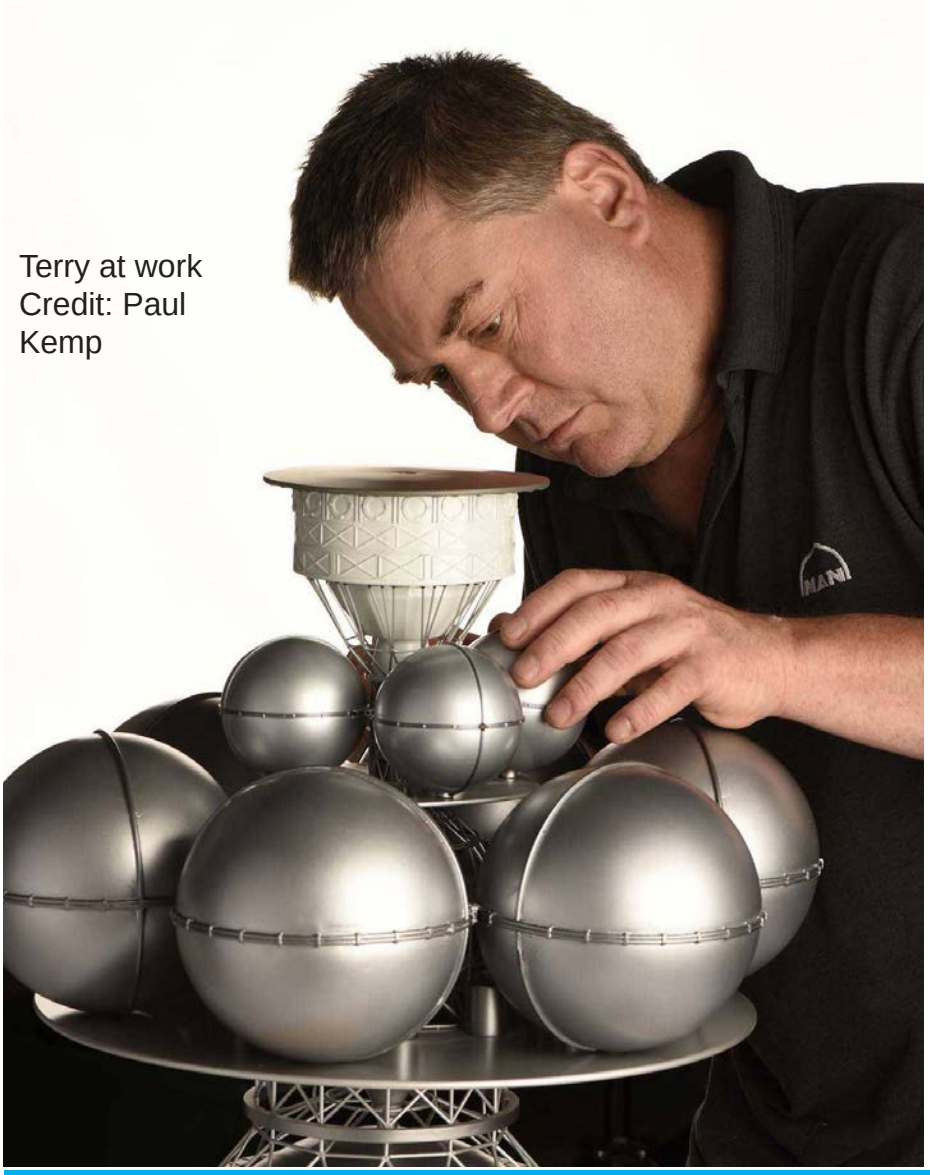
The final detail

A hole was drilled in the bottom of the funnel for the Pellet Gun and drilled into the top of the engine dome, I had a 60 mm diameter Christmas "bauble" which was just perfect for the LH tank. This was wrapped in gold foil from a chocolate sweet Rolo wrapper with a rod glued in the bottom for the pellet gun. Twelve power supply/power storage systems were made from 21.5 mm plumber's plastic pipe - detailed.

The finishing stage - Painting.

At this point not much had been glued together so the whole model was disassembled ready for painting, I wanted to give a very real engineering feel to the model so a trip down to Halfords car accessory shop was required! I looked at their car paint range and picked up several different shades of silver. The whole model was given a few coats of primer. The main engine dome was given a coat of graphite grey, the

support structure bright silver, the fuel tanks in an aluminium shade and so on - trying not to clash with colours. The fine detail was airbrushed using car paints. Now to get the paints from the "rattle" cans I formed a funnel from greaseproof paper used in cooking, put it into a jar and sprayed onto the paper. Collected it in the bottom of the jar and then poured it into the airbrush. I wanted to add panelling detail to the Parabolic Reflector and I wanted to keep it to an astronomical/interstellar theme so I sprayed the disc in Rover Starburst Silver then masked up into panels. Next was Ford Moon Dust silver followed by Nissan Stardust silver and finally Ford Cosmic Silver. The whole model was then reassembled and glued. A base was needed so I got a piece of Pine wood 600x600 mm rounded the edges off and gave it several coats of vanish, rubbing down each coat until it was like glass. The BIS and Icarus Interstellar logos were made and finally a brass plaque will be fitted and one final thing to be made is a carrying box. The model will have to be transported and custom made boxes will be the easiest way to do this.



Terry at work
Credit: Paul Kemp

Conclusion

My total work, including the second stage, was just over 700 hours.

When Kelvin Long of i4is first asked me if I could build a Daedalus Model and then showed me the pictures I just didn't think I could build it due to the complex shape and construction. The model would be quite fragile and it pushed the boundaries of my scratch building abilities. Well this is the end result. It has been an interesting, frustrating, but enjoyable project but it did come with blood, sweat and tears. And yes, blood **was** shed a few times. The model is on the fragile side but I have just heard that an acrylic display case has been delivered to BIS so it has a secure home.

