PRINCIPIUM

The Newsletter of the Initiative for Interstellar Studies
Issue 15 | November 2016

ISSN 2397-9127

www.i4is.org

Editorial

Welcome to Principium 15, the quarterly newsletter about all things interstellar.

Interstellar News this time reports on the 60th birthday of BIS Spaceflight magazine. We hope we can be as good - and last as long! We report from the annual Starfest of the North Essex Astronomy Society in Chelmsford and on our annual Progress and Planning meeting. We greet two major films on interstellar themes for the Christmas season and chronicle the seemingly endless travels of our Executive Director, Kelvin F Long.

Our Guest Introduction this time is by Nick Kanas MD, who has advised NASA on astronaut psychology over many years. He examines the psychological and sociological issues which may arise for both generation ships and sleeper ships on very long duration interstellar voyages. Nick is Professor Emeritus of the University of California San Francisco and has also published several novels including one, *The Protos Mandate*, about a colony ship bound for an exoplanet orbiting Epsilon Eridani.

Our series of reports on the i4is/ISU 2016 elective on Interstellar Studies at the International Space University, Strasbourg, continues with a summary of the unit on Space Environment & Spacecraft Systems Engineering by Marc Casson of Surrey Satellite Technology Limited (SSTL).

And as his work takes its place at BIS HQ London, we compare Terry Regan's model of the BIS Daedalus starship with the art of our old friend Adrian Mann. Technical photographer Paul Kemp places the model in a setting inspired by Adrian's art. I think you will agree that both representations of this historic design show the beauty which often arises from great engineering.

And as promised, Andreas Hein (Technical Director, i4is) and Kelvin F Long (Executive Director, i4is) give an account of the Andromeda Study. An i4is team had three days to produce a design for a laser-propelled interstellar mission. This was the i4is response to a March 2016 request from the Breakthrough Initiative. Drawing on earlier work including Project Dragonfly (see Principium Issues 11 and 12, www.i4is.org/Publications#Principium) the team delivered in this very short time. The design differs in some ways from the Breakthrough Starshot proposal but both approaches, the earlier Project Dragonfly work and other recent studies suggest that ultra-light spacecraft using laser-push technology look like our best chance for early interstellar missions.

Our first book review for a while is by a new friend to i4is, Patrick Mahon. Patrick makes a strong case for Gypsy by Carter Scholz as the best hard SF novella in many years. Patrick recounts its plausible technology and rounded characters - still too rare in interstellar SF.

Also promised last time, we celebrate the art and imagination of David A Hardy. David is both a grandmaster of SF and astronomical art and a good friend to i4is. Our piece concentrates mainly on interstellar themes from David's vast portfolio.

The front cover illustration this time is another work of Adrian Mann, extracted from the i4is report on our Andromeda project. It depicts the spacecraft as it approaches its target star. Thanks, as always, to Adrian for lending his talent to i4is and the interstellar cause.

For our rear cover we have an image from David A. Hardy's science fiction work. In this case an image of the starship Liberator from the TV series *Blake's 7*. Despite the dodgy sets and dated effects it was fine space opera made in an era when such stories were very rare on TV - or film for that matter.

Look out for the latest issue of our academic education journal, *Axiom*, out now, 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

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.

The Psychology and Sociology of Interstellar Travel

INTRODUCTION Nick Kanas, M.D.

Professor Nick Kanas, University of California San Francisco, is a long established NASA researcher into the psychological and social issues arising in long duration space missions. Here he looks into the implications arising from very long duration interstellar missions for both multi-generational and "sleeper" crews.

For over 15 years, my research colleagues and I were funded by NASA to investigate psychological and interpersonal issues affecting near-Earth manned space missions[1, 2]. The results of our work and studies from other labs have isolated a number of psychosocial issues that are characteristic of these missions[3]. For example, crew-members working in orbiting space stations experience isolation and confinement in an environment fraught with danger and psychological challenges. Transient depression and psychosomatic problems have occurred. Personality conflicts can result after one to two months, and interpersonal tension can arise. This on-board tension may be displaced outwardly to people working in mission control, disrupting the crew-ground relationship. People from different cultural backgrounds can have different experiences, especially in terms of perceived work pressure.

Problems resulting from such stressors can be countered by supportive activities from flight surgeons and psychologists on Earth and by frequent audiovisual contact with family and friends. However, this support may be less effective during future exploratory missions to Mars or beyond, where the long distances and mission durations, the delayed communication times, and the need for the crew to be more autonomous lessens the effectiveness of countermeasures initiated by crew-ground interactions[3]. The crew-members will have to deal with all emergencies themselves, including medical issues and psychiatric problems such as suicide and psychosis.

In researching the background for my second science fiction novel, The Protos Mandate[4], I had to consider what some of the psychosocial issues would be involving a large group of people engaged on an expedition to colonize a planet orbiting a distant star where the outbound journey would last for over a century. In this scenario, the distances would be measured in terms of light-years, real-time communication with the Earth would not occur, and the crew-members would have to rely on their own resources to survive. If suspended animation is planned, this will have non-trivial ramifications on the psychology of the crew-members. If it is not used, then a multigenerational approach will be needed. The number of births and deaths must be matched in order to conform to the limited space and resources available on the starship. Consequently, social control will need to be established that would govern coupling and interpersonal relationships.

Let’s examine some of the psychological and sociological ramifications of an interstellar mission lasting 107 years to a planet around the star Epsilon Eridani, which is 10.5 light years away[4]. Assume that the vehicle is a giant starship with a crew of around 280 people.

One way to minimize the vicissitudes of such a long mission is to put some or all of the future colonists in suspended animation. In this scenario, after the critical activities involving the launch and course verification are completed, the crew-members would enter capsules that would slow down their physiological functions until such time as they neared their final destination, when the crew would be revived to perform landing and colonization activities. The space vehicle would be on autopilot during most of the mission, with computers monitoring life support and navigational progress. However, the technology involved with putting people in suspended animation and later reviving them is complicated. Although freezing is used today to preserve red blood cells and corneas for transplantation, the ability to freeze and later thaw whole bodies whose organ systems are composed of differentiated cells with their own freeze-thaw rate profiles is beyond our abilities in the foreseeable future[5]. Ice crystals can form during both freezing and thawing procedures, and these can damage cells. In addition, areas of the body can be deprived of oxygen from blood clotting or premature freezing before metabolism is slowed down, leading to cell death and the likely demise of the individual.

But even if suspended animation becomes technically possible, problems could still occur. Over the course of a 100-plus year mission, power surges or breakdowns of the suspended animation equipment could occur. In addition, an impending freezing procedure could create psychological problems in people fearful of being helplessly incapacitated for decades or worrying that some unanticipated threat could occur to the equipment, such as a meteoroid penetration. Many people would prefer a multigenerational option for a space colony mission, since they would be awake and more in control of their destiny.

In such a multigenerational mission, the selection of the initial crew-members would be an issue. Who would be selected? How many family members would be allowed to come along? Who would be left behind? How much cultural and religious diversity would be permitted? How would a diverse enough gene pool be assured to minimize the appearance of dangerous recessives? These are difficult questions that would have ramifications throughout the entire mission.

In addition, unique psychological effects would impact on the first generation. Even though they signed up to participate in the mission, they would never live to see the ultimate arrival and colonization of their exoplanet destination. Also, these individuals would vividly remember the Earth and the family members and friends they left behind. Unlike modern day immigrants, there would be no possibility for return to their original homeland after landfall.

Subsequent generations would be less affected, since the only home they have ever known would be the starship. In all likelihood, images and stories of the Earth would be preserved and might become the subject of mythic tales over time.

As the mission progressed, the crew-members would experience an increasing sense of isolation and separation from the Earth, with no hope of evacuation or assistance from home during emergencies. The tremendous distances involved would increase the average two-way communication times to minutes, then hours, then days, then years. Consequently, there soon would be no opportunity to speak with loved ones back home. In fact, the Earth would become an insignificant dot in the heavens. No human being has ever experienced the Earth in this manner, the so-called ‘‘Earth-out-of-view phenomenon’’[3]. The profound sense of isolation resulting from this situation could result in increased homesickness, depression, and other psychological problems that would affect many of the crew-members.

What about the sociological structure on board the starship? Some of the ethical and demographic issues of such a mission have been studied by Moore[6]. Using computer modelling technology, he studied a potential interstellar crew of 150-180 people travelling on a 200-year expedition to Alpha Centauri. He attempted to establish a stable population that could be productive and live within the physical and supply constraints of the mission. His findings supported a model that began the mission with a crew of young, childless married couples who would be asked to postpone parenthood until the women were in their mid-30s. Since the birthrate would be controlled, small sibships comprising one or two children of the same parents born close to each other in time would help to maintain genetic variation. Over time, three well-defined demographic echelons would occur, each 30 years apart. The middle adult echelon would perform most of the tasks needed to support the mission, and as they aged they would become senior statesmen who would take over some of the teaching and childcare for the youngest echelon. In this way, resources would be distributed equally, without too many old or young people and with the birth rate set to match the death rate.

This kind of social engineering raises a number of questions. Will later generations view these echelons as a normal part of life, or will they rebel? How would the echelon system cope with a disease or accident that suddenly kills a lot of people? How will this society deal with people comfortable with travelling in space who may not want to land on a planet, or who will want to return back to Earth? Where would criminals or mentally ill individuals be housed in such a confined environment, and who would watch them?

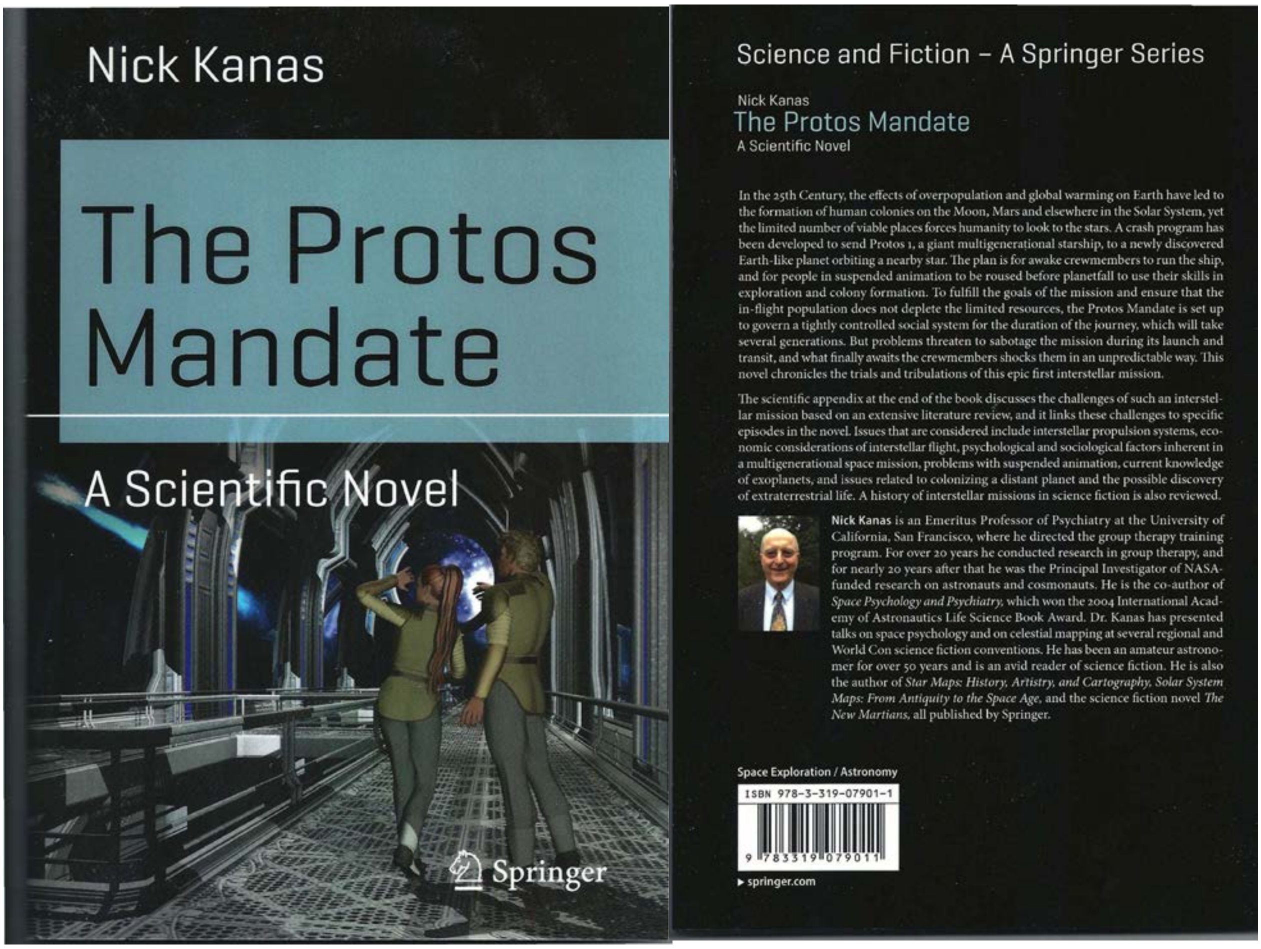
Anticipatory planning for dealing with the psychological and sociological issues described above must be made prior to departure. In all likelihood, by the time of the first interstellar mission, humans will have had much experience coping with long term space missions and colonies to closer destinations, such as planets and moons in the Solar System and icy bodies in the Kuiper Belt and Oort Cloud. However, the on-board leadership of an interstellar mission will need to be mindful of the impact of unanticipated psychological and sociological events on the psyche of the crew-members and the stability of the social system, and they must be prepared to make interventions to cope with these events as the journey progresses.

References

1. Kanas, N.A., Salnitskiy, V.P., Boyd, J.E., Gushin, V.I., Weiss, D.S., Saylor, S.A., Kozerenko, O.P., and Marmar, C.R. (2007). Crew-member and mission control personnel interactions during International Space Station Missions. Aviation, Space, and Environmental Medicine (now Aerospace Medicine and Human Performance), 78:601–607.
2. Boyd, J.E., Kanas, N.A., Salnitskiy, V.P., Gushin, V.I., Saylor, S.A., Weiss, D.S., and Marmar, C.R. (2009). Cultural differences in crew-members and mission control personnel during two space station programs. Aviation, Space, and Environmental Medicine (now Aerospace Medicine and Human Performance), 80:1–9.
3. Kanas, N. (2015). Humans in Space: The Psychological Hurdles. Switzerland: Springer International Publishing
4. Kanas, N. (2014). The Protos Mandate: A Scientific Novel. Switzerland: Springer International Publishing.
5. Stratmann, H.G. (2016). Using Medicine in Science Fiction. Switzerland: Springer International Publishing, pp. 211-248. ISBN 978-3-319-07901-1, www.springer.com/gp/book/9783319079011
6. Moore, J.H. (2003). Kin-based crews for interstellar multi-generational space travel. In: Kondo, Y., Bruhweiler, F.C., Moore, J., Sheffield, C. (Eds.): Interstellar Travel and Multi- Generation Space Ships. Burlington, Ontario, Canada, Apogee Books, pp. 80-88.

About the Author

Dr Kanas is a Professor Emeritus (Psychiatry) at the University of California, San Francisco. He is a former NASA-funded research Principal Investigator who has written about manned space travel for over 40 years, most recently the book Humans in Space: The Psychological Hurdles. He has also written three science fiction novels: The New Martians, The Protos Mandate, and The Caloris Network.



Interstellar News

John Davies with the latest interstellar-related news.

BIS Spaceflight 60th birthday

Our warm congratulations to the British Interplanetary Society magazine Spaceflight on the 60th anniversary of its first publication. The BIS is our older sibling and Spaceflight is therefore our cousin, or a close relation, to Spaceflight. Take a look at the anniversary issue (Spaceflight Vol 58 No 10 – October 2016) it includes reminiscence by veteran space artist David Hardy who is featured elsewhere in this issue of Principium. We hope to last as long as Spaceflight! It was launched in October 1956 just about one year before Sputnik 1 in October 1957. Within 13 years we had the first human on an extraterrestrial body, the Moon, Apollo 11 June 1969.

If we want to achieve our first interstellar milestone, say the launch of a small probe to Alpha Centauri, in the same timescale then we had better get moving!

The first issue of Principium was December 2012 so our scientists and engineers, and their peers worldwide, have about 9 years. No pressure guys!

Whatever happens Principium aims to continue to inform and entertain all who feel that outward urge so well expressed by Konstantin Tsiolkovsky "Earth is the cradle of humanity, but one cannot live in a cradle forever."

Back down to Earth at Principium, your monthly Spaceflight began as a quarterly, like Principium. But we have aspirations!

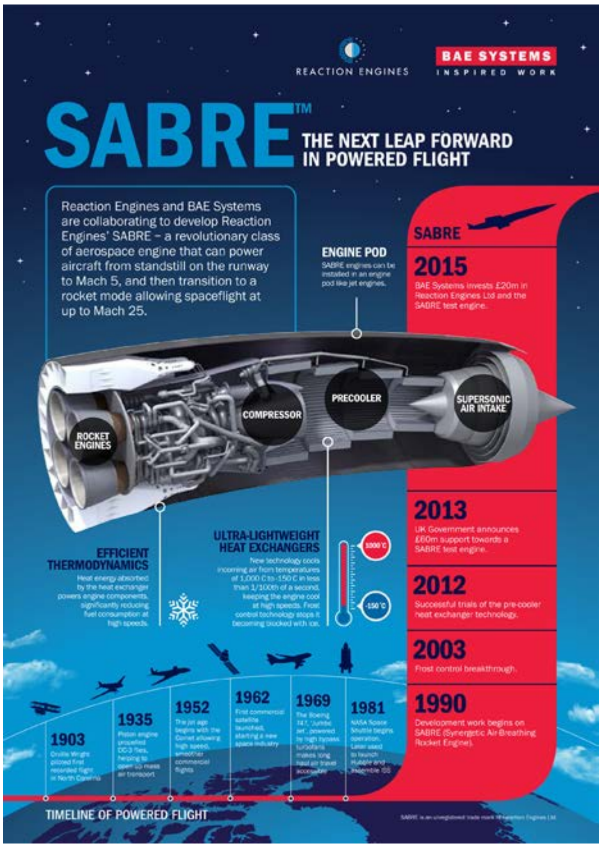
i4is Technical Committee

The i4is Technical Committee coordinated by Andreas Hein continues to work on advanced concepts for propulsion. The pioneer work of Project Dragonfly is being built upon. And the concepts arising from the i4is association with Breakthrough Starshot, reported in the last issue, are important but there is also parallel work which we hope to report on in the next issue of Principium. The Andromeda study, reported in this issue, shows what the team can achieve.

Summer Placements June 2017 - Reaction Engines Ltd

We often feature the work of Reaction Engines in Principium. Along with several more famous US-based organisations like SpaceX and Blue Origin, they aim to cut the costs of access to space - a vital precursor to an interplanetary and interstellar culture. And their founders include the Daedalus project leader, Alan Bond. Next summer they are offering 12 week summer internships to students studying for science, engineering or business-related degrees. The closing date is the end of November so we hope we are out on schedule in time for this!

www.reactionengines.co.uk/careers_038summer2017.html



The Reaction Engines core technology: SABRE

i4is at Starfest 2016

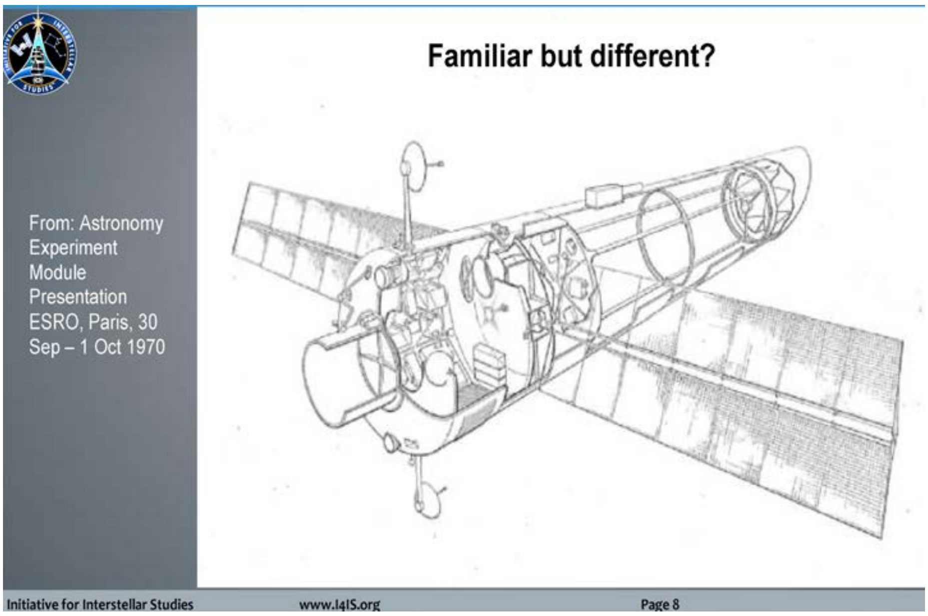
Rob Swinney (i4is Director of Education) and John Davies were at the annual Starfest of the North Essex Astronomy Society in Chelmsford. We spoke to many astronomy enthusiasts, from the fanatical to the casual. Thanks to all who visited our stall and especially to those who requested subscriptions to Principium - Welcome to your first issue!
Alongside some far more distinguished presenters from Queen Mary University of London, Cambridge University and the Scottish Dark Skies Observatory, John Davies presented a nostalgic "The Hubble Telescope that never was" John reminisced about a project he was involved in which studied a possible space telescope to be launched by a space shuttle and compared these early designs with the Hubble and Shuttle as it was built. Based on a 1970 design study at Hawker-Siddeley Dynamics, Stevenage (now Airbus Defence and Space), the issues of launch capacity and civil/military interaction which John explored are still with us today. Contact him via info@i4is.org if you would like a copy of his presentation or the 1970 presentation to ESRO and NASA on which it is based.

Schools Outreach

As we reported last quarter, John Davies and Rob Swinney (i4is Director of Education) have been planning a major event for schools in London. This will be the Interstellar Challenge of London Schools. We are working with STEM Learning (www.stem.org.uk), the British Interplanetary Society (BIS) and the Outreach Department of Imperial College, London. We also have the support of student volunteers from ICSEDS (www.union.ic.ac.uk/guilds/icseds). Much more about this in the next issue of Principium when we also hope to have more about rolling out ideas from this to schools in the UK, Europe and the world.

i4is Progress and Planning meeting

i4is is a very distributed organisation so we especially value the occasions when we can get together, either as the core team who lead our work or in larger gatherings. An example of the former was our September 16-19 meeting.
For your editor it was both a chance to "meet the management", our leadership team of Kelvin F Long, Rob Swinney and Andreas Hein - and see a little of the seaside and countryside of one of England's beautiful West Country. Progress and Planning meetings are our best chance of getting down to details of how far we have come and where we are going and this was no exception. Several of our board members including Robert Kennedy from the USA and Stefan Zeidler from Germany were also able to attend a Skype AGM as part of P & P. We also welcomed our new Marketing and Membership manager, Dave Miller, who will be ensuring we reach out and serve the interstellar community - both the virtual full timers like those at our P&P meeting and the seriously interested, like most Principium readers.
Kelvin and the family made us all very welcome at the Long residence and showed us the sights of coast and countryside.



Passengers starship Avalon from trailer
Credit: Sony Pictures

Interstellar Adventures on Film

Interstellar is a more and more attractive topic for big budget films. We note two in particular for late 2016 release.

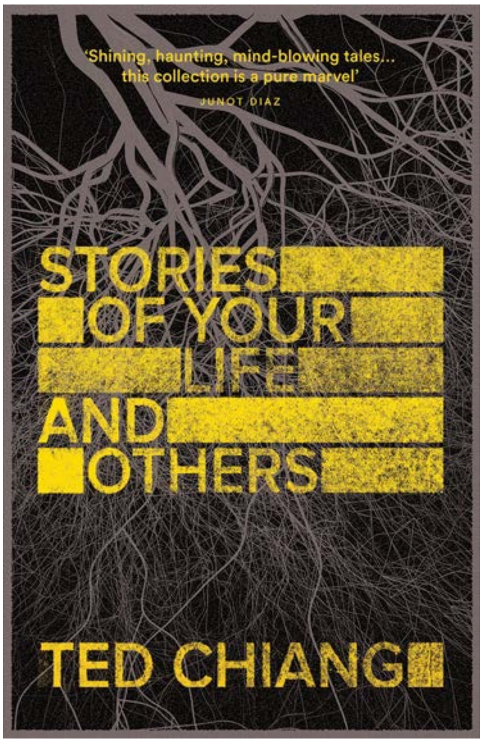
Passengers is a romantic thriller about a sleeper ship (not very dramatic unless we have dream sequences!) where the two most attractive people on the ship just happen to wake up by accident. And there is still 90 years to go on the voyage so we now have a generation starship, I think we should assume! Will they change Chris Pratt (of the most recent Jurassic movie) and Jennifer Lawrence (of The Hunger Games series) in CGI or make-up so they look like centenarians at the end of the voyage? And how many generations will they have produced? There's also some serious non-romantic action when the pair have to save the ship. The details of the ship and the hibernation mechanism are not yet available so this will be intriguing for interstellar enthusiasts as well as providing romance and action. The ship rotates (see the trailer) and appears to have 1G inside so we can guess the rotation rate and work out how big it is! My own best guess is about 1 RPM so it's about 2km diameter and thus several km long.

Arrival is a drama about the arrival of mysterious aliens - saving us the trouble of building starships! It's already been seen at the Venice Film Festival and

Alien ship with Chinook helicopter approaching. From the official *Arrival* trailer, Credit: Paramount Pictures

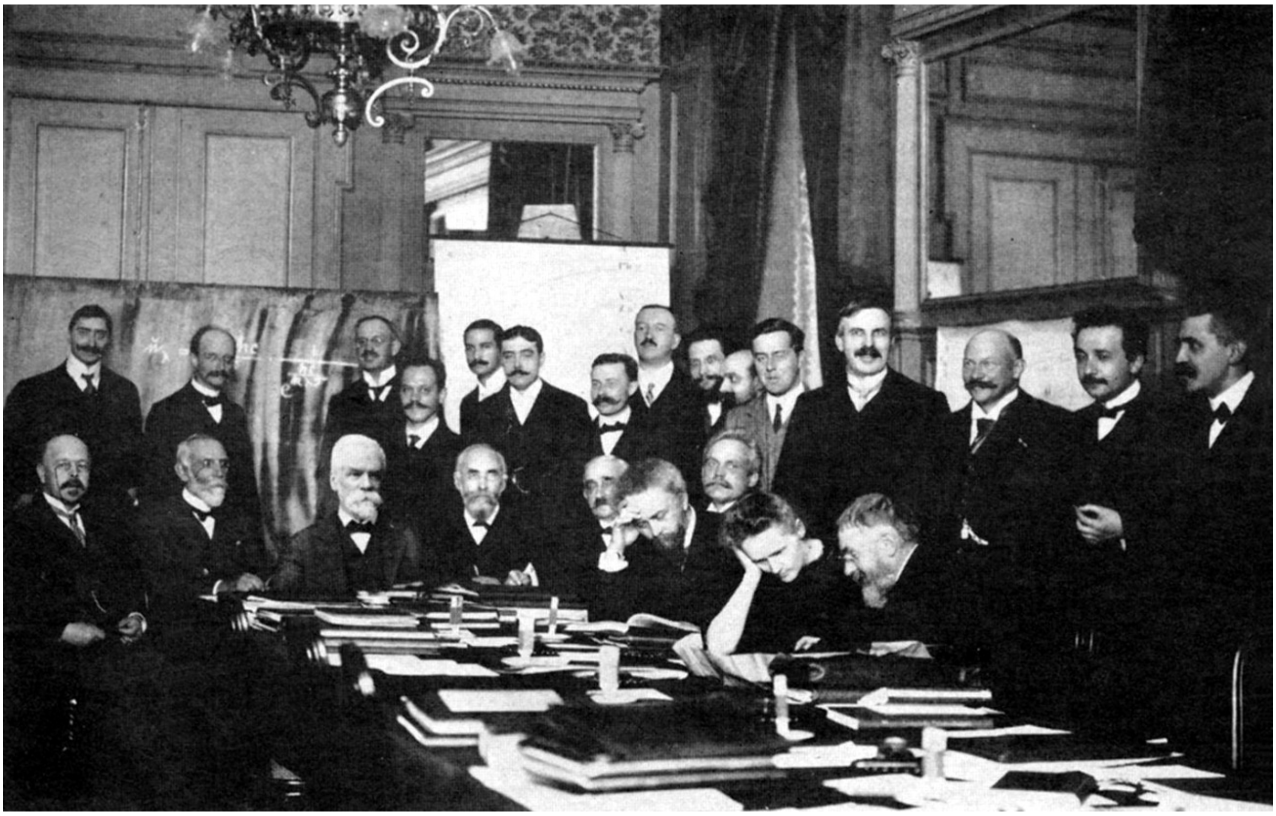
is now on general release. It's a heavier theme than Passengers. The film is based on *Story of Your Life*, a short story by Ted Chiang. The two principal characters try to understand the language and mathematics, respectively, of the aliens Chiang has invented - on the wilder fringes of what we might imagine.
One of the "big brains" of SF, China Miéville, has a very high opinion of the story, the collection from which it comes, *Stories of Your Life* and Chiang as a writer.