MORE ABOUT THE UNVEILING OF THE MODEL IN OUR NEWS SECTION.

About the Author
Terry Regan is a model maker to both the British Interplanetery Society (BIS) and the Initiative for Interstellar Studies (i4is). His work includes the Voyager and Pioneer deep-space probes and the winning design for the Dragonfly laser-push interstellar probe as well as this magnificent model of the BIS Daedalus starship. He also led the construction of the 4 metre high i4is 2001 monolith for the 2014 SF Worldcon in London, assisted by i4is volunteers Paul Campbell and John Davies. In his "day job" Terry maintains HGVs (trucks to our American friends).

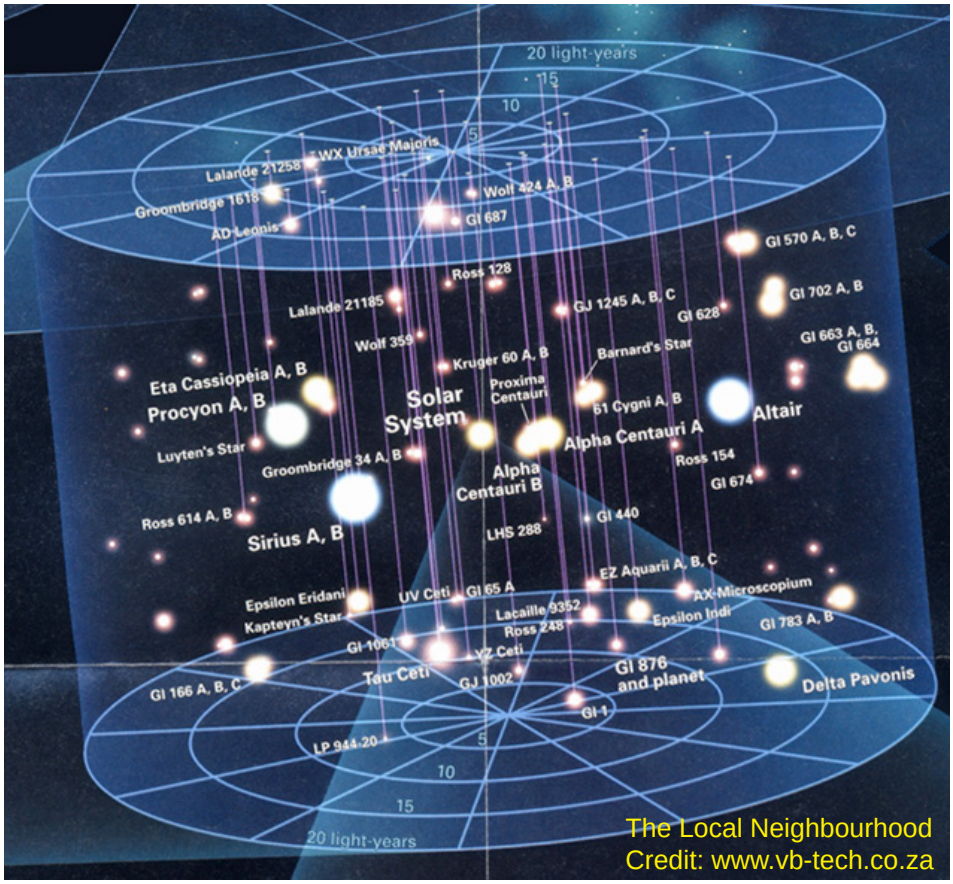
Interstellar Studies at the ISU

Rob Swinney and John Davies summarise two intensive weeks at the International Space University, Strasbourg.

Introduction

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. We aimed to broaden and deepen students' knowledge of starship design and technology. We also covered philosophical, social and economic issues in interstellar studies.

The elective concluded with the presentations of white papers by teams of the Masters students with preparation for these threaded throughout the two weeks and i4is team members assisting throughout.



The Local Neighbourhood
Credit: www.vb-tech.co.za

The Course

The opening theme on the first day was delivered by Rob Swinney *(M8-ISR-L01 Introduction to Interstellar Studies Elective, M8-ISR-L02 History and Background to Interstellar Studies, M8-ISR-L03 Scaling the Problem and M8-ISR-L04 White Paper Brief R Swinney).* Rob started by summing up i4is achievements -

- 1st general interstellar book: Beyond the Boundary
- Supervision of International Space University student reports and projects
- Project Dragonfly - first small interstellar probe design
- School Outreach
- Starship Engineer course

- and the subjects of the course -

- Introduction and Scales
- Choice of destinations
- Ideas from science fiction
- Extrapolating technology
- Precursor missions
- Advanced propulsion concepts
- Onboard systems
- Design concepts for vehicles
- The case for interstellar: Justifications from survival of humanity (threats from destruction) or the simple "outward urge".

Rob continued with the theme: Destinations (*M8-ISR-L05 Destinations, M8-ISR-L06 Precursor Missions 1, M8-ISR-L07 Precursor Missions 2)*

The following day began with Professor Chris Welch, ISU, briefing the students for their white paper work *(M8-ISR-L08 Writing a White Paper).* The main theme was Space Systems, developed by Marc Casson of i4is *(M8-ISR-L09 Space Systems 1, M8-ISR-L10 Space Systems 2)* delivered by Rob Swinney and Sam Harrison. Marc addressed -

- The interstellar space environment - The similarities and differences between conventional (ie Earth orbit) spacecraft environment and the interstellar space environment.
- The spacecraft design process - A look at some of the key budget elements involved in spacecraft design.
- The interstellar spacecraft bus - The similarities and differences between conventional spacecraft bus systems and interstellar bus systems.

The day concluded with Professor Ian Crawford, Birkbeck College, University of London, also by Webex from UK *(M8-ISR-L11 The Local Interstellar Medium).*

The third day covered Spacecraft Design with Andreas Hein *(M8-ISR-L12 Spacecraft Design and Concepts 1, M8-ISR-L13 Spacecraft Design and Concepts 2, M8-ISR-L14 Spacecraft Design and Concepts 3)* covering-

- Part 1: Concept development for interstellar missions - Spacecraft design process
- Part 2: Concept development process - TRIZ problem-solving methods and Architecture patterns
- Part 3: Technology assessment - Concept Maturity Levels (CML), Technology Maturity Levels (TRL), Technology feasibility and strategy.

Andreas was followed by Angelo Genovese, Thales Deutschland & i4is *(M8-ISR-L15 Electric Propulsion, M8-ISR-L16 Advanced Electric Propulsion Systems for Interstellar Precursor Missions).*

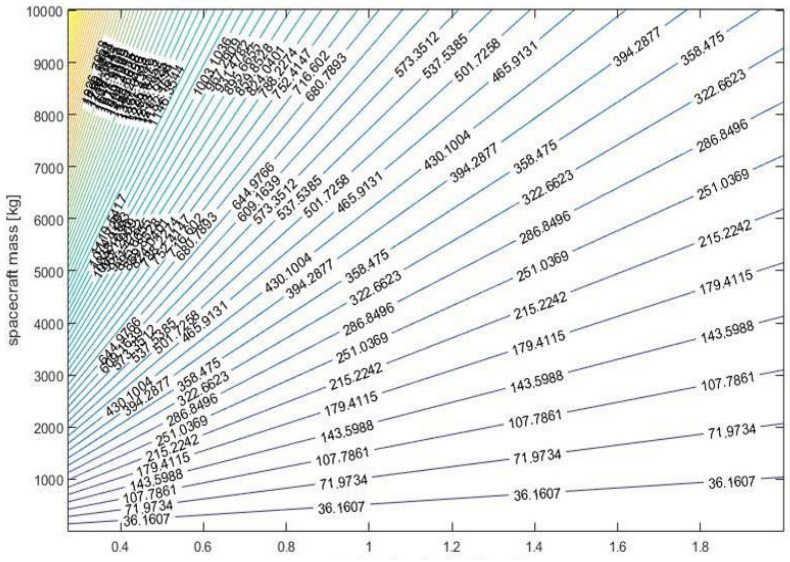
The second week of the course began with Kelvin F Long of i4is on the theme of Advanced Propulsion *(M8-ISR-L18 Advanced Propulsion Systems 1,*

M8-ISR-L19 Advanced Propulsion Systems 2, M8-ISR-L20 Advanced Propulsion Systems 3). Kelvin aimed to equip the students to -

1. Discuss how interstellar propulsion or advanced propulsion differs from conventional or interplanetary propulsion requirements.

2. Explain the basic physics and engineering challenges relevant to the design of interstellar propulsion systems.

3. Describe some of the proposed solutions, including specific propulsion types and how to calculate some fundamental performance properties.



Dragonfly mission architecture comparison (@100 GW beam power)
The higher the spacecraft mass, the more scientific instruments we can carry. The shorter the acceleration duration, the smaller the laser infrastructure (smaller lens). Credit: Andreas Hein

The following day began with the wider theme Making the Case for Interstellar, begun by John Davies of i4is *(M8-ISR-L22 The Case for Interstellar 1, M8-ISR-L23 The Case for Interstellar 2)*. John offered a tentative definition of "Interstellar" in this context -

The means to understand, communicate and travel across the space between the stars.

So "Interstellar Studies" is the study of these means.

John quoted prominent advocates Robert L Forward and Arthur C Clarke and the views of influencers from Tsiolkovsky to Harold "Sonny" White. John finished by suggesting that technological optimism, tempered with political realism, was essential to deliver popular support for Interstellar.

The day's lectures concluded with Stephen Ashworth of i4is *(M8-ISR-L24 Relationship between interstellar and interplanetary exploration)* delivered by Webex from Oxford, UK.

The next day had the theme of Imagination to Reality, paralleling the British Interplanetary Society's "From Imagination to Reality", John Davies introduced *(M8-ISR-L25 Science Fiction Concepts 1, M8-ISR-L26 Science Fiction Concepts 2)* with John acknowledging input from Kelvin Long and Rick Garcia of i4is.

The last teaching day had the theme: Using Einstein delivered by Kelvin Long *(M8-ISR-L28 Interstellar Travel using Einstein Physics 1, M8-ISR-L29 interstellar Travel using Einstein Physics 2, M8-ISR-L30 Interstellar Travel using Einstein Physics 3).*

The final day was devoted to the student teams delivering their white papers:

1. Creating an Interstellar Focussed Society

2. Breakthrough Starshot Sail and Environmental Challenges

3. World Ship Revisited

4. The Nature of Intelligent Life in the Galaxy

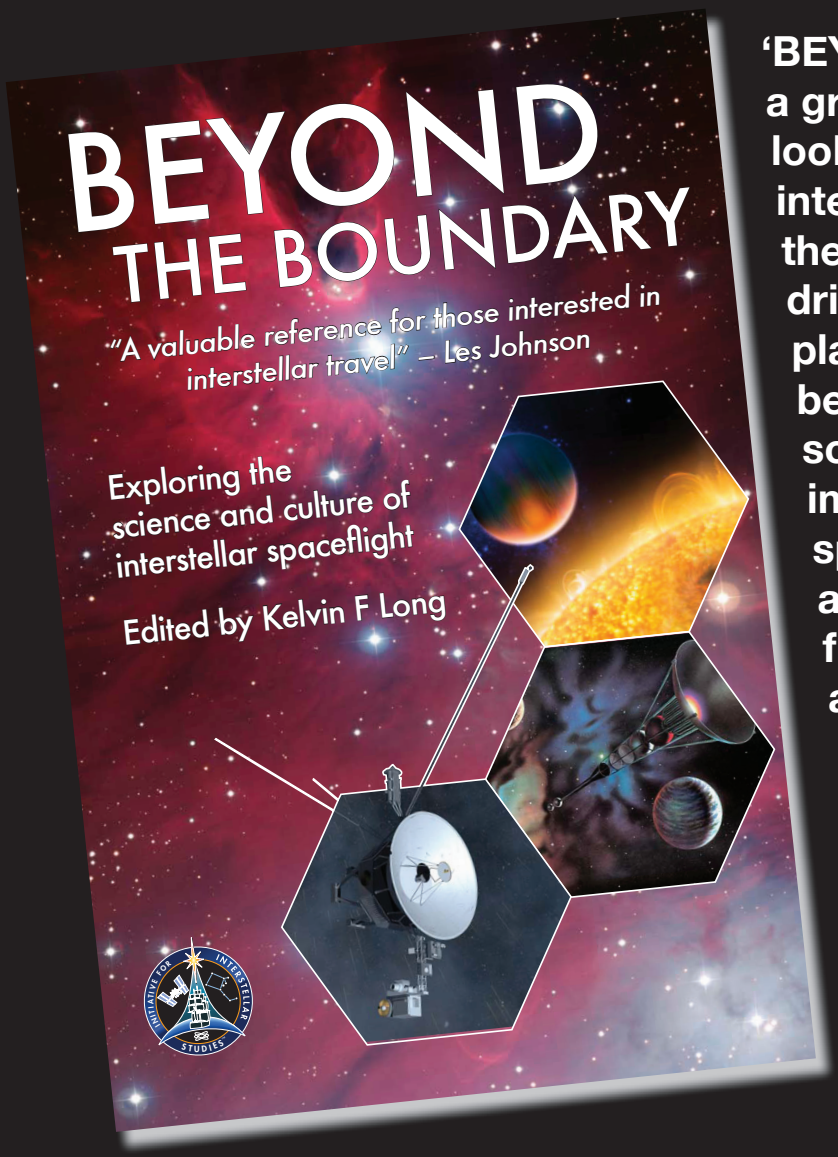
5. An Interstellar Mission Based on Advanced Artificial Intelligence

The adjudication was by Kelvin Long of i4is and Professor Chris Welch of ISU.

More about this course in subsequent editions of Principium.

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**
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- **Topics as diverse as propulsion technology, exoplanets, art and SETI**

www.i4is.org

STARSHIP ENGINEER

Rob Swinney and Kelvin F Long

News of our innovative Starship Engineer course was originally reported in Issue 12 of Principium, published in February 2016. But here, as promised, is a wider report of the course and how it was received.

Introduction

This is the i4is Educational Academy programme which was piloted during 24-25 November 2015 at the Headquarters of the British Interplanetary Society. The course was split into two separate days and participants could attend either or both, although for those that had attended the first day they had an advantage going into the second day having received a good background on spacecraft concepts. The two days were run jointly by Rob Swinney and Kelvin F Long, and although both contributed to the full curriculum, Rob took the lead on Day 1 and Kelvin took the lead on Day 2. There were 34 attendees in total.

Rob Swinney talking about the interstellar medium during Starship Engineer course

Day 1 Lectures

The participants were welcomed to the course by Rob Swinney, i4is Deputy Director and the Chairman of the Education Committee. He began by introducing the Initiative for Interstellar Studies and some of our innovative programmes such as the Project Dragonfly laser-sail propulsion studies. He talked about some of the historical achievements of the interplanetary space probes such as Pioneer, Voyager and New Horizons. He followed this by discussing the possibility of more advanced missions out into the interstellar medium and what science could be achieved. The participants were introduced to the 1990s NASA and JPL Thousand Astronomical Unit (TAU) mission which would have gone to 1,000 AU propelled by a nuclear electric engine using 12 ion thrusters. The probe would have carried a payload of 5 tonnes in mass and the total vehicle mass would have been 60 tonnes with an additional 40 tonnes for the liquid xenon propellant. He then placed this technology and the earlier interplanetary spacecraft missions in the context of the types of propulsion performance required for an interstellar mission.

In the second lecture of the day, the participants were introduced to the different spacecraft systems and this included a case study description of the Voyager probe. The types of subjects studied included the thermal and environment control, radiator theory, power systems, propulsion systems, antennas and the NASA Deep Space Network, communications link budgets.

In the third lecture of the day, the participants were given specific case studies on fusion spacecraft design. This featured elements of the General Dynamics and United States Air Force Project Orion nuclear bomb propulsion initiative from the 1960s, as well as a backgrounder on basic fusion physics theory. The BIS Project Daedalus featured of course, as the students were introduced to its large 50,000 tonnes propellant mass and 450 tonnes payload mass, and nearly twice the height of even the Project Apollo Saturn V launch rocket.

In the fourth lecture of the day, presented by Kelvin, the participants were given specific case studies on solar sail and laser sail propulsion. This started with a solid introduction to solar sail technologies and physics as well as the types of materials that could be used. Some case studies were examined including the Japan IKAROS spacecraft


Team 1 doing calculations


Team 2 doing calculations

launched in 2010 which was propelled onto the planet Venus, as well as mission proposals such as the Interstellar Probe and the Interstellar Heliosphere Probe. The participants were then given a backgrounder on laser sail physics with a specific case study into the Robert Forward 1980s Starwisp concept. To round it off they were introduced to the idea of propulsion hybridization of different engines. This was an idea from Kelvin to combine different propulsion systems as a means of finding new trade-offs to optimise the design.