Let's celebrate these films for evidence they bring that our culture is beginning to see interstellar flight and alien contact as part of the mainstream.



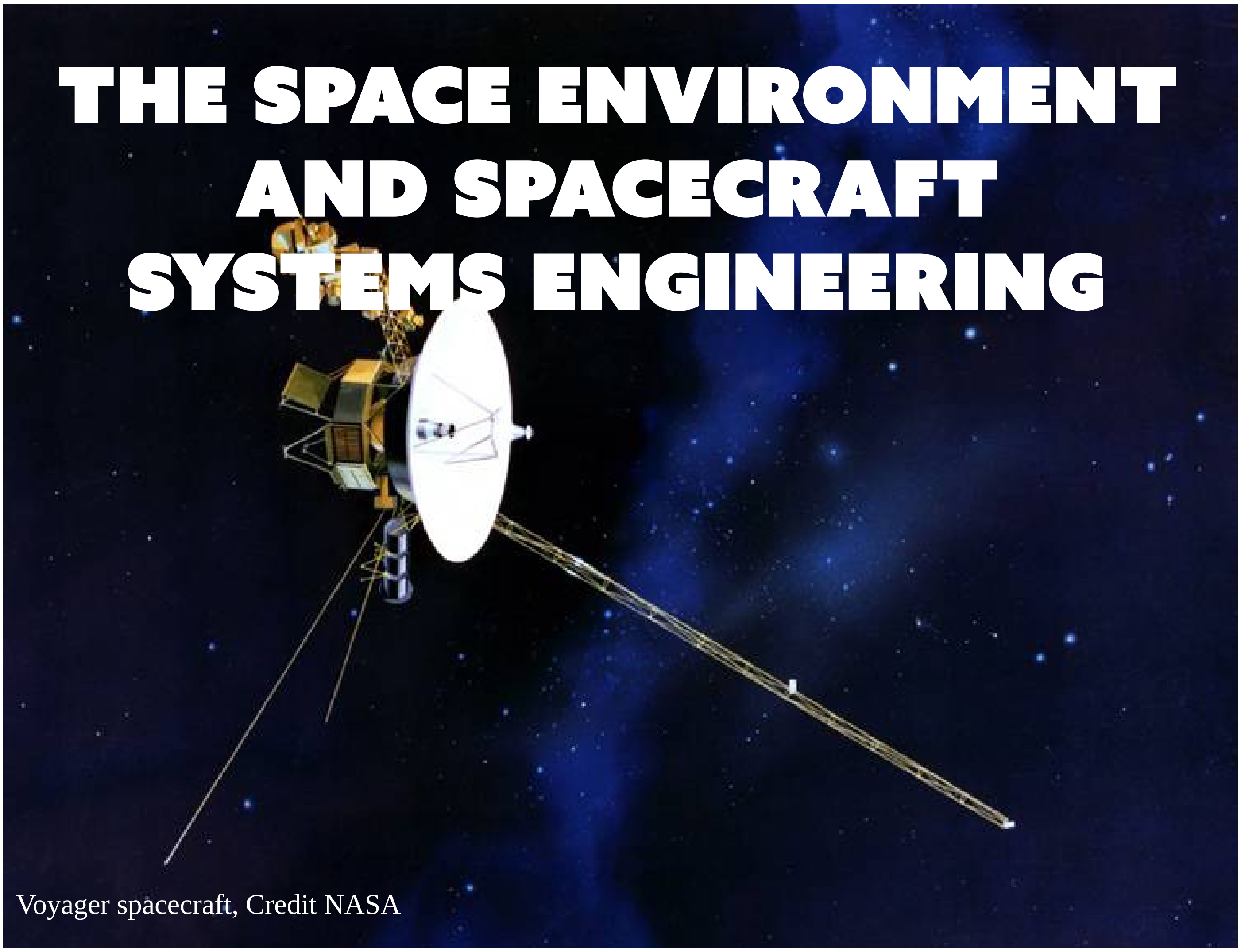
Kelvin in USA and Belgium

Kelvin Long, i4is Executive Director, was at a series of meetings of the Breakthrough Starshot advisory committee in the USA in August. We covered i4is involvement in this magnificent initiative in earlier issues of Principium.
Kelvin was also in Brussels at the BIS Belgium Annual Space Symposium 2016 in October. He presented "Interstellar Travel – Can we reach the stars?" looking at past, present and future activities in space that move us towards becoming an interstellar-capable civilisation.
An anecdote: Kelvin looked for a cheap hotel deal (we always do!) but found himself at the 5 star Hotel Metropole, site of the famous 1911 Solvay physics conference. These were the men - and one woman - who invented modern physics.



1911 Solvay Conference at the Hotel Metropole, Brussels.
Can you spot - Marie Curie, Albert Einstein, Henri Poincaré, Max Planck, Ernest Rutherford and Hendrik Lorentz? Lots of others too!
Credit: Benjamin Couprie, 1911 / Wikipedia

THE SPACE ENVIRONMENT AND SPACECRAFT SYSTEMS ENGINEERING



Voyager spacecraft, Credit NASA

Spacecraft mission systems engineer Marc Casson of Surrey Satellite Technology Ltd (SSTL) summarises his contribution to the ISU elective module, Interstellar Studies, delivered to the Masters course of the International Space University (ISU)in May 2016.

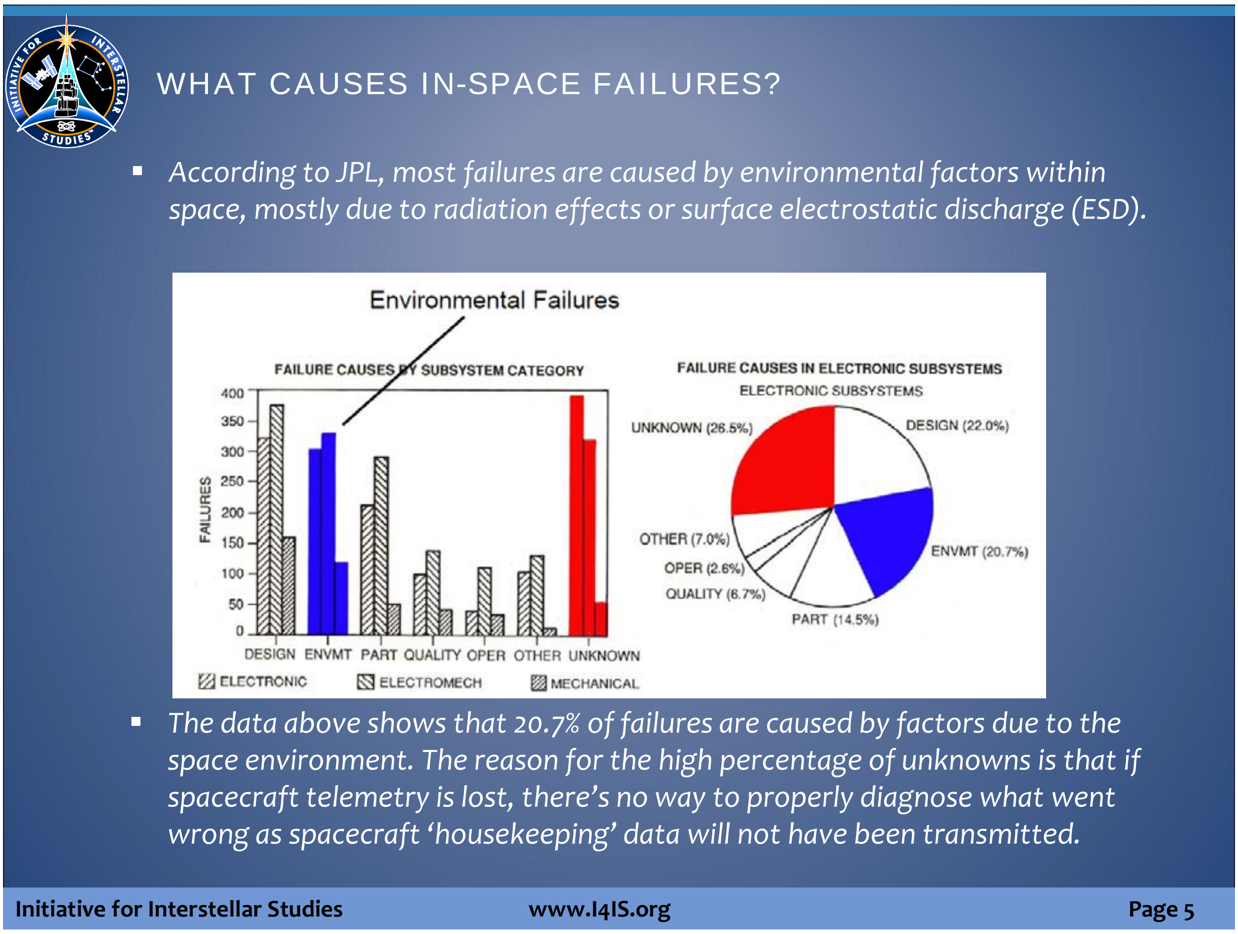
Introduction

This part of the ISU course was to provide students with an overview of spacecraft systems engineering and what would have to be considered when applying these principals to designing an interstellar spacecraft. There were three main sections; the interstellar space environment, the spacecraft design process and the spacecraft bus.

The space environment

Given the operational lifetimes required for an interstellar spacecraft (many decades instead of just years), there would be many additional challenges to those in conventional spacecraft design. In a conventional spacecraft, the space environment results in challenges due to vacuum, mechanical/thermal conditions, charging and radiation. For an interstellar mission, heavy amounts of radiation would damage the spacecraft over time, affecting its ability to reach its destination. Also, cosmic dust and the affects of the interstellar medium when travelling at high velocity would slowly degrade a spacecraft structure.

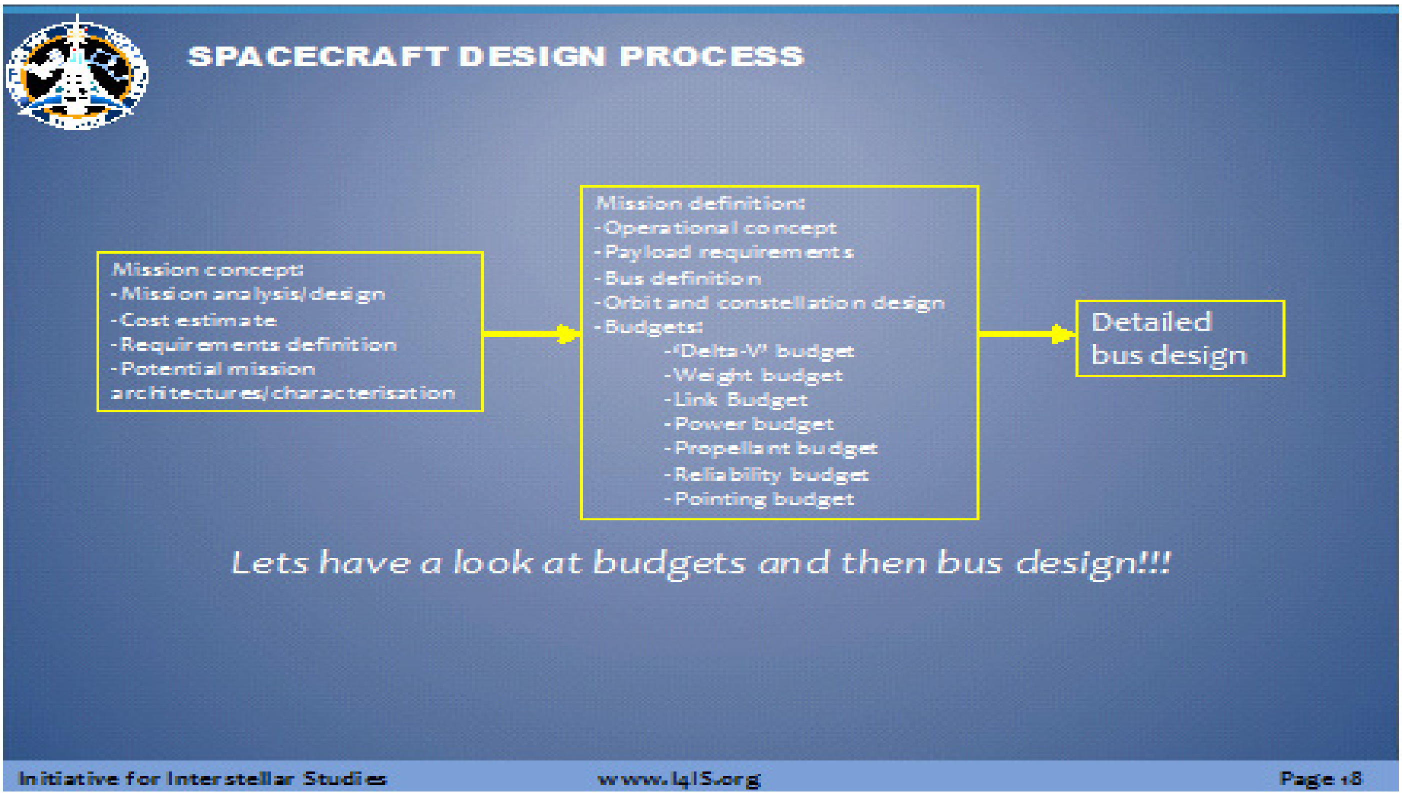
The effects of surface charging and mechanical/thermal stresses could probably be mitigated with careful design considerations, such as good conductor grounding, thermal control and proper material selection. However long term radiation degradation would require particular attention. In a conventional spacecraft, the hardware has to be designed to cope with total ionising dose (TID) over time and individual heavy ions that cause single event effects (SEEs). For an interstellar spacecraft, due to the long mission lifetimes



involved these effects would be much more pronounced. However, the use of technologies that are known to be tolerant to radiation (such as silicon on sapphire), triple mode redundancy, error detection and correction (EDAC), watchdog circuits and current monitoring would help keep the spacecraft safe. It would also be necessary to have some level of automated recovery within the spacecraft since human intervention (given the signal travel times) would be highly delayed.

The spacecraft design process

There are generally three main stages in spacecraft design; mission concept, mission definition and then detailed bus design. Concepts involves looking



at the plausibility of a mission- what can be achieved, potential architectures and probable cost. Mission definition involves taking the concept and further defining it, examining payload requirements and initial mission budgets (such as mass, link, power, propellant, pointing accuracy). From this stage, if it is agreed the mission can be built it will move into the detailed bus design stage.

Mission budgets

There are several mission budgets that have to be maintained and updated throughout the spacecraft design process: -

1. Delta-V budget; used to ensure the amount of fuel on board is sufficient for maintaining attitude, orbit correction etc. An interstellar mission would require a system of high efficiency and reasonable thrust to position a spacecraft of (likely) large mass.

2. Link budget; so that the spacecraft has sufficient RF power to maintain a communications link with Earth. This means that Earth can receive all the science data and keep an eye on the spacecraft health (referred to as telemetry). Given the vast distances involved in interstellar missions, the link will involve low bit rates and large ground stations.

3. Mass budget; feeds into the launch requirements and delta-V budget to ensure the spacecraft mass is kept within reasonable limits.

4. Power budget; all the systems have to have sufficient power at both beginning of life and end of life, the power budget ensures this. However, the systems will also run from batteries that will have charge/discharge cycles. The power budget thus ensures that the discharge depth is never too large that the batteries lose efficiency.

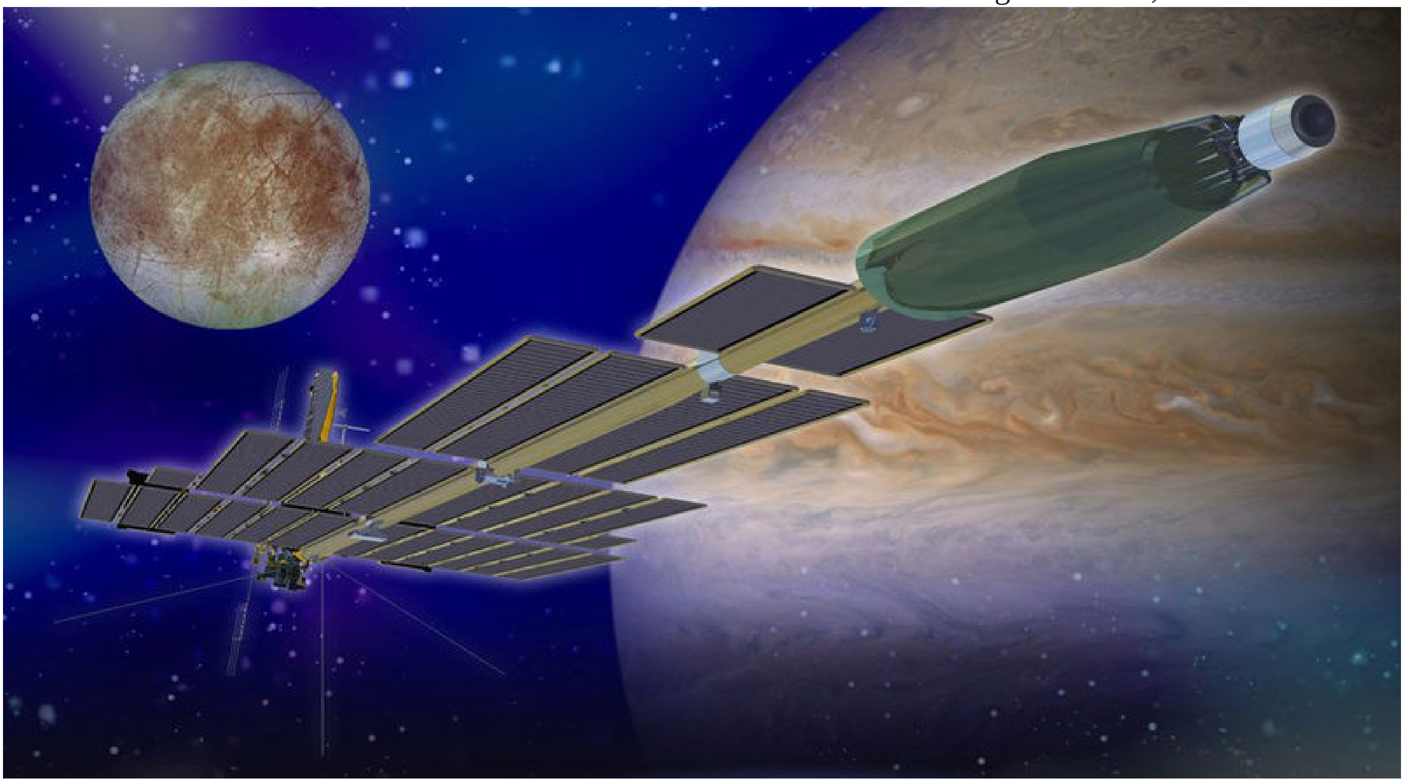
5. Payload budget; the instruments on board will collect large amounts of data but given the vast distances to the stars it can't be downloaded in real-time. Thus the payload budget will help determine the spacecraft data storage requirements, the downlink rate and contact time with the ground station.

Bus sub-systems

Once the spacecraft mission has been well defined, the detailed bus design can start. The starting point is the budgets and concept that have been established in the earlier design process and then building the systems to satisfy these budgets. However, as in any engineering project, some degree of trade off will occur.

Any spacecraft can generally be broken down into several major sub-systems, this section will provide an overview of these systems and their application to interstellar missions:

1. Payload; the scientific instruments specific to the mission; for an interstellar program these would likely be similar to what is commonly used on modern spacecraft. For example, spectrometers, magnetometers, observation



A nuclear powered craft, NASA Prometheus, Outer Planets concept

cameras at a variety of wavelengths.

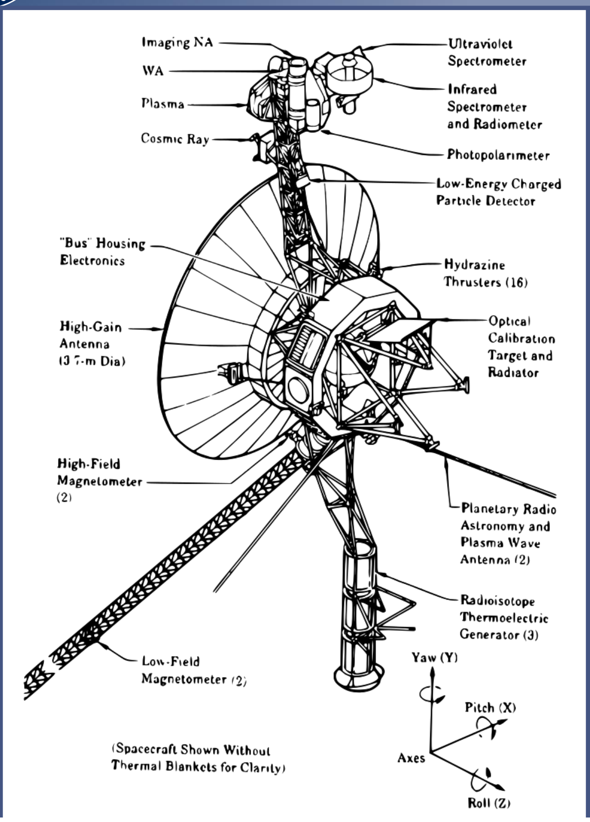
2. Power; the power budget and mission scenario will dictate the type of power system to use. Modern spacecraft use either solar, fuel cells or radioactive thermo-electric generators. However an interstellar mission would likely require a nuclear fission (or fusion if technology progression allows) source. This is because of the likely high amounts of energy required for both the spacecraft bus and the propulsion system.

3. Tracking, telemetry and command; provides the data transfer to/from the spacecraft and ground station. Its design will directly correlate to the link budget analysis, determining how much output power required and how to demodulate the signal.

4. Attitude and orbit control system; used to determine the spacecraft's attitude and the direction it is pointing. For an interstellar mission, the transmitter will have to be accurately pointing towards Earth and thus a highly accurate system would be required. However, conventional star positions couldn't be used because of the stellar parallax that would occur when moving large distances. Therefore, a possible solution may be to use pulsars with known rotation frequencies as a 'galactic GPS.'

5. Propulsion; used for attitude correction and for propelling the spacecraft to its destination. The method used will be heavily dictated by the propellant and mass budgets for the attitude correction. For the primary propulsion system to reach interstellar distances, the major drivers will be how to generate the required thrust to achieve relativistic velocity while also having an efficient fuel that doesn't require enormous amounts of propellant on board.

CASE STUDY- VOYAGER



Communications:

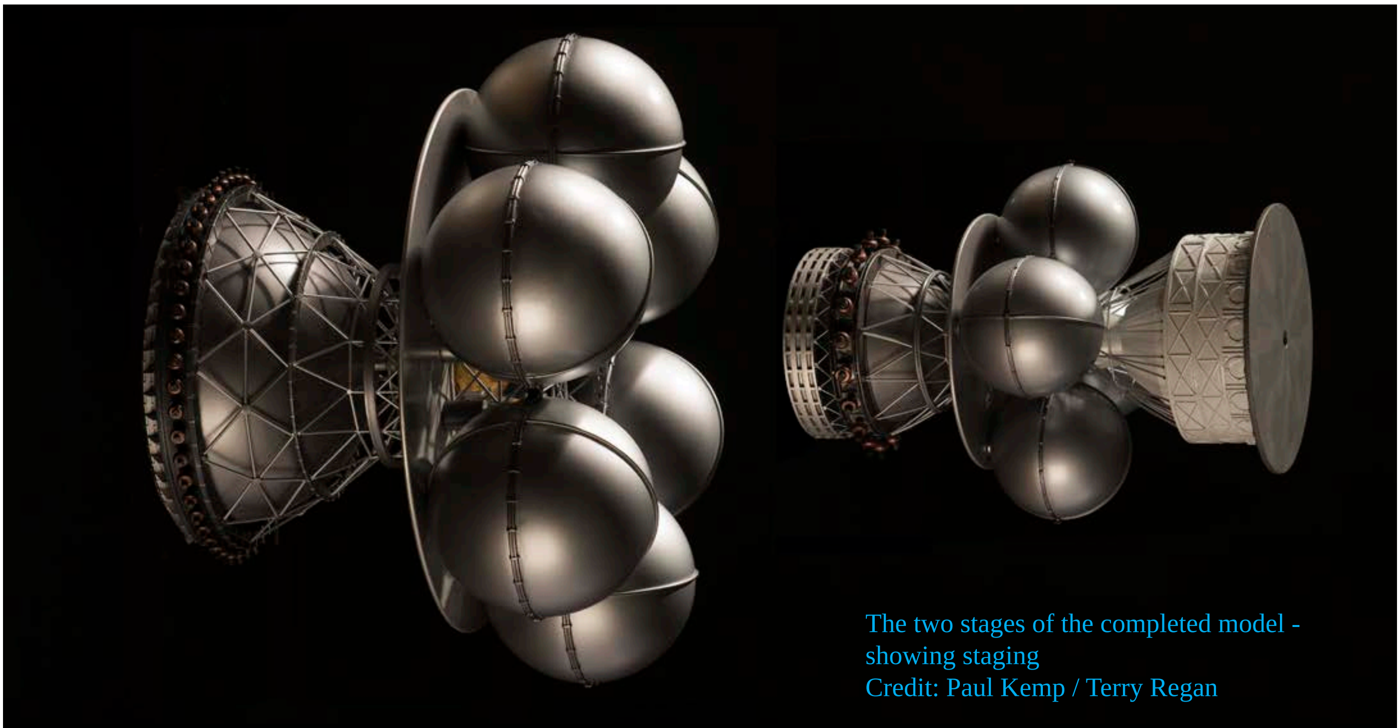
- *The uplink is in the S-band frequency domain (about 2GHz) while the downlink is X-band (about 8GHz).*
- *All uplink and downlink data is via the large 3.7 metre antenna, ensuring high gain in both directions.*
- *When the spacecraft was at Jupiter, the bit rate was 115kbits per second, however this decreased as the spacecraft travelled further away.*
- *The bit rate drop was compensated slightly by adopting larger antennas on Earth, eventually combining multiple antenna signals into one in a process called interferometry.*