Starship Engineer Workshop Day 1 Participants

Day 1 Workshop

After the comprehensive lectures the participants then split into two teams and were asked to solve a set of physics and engineering problems that built on the lectures that had been presented. The team members were assigned key positions and this was overseen by a team Captain. This involved calculations relating to propulsion specific problems for a mission to the Alpha Centauri star system 4.4 light years away. But, to throw a spanner in the works, just as the participants had thought they had solved all the problems, a 'design change' was ordered, which meant that some of the calculations had to be revised and then extended into new territory. The idea was to give the participants some experience of what it was like to work on a real world design problem. In the end, they were required to describe the propulsion performance of their final vehicle and also sketch out the mission profile.

Day 2 Lectures

During the second day the participants were introduced to the Starship concepts from Science Fiction (SF). First was coverage of distance scales in the universe, followed by how we look at concepts through the lens of physics, engineering and economics. This was followed by a discussion on different types of energy sources for starship propulsion and the demonstration of an interstellar roadmap linked to technology readiness levels.

Next came a discussion of ideas for flight, from Leonardo da Vinci and his various inventions to stories about how to get to the


Team 1 presentation of design solutions


Team 2 presentation of design solutions

moon such as Jules Verne ‘From the Earth to the Moon’ (1865) and H G Wells ‘The First Men in the Moon’ (1901) and the British Interplanetary Society lunar lander developed in the 1930s and 1950s as a demonstration of the BIS Motto ‘From Imagination to Reality’.

Kelvin F Long presenting starship ideas from SF and space art

Participants were then shown various starships from SF and asked, as part of an interactive session, what they could tell about the vehicle design. This included the Star Wars Millennium Falcon with its hyper-dimensional drive, the original Star Trek warp drive ship, the Bussard interstellar ramjet depicted in the British TV show ‘Red Dwarf’ and the hyper-drive from ‘Blakes 7’. There then followed example space art and SF art from the likes of David A Hardy, Jon Lomberg, Alex Storer and John Berkey, all an exercise in the equivalent of "starship recognition"!

There then followed a swing through various SF literature and the spacecraft and starship concepts were explored. This included concepts from various Arthur C Clarke books including the nuclear powered ramjet (Prelude to Space, 1953), the nuclear electric space drive (Earthlight, 1955), an advanced thruster engine (The Hammer of God, 1993), an atomic powered vessel (The Sands of Mars, 1951), an asymptotic black hole drive (Imperial Earth, 1975), and the hyper-dimensional Monoliths depicted in “2001: A Space Odyssey” (and the sequels), as well as the actual spaceship shown in the film, called “Discovery I”. The course also covered a reactionless space drive (Rendezvous with Rama, 1973), a quantum ramjet (The Songs of Distant Earth, 1986), solar sail spacecraft (The Wind from the Sun, 1972),

It wasn’t all just about Clarke. Other concepts covered included an Alcubierre warp drive (Stephen Baxter, Ark, 2012), Bussard ramjet (Poul Anderson, Tau Zero, 1970), antimatter torch ships (Robert Heinlein, Time for the Stars, 1956), antimatter catalysed fusion ships (Charles Pellegrino, Flying to Valhalla, 1994 and Greg Bear, Queen of Angels, 1990), laser sail propulsion (Larry Niven & Jerry Pournelle, The Mote in God’s Eye, 1974).

Throughout the day actual vehicle concepts and designs were also shown to put SF in context. This included the nuclear bomb powered Project Orion (1950s-1960s), the BIS nuclear fusion Project Daedalus (1973-1978) and Project Icarus successors, nuclear fusion Project Longshot (1988), BIS world ship designs (1984), Enzmann colony starships (1960s), project AIMStar antimatter propulsion (1990s), the microwave driven sail Starwisp concept (1984).

The participants were also given some insights into the fundamental physics issues such as relativistic flight effects due to Einstein physics, propulsion theory such as thrust, specific power and jet power, vehicle structure materials design, calculating artificial gravity, detailed case studies into world ships, fusion starship designs and laser/microwave beam propulsion concepts.

The participants were then taken through a series of physics and engineering calculation problems, originally written for the i4is Interstellar Minimum paper (see a later issue). This covered all of the key propulsion concepts as well as other design subjects necessary to begin understanding starship design principles.

Day 2 Workshop

During the afternoon the participants were again divided into two teams each choosing a project leader and other roles. They were given the challenge of constructing their own starship using the knowledge they had gained and their own imagination; after all this day’s workshop was based on SF concepts. They were to describe the power source, propulsion and provide supporting calculations for the design.

It was to be a starship that was capable of travelling at a speed much less than light but exceeding 0.5% c. There were to define the cruise velocity, typical travel times, mission destination, mass breakdown, dimensions of the vessel and an estimate for the population size. A diagram of the vessel design was also required and in addition the participants were given the challenge of describing the background society, culture, primary alien anatomy and planet of origin. They were to also describe the industry on the planet which gave rise to

the starship and its associated technology and to describe the connection between this industry and the planet's economy which gave rise to the starship society.

Another challenge set was to define the value system of the background culture which enabled value transactions (eg money), the background political system and other factors relevant to the society, including the governance structure of the starship. And if all this was not challenging enough, they were also given the additional task of adhering to the criterion of their starship being 'sustainable' including three ecological elements to it, the relationship of the vessel and its environment to the crew, such as the starship replicated elements of 'living systems' as studied by Professor Rachel Armstrong of Newcastle University. Adherence to the known laws of physics was vital and all results were to be presented to the workshop at the end of the day.