About the Author

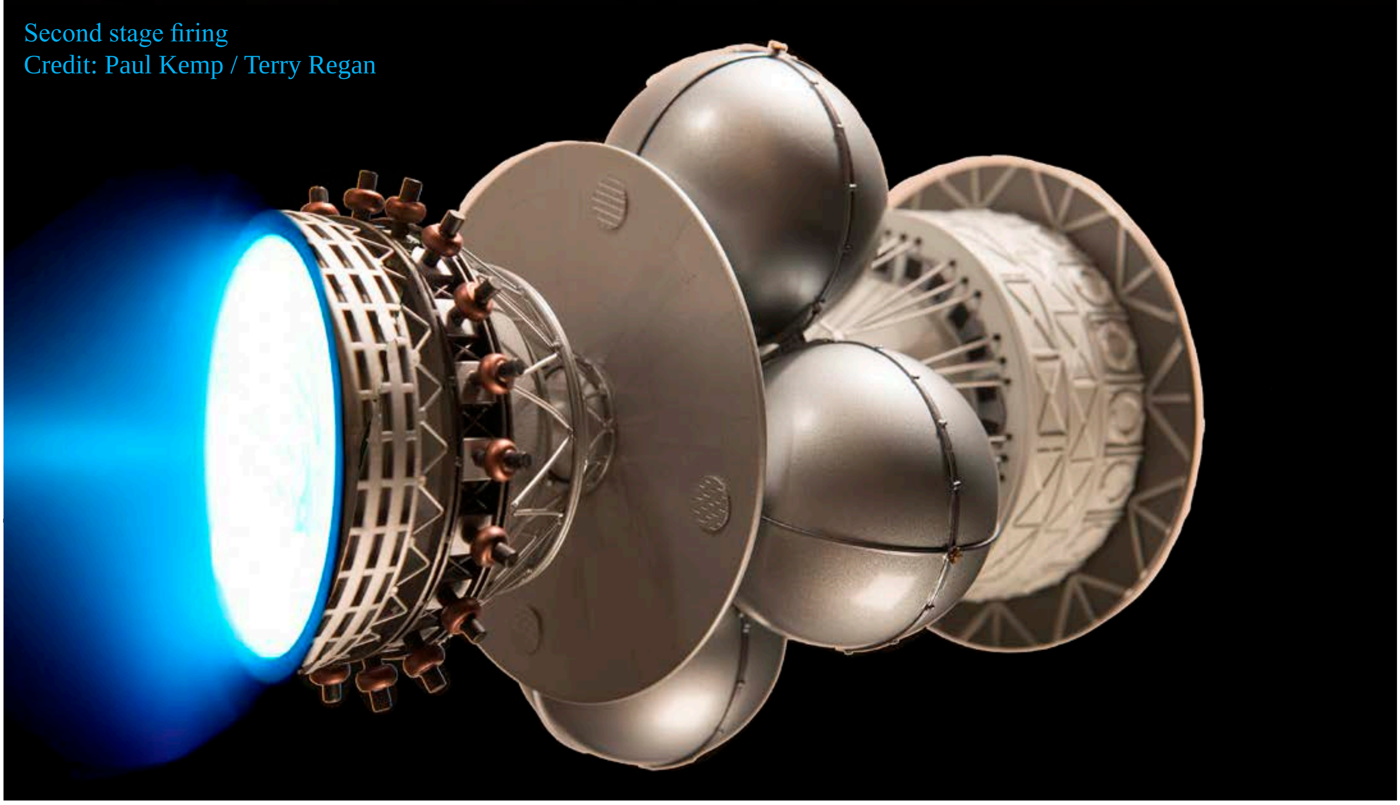
Marc Casson is a Spacecraft mission systems engineer at Surrey Satellite Technology Ltd (SSTL). SSTL is a British company delivering small satellite missions, an independent part of the Airbus Defence & Space group. Marc has an MEng in Aerospace Engineering from the University of Sheffield and a Masters in Space Technology and Planetary Exploration from the University of Surrey.

The BIS Daedalus Model by Terry Regan: Model and Art

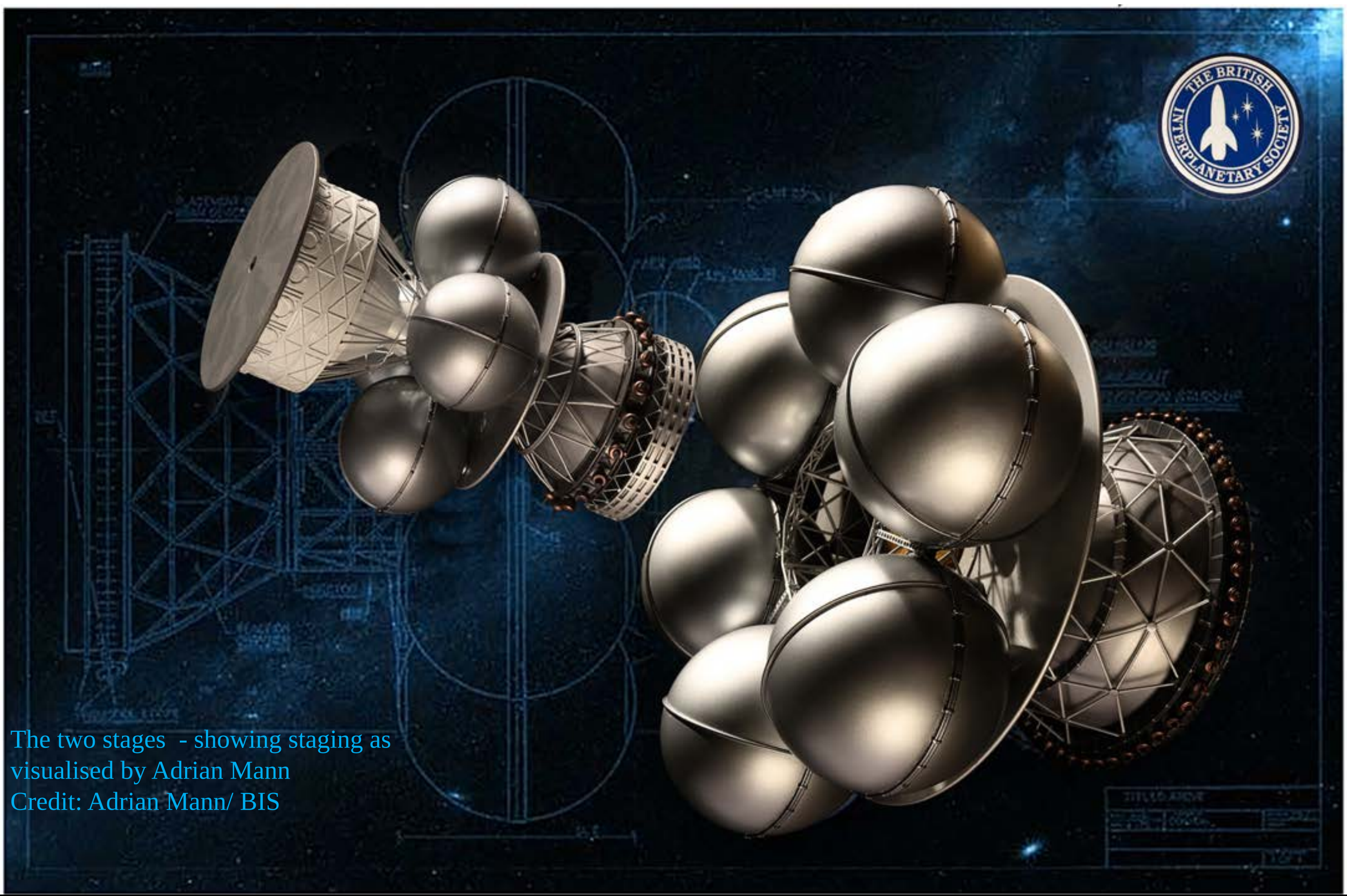
Regular readers of Principium will need no introduction to Terry's magnificent model of the Daedalus starship as devised by the BIS team in the 1970's, lead by Alan Bond and Tony Martin. As we reported in the last issue, this was unveiled to universal admiration at the BIS Charterhouse conference in July. This photo essay shows details of the final form of the model as photographed by Paul Kemp, Terry's cousin. Paul's "day job" is technical photography but some of these pictures aim to capture the artistic vision of Daedalus as envisaged by Adrian Mann. Adrian has been frequently featured in these pages but try Google Images or bisbos.com and be amazed again at what he has achieved over the years.



The two stages of the completed model - showing staging
Credit: Paul Kemp / Terry Regan



Second stage firing
Credit: Paul Kemp / Terry Regan



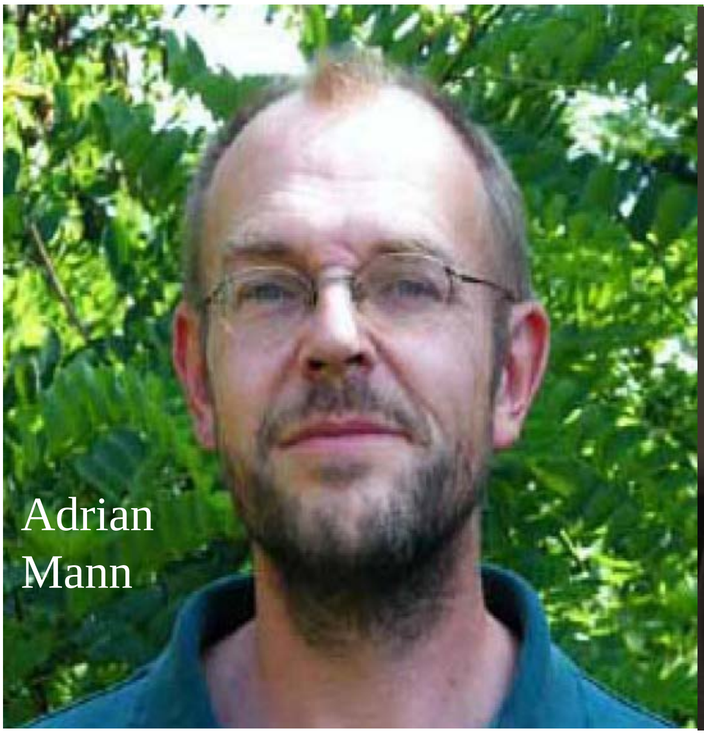
The two stages - showing staging as visualised by Adrian Mann
Credit: Adrian Mann/ BIS

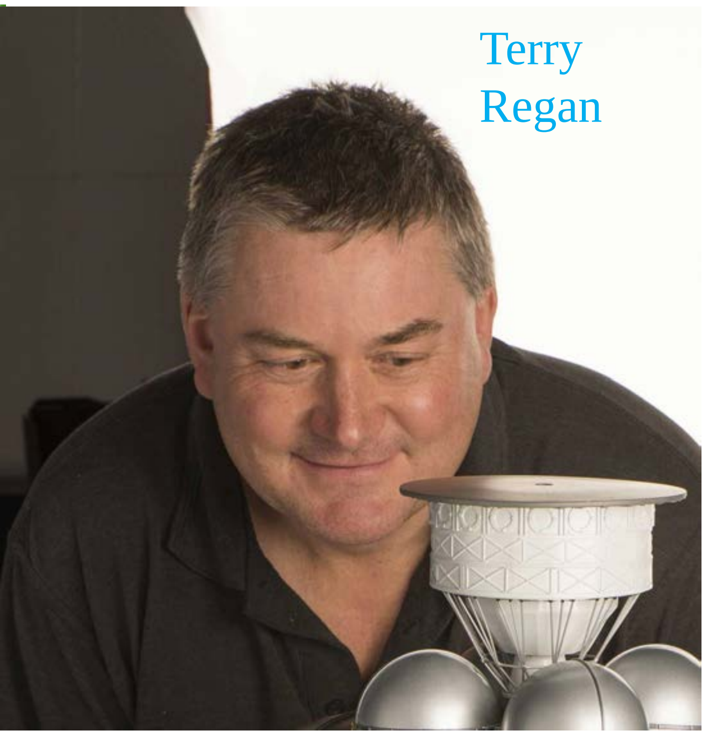

Second stage firing as visualised by Adrian Mann
Credit: Adrian Mann/ BIS

I think you will agree that this is world-class - perhaps even out-of-the-world class? Imagination is vital, both technologically and artistically if we are to take our species to the stars. Terry, Paul and Adrian are in the front rank of those who provide us with the vision of what we might achieve if we strive for it. David Hardy, féted elsewhere in this issue, is the pioneer. And none of the current work would exist without the BIS Daedalus teamwork nearly 40 years ago.

The BIS Project Daedalus Fusion Starship
Sponsored by The Initiative for Interstellar Studies
Built by Terry Regan
Picture credit: Gill Norman / BIS

See it at the headquarters of the British Interplanetary Society, 27-29 South Lambeth Rd, London SW8 1SZ. Contact BIS via www.bis-space.com. Better still, join!





HOW TO DESIGN A STARSHIP IN THREE DAYS

The Incredible Story of the i4iS Andromeda Probe Study: A Femto-Spacecraft to Proxima Centauri

Andreas Hein and Kelvin F Long.

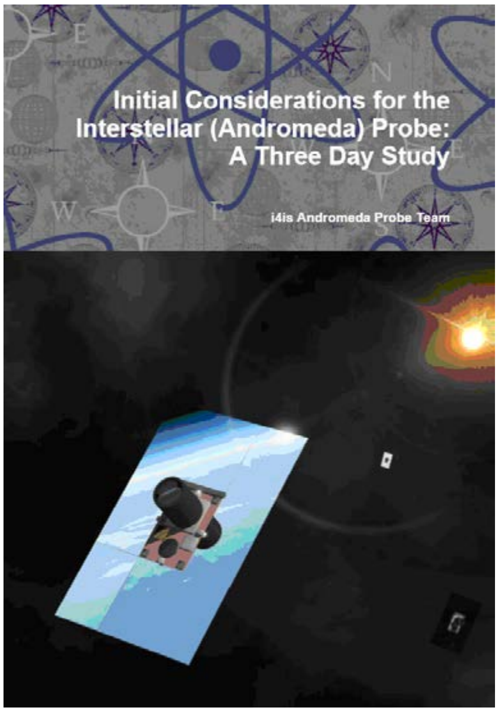
Introduction

The field of interstellar studies has taken probably the most important step in its history when on the 12th of April 2016, the physicist and entrepreneur Yuri Milner announced Project Starshot: A $100 million research and development program for a laser-propelled gram-sized probe to Proxima Centauri. However, the spectacular announcement was preceded by careful evaluation of different options for the Starshot architecture. The Project Starshot team has been informed from various sides regarding the architecture of the mission and had consulted certain groups.