It will not come as a surprise that all of this turned out to be a hefty demand for the short time that the participants had to address the problems, although that was one of the learning experiences of running the workshop, and for sure the participants had a lot of fun. The output from the two teams is described below, although a modified design layout is represented in Table 1, based on an assessment of the team's calculated design numbers and the conclusion that further changes had to be made to make them at least self-consistent.

Team Antrix (meaning 'between the worlds' from Sanskrit), envisioned a race of people who lived on a planet around a star. These people had eventually became space capable and then discovered a species of space born creatures that took nutrition by feeding on energy from the local star. These space creatures were not necessarily intelligent, although they had evolved naturally in space, and could reproduce. They were not in themselves interstellar capable. It was discovered that what they actually farmed were antimatter particles by converting them from particles emitted by solar flares.

The people found a way to domesticate these creatures, and then utilise them by capturing them and placing habitats within their structure. In the same way that bacteria lives within a body, so the people could live within these creatures. This living process was sustainable in that the waste products of the creature would be re-used by the society on board. It was realised that there was potential to use these creatures like world ships and to adapt them as living vessels, and so using techniques from genetic engineering the creatures were bred up over multiple generations into actual world ships.

The creatures, which had a squid like appearance, would move close to the star, and open wing like structures to make a large surface area of at least 100 km in each direction. This would then act as a solar collecting area, and close to the star would receive around 65 MW/m^2 of power and so on that basis would take a lot of power to generate that energy and accelerate it to the required cruise speed. So with a 10 by 10 m^2 solar collecting area, it would only take a day to power up if one assumed a 100% energy efficiency. In reality, with an assumed 10% conversion efficiency, the creature would spend between 5-10 years near the star absorbing its energy, and then convert that into antimatter. Once it was replenished it would drift away from the star, close up its 'wing like' surface area, and the habitat would be placed within its structure. It would become a hybrid between a biological entity and a spacecraft. Once fully charged it would enclose the habitat within its wing structure. They speculated that there would be lots of these hybrid spacecraft which would flock like birds.

The living world ship would be capable of travelling to speeds up to 3% of light, which meant that a journey to 2 light years would take around 60 years, or a little more when accounting for acceleration and deceleration. At the destination, the habitat could once again be separated from the main creature and it could begin the process again of mining its fuel from the local star, prior to embarking on the next leg of its journey.

The habitat would hold around 110,000 people and would have a length of around 10 km, and the whole ship would have a mass of around 100 million metric tonnes. The team estimated that travelling at the cruise speed, for a given million tonnes, that will be 5×10^{22} joules per million tonnes of kinetic energy for that speed.

The team estimated that to get the required energy for a single interstellar flight, they would need to mine around half a million tonnes of antimatter to generate the required energy, and this would also be combined with an equivalent mass in matter, so the total fuel mass would be around 1 million tonnes. This implied that with the 3% c cruise velocity that the final mass would be around the same as the initial mass. Therefore for the total

combined mass of 100 million tonnes, around 3 million tonnes of that would be the fuel, on the basis that rocket equation showed that the initial mass and the final mass would be nearly the same, due to the high performance of antimatter fuels.

In consideration of the economic steps to interstellar flight, two phases were envisioned. The first was the development of an economic capability to get off world and so domesticate these space born creatures. The second was the independent economy to build the world ships. Once the society was out into space visiting other planetary systems, it sustains itself economically by trading resources between different stellar systems, in an analogue to a chain like group of Pacific islands. Developing this interstellar capability obviously depended heavily on the construction of these biological starships, which had to be grown and this process could take up to 1,000 years before they reached maturity.

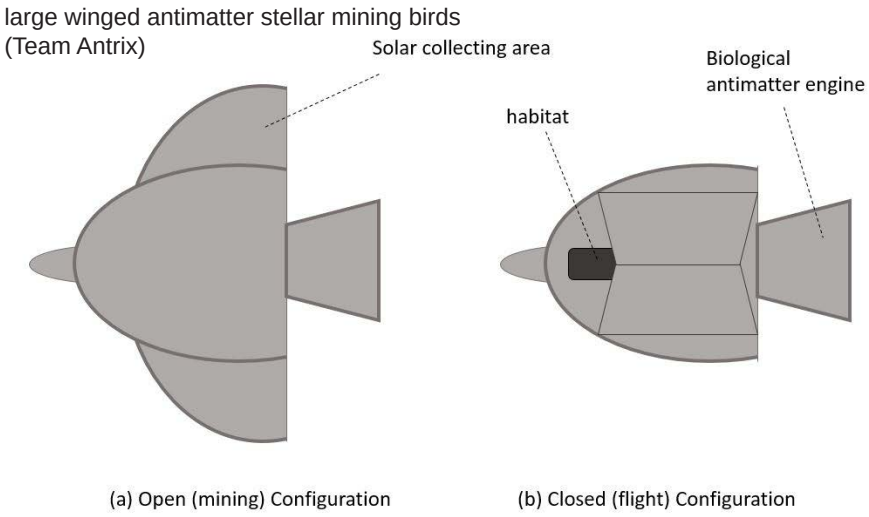
Team Griffin (who named their starship 'Phoenix') envisaged a race of spawn people, who were bipedal and mostly lived on land, but were also partly amphibious, and had evolved on a planet they called 'The Pond'. The species had a single compound eye and had evolved to perceive light on very low levels which included infra-red wavelengths. They are capable of carrying hundreds or thousands of eggs for each birth cycle. The species were quite tall with a height of between 6 ft and 9 ft.

The species were already space capable and had evolved their society to the point of mining local asteroids and had sent probes into their local interstellar

The Initiative for Interstellar Studies is Hiring!

For the moment this is pro bono - though we have ambitions. We produced the flyer below for the BIS Charterhouse Conference, July 2016, but the message is, of course, universal. We have new team members already helping but we need more - from all the talents and from all parts of this planet.