During early 2016, the Initiative for Interstellar Studies had also been asked by the Breakthrough team to provide its own perspective on a laser-propelled interstellar mission. This was especially because we had been running our own Project Dragonfly, an ongoing laser sail project that had been launched in 2013. During March 2016 Executive Director Kelvin F Long met with the Breakthrough Starshot team whilst on a visit to NASA Ames Research Centre in San Francisco, California. The result of this meeting led to the assembly of a group of experts within the i4is team, who had to design a starship in three days. The briefing was giving late on a Friday evening, whilst Kelvin was on a stopover in New York. Andreas Hein then assembled the team which also included Rob Swinney, Richard Osborne, John Davies, Stefan Zeidler, Angelo Genovese, Bill Cress, Martin Langer, Dan Fries, Nikolas Perakis, Lukas Schrenk, Marc Casson, Sam Harrison, Adrian Mann and Professor Rachel Armstrong. Peter Milne also gave some consultancy assistance. This team performed above and beyond the call of duty and were eventually awarded with the i4is Alpha Centauri prize and a specially designed Andromeda probe mission patch.

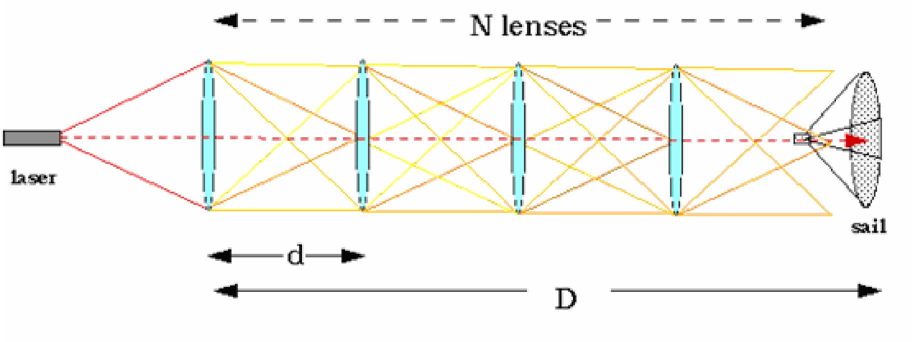
Andromeda Probe mission patch

The report was titled "Initial Considerations for the Interstellar (Andromeda) Probe: A Three Day Study" and it was delivered on the desk of the Breakthrough Initiative by the following Tuesday. This represented an astonishing effort by the team, who dropped 'normal life' to focus 100% on doing a good job for the Breakthrough Initiative and their innovative Project Starshot. The main requirements that the team had to design for included (i) laser sail propulsion (ii) 50 year time of flight (iii) 10% speed of light cruise velocity (iv) the target was assumed to be within the Alpha Centauri A/B system at around 4.3 light years away (v) gram-scale mass. Working with the Breakthrough Initiative, some subsequent work and calculations were also conducted by the i4is team to give improved insights into the problems and potential solutions. The results of our teams work, complemented work done by others (particularly Professor Philip Lubin and scientists from Harvard University), to give the Breakthrough Initiative confidence in the concept of a laser-sail mission to the stars, and Yuri and his team went live on the 12th April 2016 to announce this incredible and inspiring project. In the rest of this short report, we will provide an overview of the mission architecture, subsystems of the spacecraft, and the proposed beaming infrastructure that was derived by the i4is Andromeda probe team during our brief 3-day study.



Andromeda Probe Report

Figure 1: Sequential lenses for sustaining laser beam focus on the sail (Landis, 1989)



The Andromeda Probe

Before we present our mission architecture, we present two key parameters for a laser sail mission. All existing mission architectures take a certain spot within this coordinate system. A laser-propelled interstellar mission comprises two basic elements: the laser infrastructure and the spacecraft. First, the longer that the laser beam from the infrastructure can hit the spacecraft with the laser sail, the longer it accelerates and the higher its final velocity. However, the longer the distance to the spacecraft from the laser, the more difficult it gets to focus the beam on the sail. Hence, either you accelerate the spacecraft extremely quickly, in order to avoid any focusing issues or you accelerate for a long time. But in the latter case, you need a kilometre-sized lens. In the former case, you need a lot of power and you need a sail material that can withstand the extremely high power flux (up to dozens of GW per square metre). Previous laser sail missions have positioned themselves in the long acceleration spot of the trade space due to material temperature limitations (Forward, 1984). If the power flux from the laser is too high, the material will absorb too much heat and the sail will simply melt away. Geoffrey Landis was the first to propose a concept that uses dielectric materials that have very high reflectivity values, which allows for a high power flux on the sail, as the sail does not absorb as much heat as a material with low reflectivity values (Landis, 1989). Finally, Phil Lubin's proposal for a laser-propelled interstellar mission went to the extreme by proposing an acceleration within minutes to velocities of 20% of the speed of light, only possible by using materials with a 99.9999% reflectivity that still need to be developed (Lubin, 2016).

The key parameter is the size of the sail and correspondingly its mass. The smaller the sail, the more difficult it is to hit it with the laser beam. But a smaller sail is also lighter. The larger the sail, the easier to hit, but also heavier. Furthermore, the larger the sail, the lower the power density, as the beam is spread out on a larger surface. Again, past concepts have positioned themselves differently with respect to this trade-off. The concepts of Robert Forward and Geoffrey Landis proposed large sails, mainly to reduce the power flux by distributing it on a larger surface area of several square kilometres. Conversely, Professor Lubin proposed to use a sail of just a few square metres.

The i4is Andromeda architecture positions itself similar to past laser sail architectures: We use a long duration for acceleration and use a large sail. However, we leverage on recent innovations that could have a disruptive effect on how we think about laser sail missions. First, we use a segmented lens, meaning that the lens that focuses the beam on the sail consists of several lenses that are positioned sequentially. Each individual lens has a size of a few hundred metres. This is still larger than anything that has been put into space. However, recent advances in 3D-printing have now lead to a stage where in just a few years, large truss structures of up to 100 metres can actually be manufactured in space. The lenses are put at different locations along the path the spacecraft intends to travel. Each time the spacecraft passes a lens, the laser beam is transmitted from lens to lens and each subsequent lens refocuses the beam on the spacecraft. With this approach, kilometre-sized lenses can be avoided. Ten sequential Fresnel lenses, each with a radius of 95 m, are used. Circular structures of this diameter are currently conceived by Tethers Unlimited for in-orbit manufacturing. A potential Fresnel lens material is Graphene sandwich. Graphene lenses have been demonstrated in the lab in 2016. A graphene lens is expected to be extremely light. The lens infrastructure is shown in Figure 1 (Landis, 1989).

The parameters for the laser infrastructure are given in Table 1. It shows that the laser beam power is orders of magnitudes lower than for the architecture proposed by Lubin. The acceleration distance with about 2 astronomical units (300 Mkm) is also much shorter than previous architectures.

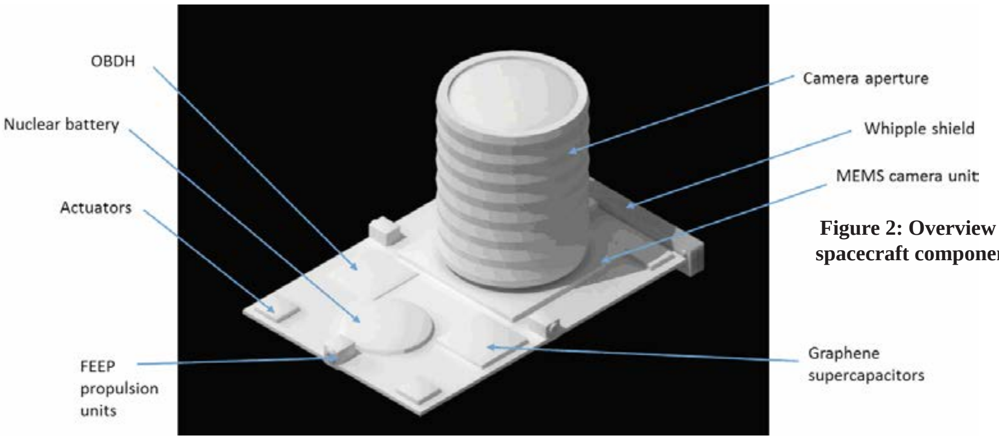


Figure 2: Overview of spacecraft components

The second innovation is carbon nanotube sails. They have been proposed by Greg Matloff (Matloff, 2012). Although carbon nanotubes have a very low reflectivity value, they have the advantage that they are extremely light and can withstand very high temperatures.

Table 1: Key parameters of the laser infrastructure	
Laser infrastructure power [MW]	1150
Lens radius [m]	95
Number of lenses	10
Acceleration distance [AU]	1.8
Cruise velocity [%c]	10

Further innovation has been inserted in the subsystems of the spacecraft. We propose an inflatable camera aperture that can be extended, once the probe nears Proxima Centauri and its recently discovered exoplanet. The camera is at the same time used for taking pictures but also as a star tracker for navigation in interstellar space. For power supply, an advanced beta-voltaic battery is used. Beta-voltaic batteries directly convert the impact of radioactive particles from a radioactive material into electricity, in contrast to radio-isotopic batteries which use heat to generate electricity. The advantage is a higher efficiency and smaller size. The battery serves two purposes. First, it powers the spacecraft subsystems. Second, it heats critical components of the spacecraft that need to be kept at temperatures above 3 Kelvin, the cosmic background temperature. As the power output of such a battery is below 1 W, the energy needs to be stored and accumulated, in order to enable short bursts of communication with Earth over interstellar distances. For storage, recently developed graphene capacitors are used that have an extremely high power density and can be rapidly discharged.

In the following section, we will provide an overview of the spacecraft's configuration. Figure 2 shows the configuration of the spacecraft with its subsystems. The large cylinder is the camera with its lens aperture. The Whipple shield protecting against interstellar particles is located at

Figure 3: Orthographic Layout Drawing for Interstellar Probe

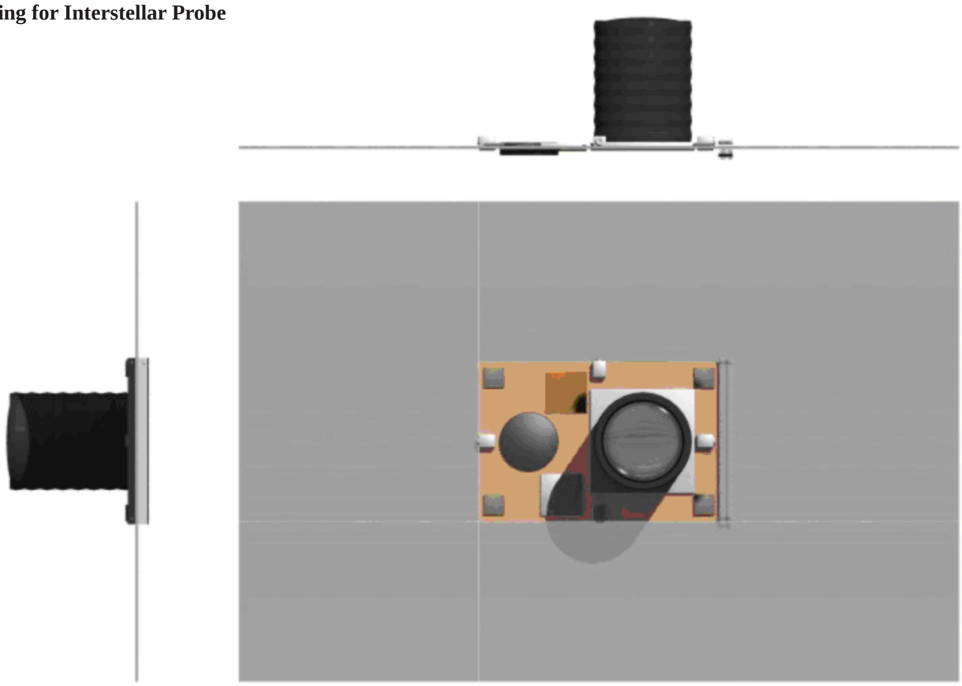


Table 2: Mass budget for spacecraft			
Subsystem	**Technology**	**Description**	**Mass [grams]**
Payload	Sensor package	• Sensors are microelectromechanical system (MEMS)-based. Even MEMS spectrometers have recently been developed. • The startracker with a foldable aperture is used at the same time as a camera. Gram-sized startrackers are already available today. A MEMS camera is used.	2.4
On-Board Data Handling system	Nano Field-Programmable Gate Array (FPGA)-based On-Board Data Handling system	On-board computer for processing data weighing a few grams already exist.	1
Power	Graphene supercapacitors + Nuclear battery	• The supercapacitors are used for storing energy. Prototypes of this technology exists already. • Gram-sized nuclear batteries have been proposed within the CubeSat community. An alternative is the use of very long electrodynamic tethers that can harvest electric current from the interstellar medium.	6.5
Structure	Rigid Graphene matrix	Based on an extremely light material such as a Graphene or Carbon Nanotube composite material.	0.1
Communications	Laser	Laser or radiofrequency-based communication is deemed to be feasible. For the laser-based communication with an area of 0.1m.	3
Attitude Determination and Control System (ADCS)	Momentum wheels, MEMS FEEP thrusters	MEMS field-emission electric propulsion (FEEP) is used, which is a mature technology. It allows for very small thrust levels and weighs in the orders of grams, including the propellant. The thrusters are used for occasional desaturation of the momentum wheels.	1
Navigation	Star tracker / camera + telescope	Camera is used.	-
Interstellar dust protection	Graphene Whipple shield	Graphene is used as a Whipple shield. The spacecraft is flying into flight direction showing its thin side. Momentum wheels are needed for keeping the spacecraft showing this side into flight direction. The momentum wheels are desaturated by the FEEP thrusters.	2
Bus mass			***15***
Sail	Graphene sandwich	4-layer Graphene sandwich (Radius: 34m) The sail is attached to the spacecraft via thin Graphene wires.	8
Total mass			***23***

the front of the spacecraft. This part is facing the direction of flight.

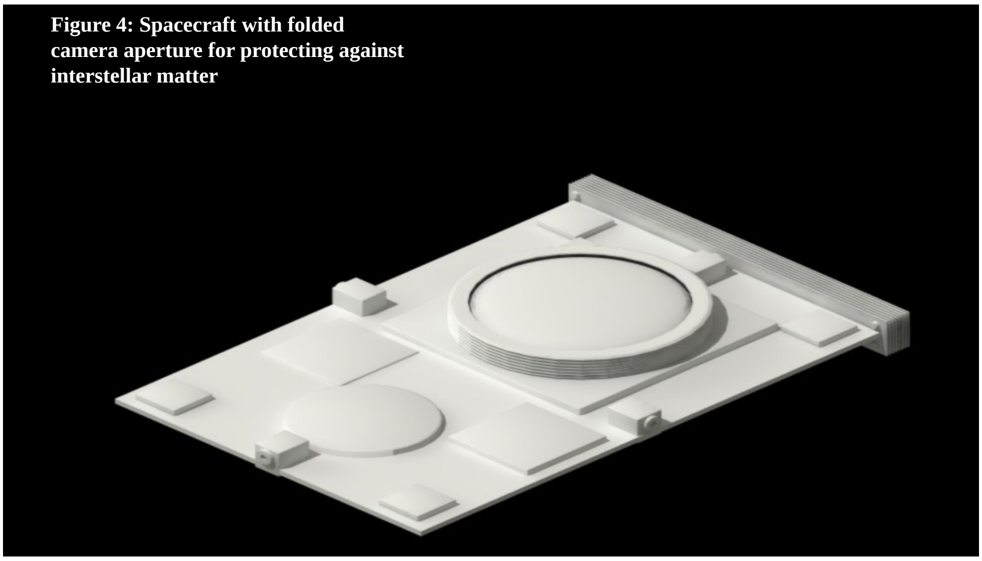


Figure 4: Spacecraft with folded camera aperture for protecting against interstellar matter

Figure 3 shows an orthographic view of the spacecraft without the sail. The size of the depicted spacecraft is about twice the size of a smartphone: about 12 cm by 10 cm. The grey area is the antenna transmitting data using a

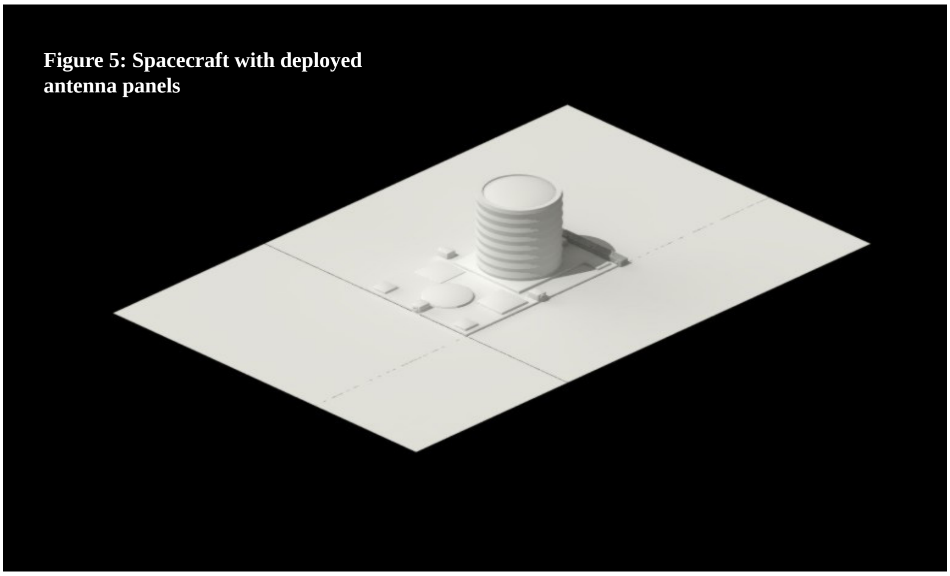


Figure 5: Spacecraft with deployed antenna panels

laser beam. In order to decrease the cross-section of the probe during flight through interstellar space, the antenna is folded during flight. The lens aperture for the camera is also folded, as shown in Figure 4.

Figure 5 shows the spacecraft with the unfolded antenna. The antenna is unfolded and pointed at Earth each time the spacecraft communicates. The power for the communication system is supplied by the graphene supercapacitors which are slowly charged by electromagnetic tethers.

The laser array that is located in space has a total power output of 1.12GW. This solution is preferred to an Earth-based system; there are no atmospheric losses and the laser beam can be continuously pointed at the spacecraft sail. 10 intermediate lenses keep the beam collimated.

Figure 6 shows the mission architecture. The spacecraft is accelerated over a distance of 1.8 astronomical units (270 million km) by a space-based laser array. After its acceleration phase, the graphene sandwich sail is detached and the spacecraft continues its flight into interstellar space. Using the FEEP thrusters and momentum wheels, the spacecraft keeps its orientation into flight direction in order to minimize the impact of interstellar dust. Once arriving at the target star system, measurements and pictures are taken by using the on-board sensors and camera with telescope.

Summary

The work performed by the i4is Andromeda probe team was astonishing given the short time we had to complete the work. We also contributed positively to the inspiring Breakthrough Initiative Project Starshot.
The architecture chosen by the Breakthrough Initiative team is different to that recommended by the i4is team, (ie ground based beaming versus space based beaming). But there are clear benefits in a ground-based beaming approach in the interim, including nearer term maturation of the required architecture. The Breakthrough Initiative has also gone for a 20% speed of light mission, which is a lot more challenging than a 10% speed of light mission, but where would physics be without challenges? The main implications of this is a different laser power requirement that moves from around 1 GW up to something around 100 GW. There are many physics and engineering challenges to be solved on the programme, and these were listed during the April 12th 2016 announcement by Yuri Milner. With effort, determined commitment and the will to succeed we are confident that the stars can be won.

References

Forward, R., 1984. Roundtrip interstellar travel using laser-pushed lightsails. J. Spacecr. Rockets.

Landis, G., 1989. Optics and materials considerations for a laser-propelled lightsail.

Lubin, P., 2016. A Roadmap to Interstellar Flight, JBIS, 69, pp.40-72.

Matloff, G.L., 2012. Graphene, the Ultimate Interstellar Solar Sail Material?, JBIS, 65, pp.378-381, .

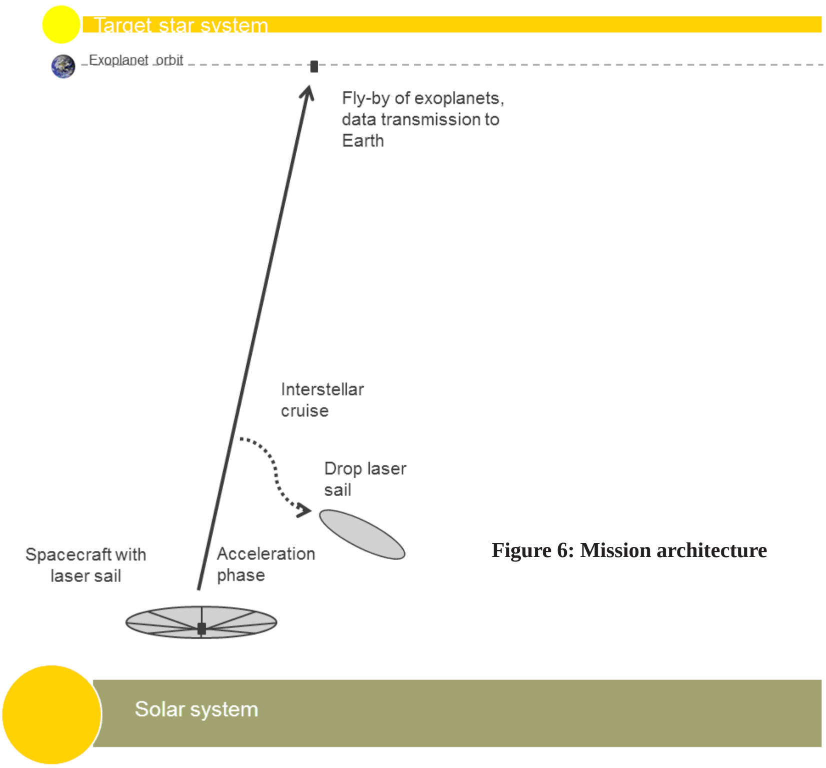
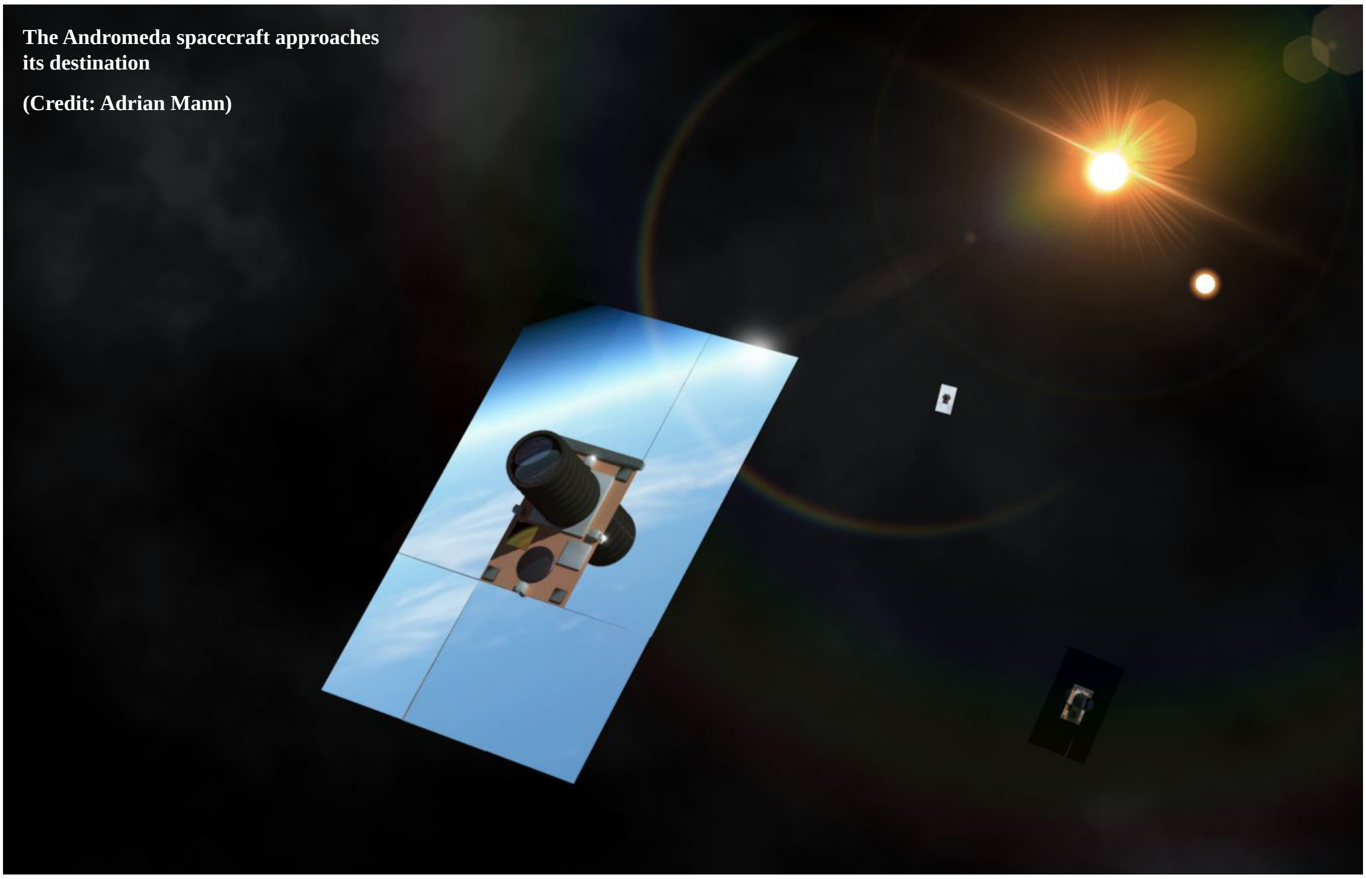


Figure 6: Mission architecture



The Andromeda spacecraft approaches its destination

(Credit: Adrian Mann)

BOOK REVIEW: Gypsy: Carter Scholz

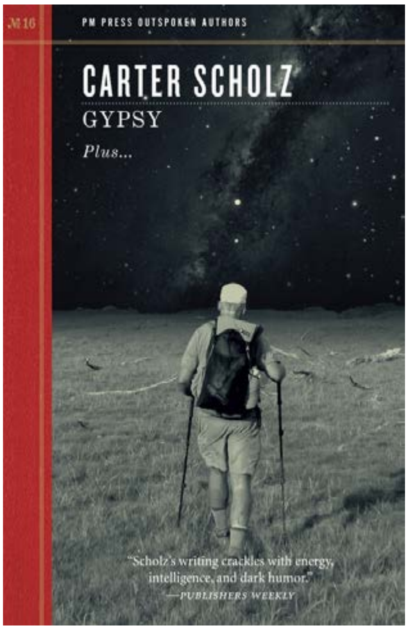
Reviewed by Patrick Mahon

Following on from three film reviews in recent issues (*Star Wars: The Force Awakens* in Principium 12, *The Martian* in Principium 11 and *Interstellar* in Principium 9), we turn back to books. Here is a review of a hard SF novella that combines a rigorous approach to the science and engineering of interstellar travel with a strong cast of characters and an all too believable plot.