Get in touch with any of our team if you have a drive to help us go to the stars - or just email info@i4is.org

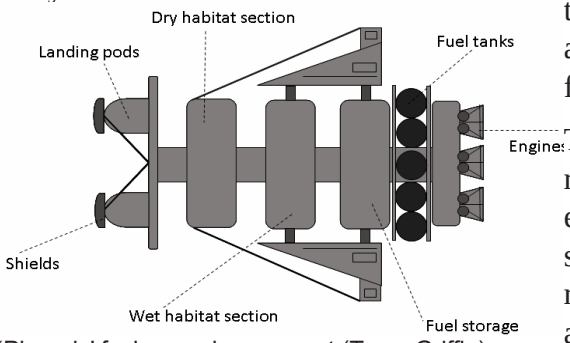


medium. In particular, the species were said to be aggressive in nature, and to have evolved weapons based technologies, including nuclear, which enabled them to build the starship power and propulsion systems. To moderate their aggressive and self-destructive tendencies, they had created a system of control which deferred decisions to a single female egg carrier. They had no concept of trade or commerce, and to control their own population sizes they would resort to cannibalism.

The species lived on the third planet from their star, and there were other populated planets in their system from separately evolved species. But an accident wiped out one of the other species and a lot of their knowledge was passed on to the spawn people. The earlier species had a technological capability that was 1,500 years ahead of the spawn people.

They had set their attention to the design of starships due to a pending ecological disaster due to the volcanic eruptions and the danger of a runaway greenhouse effect (as on the planet Venus) and the expected expansion of their star. To avoid this pending disaster, they estimated they had 50-100 years to develop the starships and escape off world. Approximately 1,000 to 10,000 people would be sent to populate the new planet.

The starship designs they invented were powered by three deuterium-helium-3 fusion engines and had a payload of typically 10,000 tonnes and a total ship mass of around 10 million tonnes when setting out. The starships would leave the stellar system entirely, and would typically set out to travel a distance of 10 lightyears (LY) to the next star system. They would accelerate at around 2% Earth gravity and reach 10% of the speed of light in around 5.5 years. They would take around 90-100 years to complete the journey and this would be followed by approximately 6 months for deceleration.



'Phoenix' fusion engine concept (Team Griffin)

The creatures achieved regulation of the environment on the starship using a self-regulating ecosystem, animal, plant, atmosphere, which would then interact. It would be continually regulated but they can intervene if the system started to fail. It was built around a main ecology pod. Other pods on board the starship included one that contains water, which is where the eggs are laid. This was required for the species development as partly aquatic life forms. So it would have both a dry and wet environment. The large pods would be positioned on the back of the starship and the smaller ones towards the front. A heat shield would be located on the front of the vessel. Small thrusters would be positioned on the side of the starship to control gravity spin and manoeuvring. The vessel would also host an artificial intelligence and spare parts for en route maintenance.

Table 1 is an attempt to compare the two designs from Team Antrix and Team Griffin, modifying the numbers a little in order to provide a consistent model. Where significant changes to the designs were made this was necessary in order to prevent a design inconsistency. The two important parameters that were adhered to from the original concepts were the cruise velocity and the total wet mass (structure + payload + fuel).

What emerges is two very inefficient concepts, both in their use of mass and in their use of energy. However, it is the intention here to show the output of the workshops, 'warts and all' and the reader should keep in mind that the majority of participants had no experience with spacecraft design and a sometimes only rudimentary knowledge of science and mathematics. Despite the output, it was an interesting exercise to see what creative ideas the participants would come up with

after only one day of learning.

The Starship Engineer education course was a pilot programme and the i4is team learned a lot from running such an event. Indeed, a similar event has now been tested on four separate occasions and the learning experiences from this will be used in the future to help develop a credible spacecraft education course but one that also produces realistic and usable output, deserving of the name Starship Engineer.

As well as a certificate, the participants attending both events also received a specially printed publication titled 'Starship Engineering: Foundational Topics for Interstellar Space Exploration – An Interstellar Monograph' co-written by the organisers as an introduction to Interstellar Studies. i4is plans to continue to build these educational courses. They are a lot of fun and a great way for students, enthusiasts and even professionals to get up to speed on fairly complex concepts relating to interstellar spacecraft and starship engineering. The organisers of the workshop from the Initiative for Interstellar Studies would like to thank the participants for their enthusiastic involvement in this pilot educational programme.

Table 1 Approximate decelerating starship performance for two teams on Starship Engineer Science Fiction workshop with post analysis changes.

	Team Antrix	Team Griffin
Propulsion system	Antimatter engine	Fusion engine
Fuel type	Proton-antiproton	Deuterium-Helium-3
Combined mass (tonnes)	100 million	10 million
Fuel mass (tonnes)	1 million	7 million
Structure mass (tonnes)	24.2 million	346,700
Throw away mass en route (tonnes)	64.8 million	2.64 million
Payload mass (tonnes)	10 million	10 thousand
Population	110,000	10,000
Total mass ratio	8.5	785.8
Mass ratio	2.9	28
Exhaust velocity (%c)(km/s)	2.8 (8,400)	3.0 (9,000)
Implied mass flow rate (kg/s)	7.9	40.4
Implied Thrust (MN)	66.4	363.2
Implied Jet Power (TW)	279.9	1,634.5
Implied Specific Power assuming 10,000 tonnes propulsion mass (MW/kg)	27.9	163.4
Cruise velocity (%c)	3.0 (9,000)	10 (30,000)
Time duration for 5 LY and 10 LY mission (Years)	170.0, 337.0	60, 110
Boost time (Years)	2.0	5.5
Average acceleration (m/s²)	0.000285	0.2

Starship Engineer Workshop Day 2

STOP PRESS!

Starship Engineer 2016 - Weekend of 12-13 November, BIS London

The Initiative for Interstellar Studies will deliver a revised and updated Starship Engineer course over the weekend of 12-13 November at BIS HQ, Vauxhall, London. This is an opportunity to help you understand the issues in deep space and interstellar exploration. We hope it appeals especially to people who find a weekday course hard to schedule - and also those who find weekday accommodation in London expensive. Contact info@i4is.org for details.

NEXT ISSUE

Next time we aim to say much more about our Project Andromeda, reported in the News this time. We will also have a major piece about David Hardy and his artistic and imaginative contribution to making us all more interstellar minded. Our Guest Introduction will be by Professor Nick Kanas, of University of California, San Francisco, and former NASA Principal Investigator. We'll be looking in more detail at one of the course items from the ISU elective reported in this issue. And we'll celebrate the installation of Terry Regan's Daedalus model at BIS HQ with some imaginative picturing of the model inspired by Adrian Mann's art work for Daedalus.

Mission

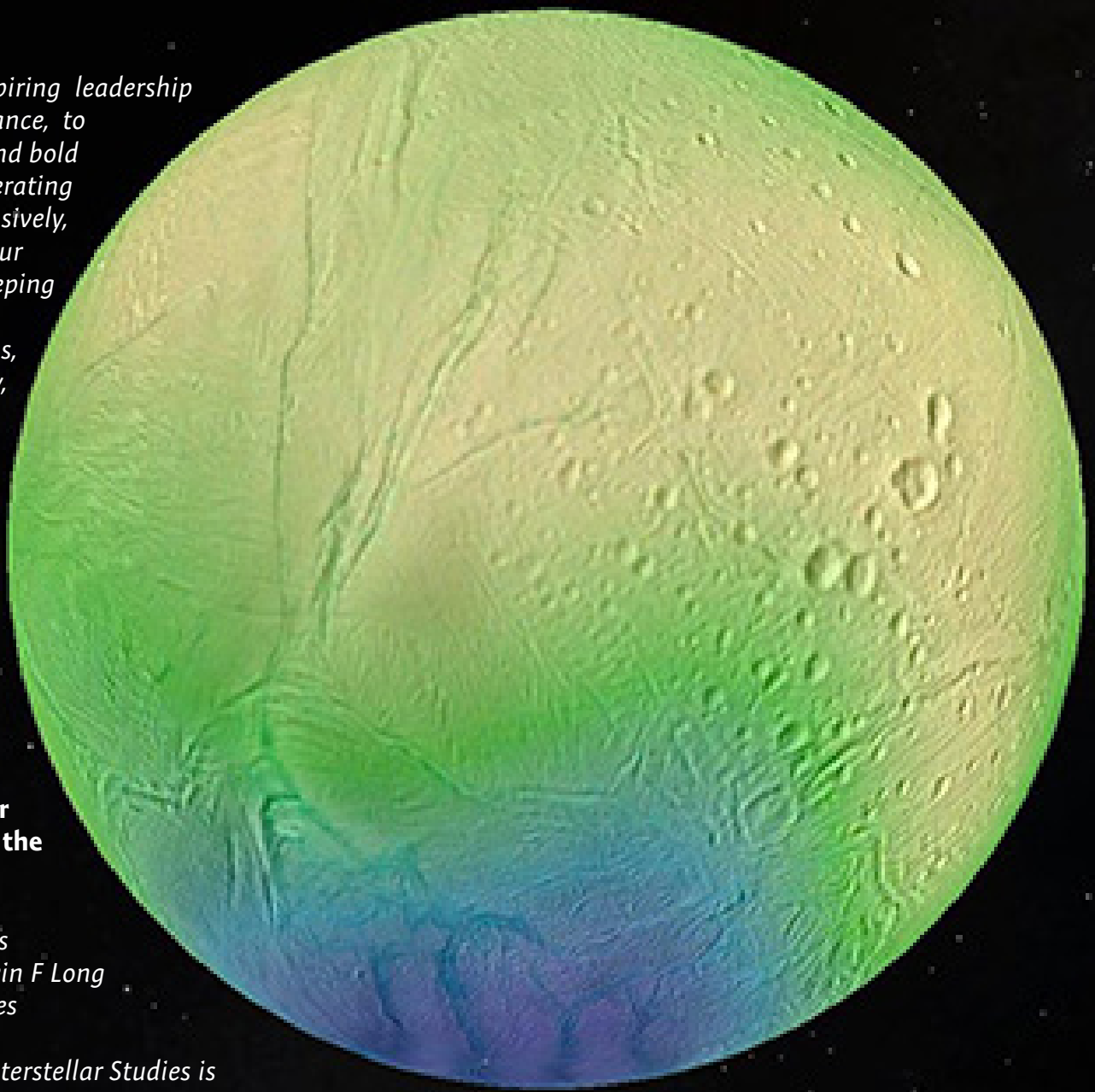
The mission of the Initiative for Interstellar Studies is to foster and promote education, knowledge and technical capabilities which lead to designs, technologies or enterprise that will enable the construction and launch of interstellar spacecraft.

Vision

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

Values

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



We'd love to hear your thoughts on Principium, the Initiative or interstellar flight in general. Email - info@i4is.org - or come along to Facebook, Twitter (@I4Interstellar) or LinkedIn to join in the conversation.

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Front cover: Engineering drawing of Orion spacecraft, produced for the Cosmos series. Credit: Rick Sternbach / K F Long collection
Back cover: The thickness of Enceladus's ice shell, which reaches 35 kilometres in the cratered equatorial regions (shown in yellow) and less than 5 kilometres in the active south polar region (shown in blue). Credit: LPG-CNRS-U. Nantes/U. Charles, Prague.
www.centauri-dreams.org/wp-content/uploads/2016/06/lpgn_a.jpg

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