Hard versus soft SF

Travel between the stars has been a core element of written science fiction for many decades. However, faced with the almost unimaginable distances and energies involved, many SF authors have chosen to gloss over the challenges of interstellar spaceflight by adopting invented physics or engineering solutions such as warp drives, hyperspace, wormholes and the like, allowing starship crews to travel much faster than the speed of light so that they can reach their destinations within a matter of hours or days, rather than decades or centuries. Given an author's understandable wish that their characters still be alive when they arrive at their target planet, such shortcuts are forgiveable in the service of getting on with the story.

On the other hand, some authors of so-called 'hard SF' have tried to limit themselves to the use of technologies that do not contradict the laws of physics as we currently understand them. For many, the pre-eminent exemplar of this approach would be Sir Arthur C Clarke, whose fiction is filled with spacecraft based on sound science. More recent exponents would include Alastair Reynolds, Stephen Baxter and Kim Stanley Robinson, amongst others. The constraints imposed on a story by such an approach are manageable when writing



Cover Credit: PM Press

about space travel within the solar system. However, as soon as travel between the stars is mooted, a hard SF approach comes up against real problems. The design for Project Daedalus envisaged a fusion-powered ship reaching 12% of the speed of light. Even at this incredible speed, travel to our nearest star, Alpha Centauri, which is 4.3 light years away, would take 36 years. That's a long time for the crew of a fictional starship to twiddle their thumbs before they get to their destination.

Carter Scholz, an American SF writer, normally writes literary SF where such concerns are irrelevant. His 2015 novella Gypsy, though, is a hard SF tale *par excellence*, which considers in great detail the many practical problems inherent in a decades-long journey to our nearest star.

The plot

The background to the story is familiar enough, extrapolated as it is from today's many global challenges. Scholz imagines a planet which is being overwhelmed by a perfect storm of over-population, rampant capitalism, resource depletion, war, climate change and aggressively nationalistic politics. Come the 2030s, a brilliant physicist called Roger Fry, having decided that humanity is doomed, starts a project to send a manned spacecraft to Alpha Centauri, intending to colonise whichever of the exoplanets there is most amenable to human life. Over the following few years, Fry secretly recruits a team of like-minded scientists and engineers to beg, borrow and steal the technologies they need for their mission. Come 2041, the starship is launched from Earth orbit on a journey intended to take 72 years to reach their destination, with a crew of sixteen in suspended animation pods on board.

Although the ship's Artificial Intelligence is able to deal with many problems itself, some are beyond its capabilities. In 2043, a mere two years into the mission, one of the astronauts is woken from her enforced slumber to deal with just such an issue. Sophie quickly realises that the ship's fusion engine didn't complete its burn correctly. As a result, they are cruising more slowly than expected, meaning that the journey to Alpha Centauri will now take 84 years, 12 longer than expected. This might not sound too bad, but with the mission already on the edge of technical feasibility, the extra flight time has a major impact on the likelihood of success, with the mission's risk of failure increasing from below 20% to over 50%. Sophie does what she can to compensate for this, then goes back into hibernation.

Over the following decades, one after another astronaut is woken up in order to deal with other such problems, including a communications system breakdown, fungal infections amongst the sleeping astronauts, a failure to deploy the magsail intended to slow them down as they approach their destination and so on. The longer they're out there, the more such failures there are. Will they make it to Alpha Centauri in one piece? And if they do, will they find a habitable planet to land on?

Is it a good story?

Putting the technical details to one side for a minute, Gypsy is an extremely impressive story about real people overcoming real problems. As each astronaut is woken to deal with an issue, Scholz gives us their backstory in a way that makes them a three dimensional individual, whilst showing how their life experiences led to them joining the crew. We see one after another struggling to deal with whatever the ship has thrown at them, and yet using their scientific and engineering knowledge to solve these problems. In my view, this is a story that should be required reading for all sixth form students of STEM subjects, but it's also a great piece of storytelling, full stop.

But is it realistic?

Readers of *Principium* will, of course, want to know how realistic the story's science and engineering is. As a former physicist who has been out of the field for over two decades, I'm not sure I'm too well-placed to give a definitive judgement. However, Scholz has included a lot of plausible-sounding technologies and measurements. For example, the ship is a twenty metre diameter, 100 metric tonne dry weight torus that rotates twice a minute to provide artificial gravity of one-tenth Earth normal. The propulsion system uses an anti-proton fusion engine to launch out of Earth orbit, a

Alpha Centauri and the Southern Cross.
Credit;Claus Madsen/Centauri Dreams

magsail to provide a decade of deceleration at the other end, and a gas-core nuclear rocket on arrival, aided by gravity assists around both the stars in the Alpha Centauri system. Although I don't think I'm in a position to judge, Scholz did say in an interview with Fantasy & Science Fiction magazine, who published the story in their November/ December 2015 issue, that he did a lot of background research, and based the physics and engineering on published academic papers wherever he could.

There are a couple of aspects of the story that I would question. Most obvious is the central idea that Roger Fry and his colleagues basically steal everything they need from their employers without anyone noticing. This seems pretty unlikely in the Big Brother society they are supposed to inhabit. In addition, the timeframe for the story seems a little too optimistic, as it pre-supposes that fusion will be a working and scalable technology by 2040, which is now a mere quarter of a century away.

Nonetheless, keeping in mind that this is a piece of fiction rather than a research study, I think Scholz has done a pretty good job of creating a plausible hard SF scenario that still enables him to tell a cracking story.

Conclusion

I have now read *Gypsy* several times, and I still think it's the best hard SF novella I have had the pleasure of coming across in many years. I'm not alone in this, either. No less an SF luminary than Gardner Dozois, the editor of probably the best annual survey of short SF available in the UK and USA, called it 'nail-bitingly tense' and 'heartbreakingly poignant' when he included it in his 2016 anthology. I agree wholeheartedly. If you want to read a science fiction story that treats the incredible challenge of interstellar travel with the seriousness it deserves, get hold of a copy of *Gypsy*. In addition to being available in *F&SF* and in Dozois's anthology, it's also available as the main story in a 2015 collection of Scholz's short fiction from PM Press.

The Propulsion System

Carter Scholz has set up a website to illustrate some aspects of the story (www.gypsyweb.net) this includes a page of references (www.gypsyweb.net/references.html).

In an interview with F&SF when they published the story, he referred to basing the workings of the ship's propulsion system on a paper written by a team at Penn State University. From his list of references, this appears to be the AIMStar paper mentioned below, which, amongst other things, gives the Specific Impulse of the fusion drive their proposed fusion drive as being 61,000 seconds.

AIMStar: Antimatter Initiated Microfusion For Pre-cursor Interstellar Missions, Raymond A. Lewis, Kirby Meyer, Gerald A. Smith and Steven D. - Howe Laboratory for Elementary Particle Science, Department of Physics The Pennsylvania State University

Presented at the 35th Joint Propulsion Conference and Exhibit Los Angeles,CA,U.S.A.

Abstract: We address the challenge of delivering a scientific payload to 10,000 A.U. in 50 years. This mission may be viewed as a pre-cursor to later missions to Alpha Centauri and beyond. We consider a small, nuclear fusion engine sparked by clouds of antiprotons, and describe the principle and operation of the engine and mission parameters. An R&D program currently in progress is discussed.

Retrieved 25/10/2016 from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.577.1826&rep=rep1&type=pdf

Summary of technical details covered in the story (pagination from F&SF, Nov/Dec 15):

• Pp.89-90: the ship is a **rotating torus**. It rotates twice a minute to provide **artificial gravity** of 0.1g. External structure: outside the 'floor' are water tanks, then aerogel sandwiched between carbon composites, the liquid (slush) hydrogen tanks. **Propulsion** uses nuclear fusion bomblets at launch (from Earth orbit), a fission reactor to start up the second fusion engine on arrival at Alpha Centauri, and onboard heat and electricity is provided by a Plutonium 238 powered Radioisotope Thermal Generator (**RTG**) (cf Voyager 2). The ship's mass is 100 metric tonnes (p.135).

• Pp.91-92: details of the communications system.

• P.93: their actual velocity is 0.056c, not the planned 0.067c, probably due to the failure of the igniters in some of the fusion bomblets. This adds 12 years to the **mission duration** (84 years, instead of 72), which increases the **risk of mission failure** from under 20% to over 50%.

• Pp.94-95: Why they picked Alpha Centauri as a **target**.

• P.96: Sophie sets the ship up to **brake** later and harder when they arrive, in order to reduce the journey time.

• P.98: the **crew complement** was 20, but one shuttle didn't make it, so they've actually got 16 people aboard.

• P.98: **Ship's speed and distance** after first minute, hour, day, year. "In its first few minutes, [*the ship*] advanced less than a kilometre. In its first hour it moved two thousand kilometres. In its first day, a million kilometres. After a year, when the last bomb was expended, it would be some two thousand astronomical units from the Earth, and Gypsy would coast on at her fixed speed [*which was supposed to be 0.067c*] for decades."

• P.99: **Date of launch** is 10 September 2041.

• P.100: details of the technology of the **fusion bomblets**.

• P.101: their '**suspended animation**' technology is actually induced hypothermia.

• P.105: details of the **technologies monitoring the sleeping astronauts** and exercising their dormant limbs. Also, Reza is covered in f**ungal growths** despite UV lights & other precautions in the suspended animation pods to prevent this. This appears to be due to him being repeatedly warmed and refrozen several times in failed attempts to wake him up, but may also be due to the gene therapy that Fang developed to enable the suspended animation.

• P.112: mission analysis phases – these were solved by developing the Gypsy website (nominally a geeky gaming site, but actually a front for a set of starship design 'games').

• P.113: **how they built the ship**, and then filled it with the cargo they'll need at the other end.

• P.114: a **magsail** as the **means of slowing down** at the destination.

• P.115: **EVA suit** technology.

• Pp.116-117: Sergei fixes the problem with the deployment of the magsail (a tripped fuse!), but because he's in a hurry and hasn't tethered himself to the ship, his reward is separation from the ship and **a lonely death in the EVA suit**.

• P.117: mission **fuel requirements**, and the value of the magsail in reducing this.

• P.118: details of the **fusion bomb approach** to propulsion. More details of the **propulsion systems**: an anti-proton fusion engine on the way out; a magsail to slow down on arrival; then a gas-core nuclear rocket on arrival, aided by two gravity assists.

• Pp.122-124: Project creator **Roger** helps a Greek oligarch to build a **spaceship** full of dual-use technologies: nominally great as a lifeboat in orbit, while the Earth slowly destroys itself below, but also excellent for a mission to Alpha Centauri. When it's completed, they then steal it! It is 10 metres long by 20 metres wide (not circular?), a torus, and weighs 100 metric tonnes (dry).

• P.124: the fungus has killed most of the crew.

• P.126: There is 2 years of further magsail deceleration to go. They are 300AU out from Alpha C and travelling at 0.001c.

• Pp.126-7, 129-130: the **magsail** fails when they hit the hydrogen wall at the heliopause of Alpha C, so he jettisons it. Going far faster than planned, the **only viable solution left** is to shoot close to each star and use the fission engine to brake whilst close to them, as this will multiply its effects. But the two stars are now much further apart than they were 12 years earlier, when the ship was planned to arrive…

• P.139: When **Rosa** wakes up in 2125, she sees that she has aged, which wasn't supposed to happen. She looks over 60.

• P.140: the origin of the ship's (and story's) name **Gypsy**: they are landless, orphaned and dispossessed.

• P.142: Rosa has to do the calculations to start up their **20GW gas-core fission reactor** at the right time, so the hydrogen exiting the rocket with 2 million newtons of thrust slows them enough. During closest approach to Alpha C-B, the outer hull heats to 2,500 Kelvin.

• P.144: a list of the equipment they've brought to create the colony when they land.

• P.145: Sophie wakes in 2126. She is now really old, and has to 3D print some glasses to be able to read the paper logs. She's the only crew-member still alive.

• Pp.146-148: the science instruments show Sophie that the 4th planet around Alpha C A is potentially habitable, with a N-O atmosphere and liquid water! Sophie controls the 2nd braking manoeuvre around Alpha C-A – but it's not enough! They are still travelling at twice the system's escape velocity… They will miss the planet by 0.002 AU (about 180,000 miles). Sophie maps the planet and send the data back to Earth.

• P.151: Two weeks later, she receives a message from Earth: they fixed things! Earth didn't destroy itself after all. And the message says that they honour the memory of the Gypsy crew and their mission.

The Initiative for Interstellar Studies is Hiring!

For the moment this is pro bono - though we have ambitions. We produced the flyer above 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

Plot summary:

In Sep **2041**, the Earth is dying (climate change, peak oil, resource wars, flooding, etc.) and a small band of renegades steal the resources to build their own starship and launch it towards Alpha Centauri. In 2043, **Sophie** (one of the 16 crew-members) wakes from suspended animation – so something must need her attention. She works out that the scientific data they're sending back to Earth in no longer being received and acknowledged, so their buffer is full and they're losing new data. Much more seriously, though, their fusion engine's burn didn't complete properly, so they are going to be 12 years late getting to Alpha C, taking 84, rather than 72, years – which increases the risk of critical component failure from <20% to >50%. Oops. Sophie fixes the first problem, changes the schedule for decelerating at Alpha C to regain some of the lost time, and after five days she goes back to sleep. In **2081**, Chinese-Irish **Fang Tir Eoghain** wakes up, when they're about halfway there. She finds that the ship has tried three times to wake **Reza**, without success. She finds that Reza is still alive – just – but small dots of fungus have started to grow on his skin. Is the suspended animation system faulty? Then she finds that another crew-member, **Loren**, is infected with fungus too. Fang is the expert on this system, and she spends 10 days finding a solution and implementing it – but she can only hope that it will work. She can't stick around to check, because if she stays awake any longer, she won't be able to hibernate again. So she goes under, and hopes that her solution will work. **In 2118**, **Sergei** (the trained astronaut) is awoken and realises that the magsail intended to slow them down as they approach Alpha C has not deployed. He does an EVA to fix it, finds that a circuit breaker has flipped – and because he's cold and in a hurry, he resets it immediately, without thinking. It starts the magsail deployment process immediately (saving the mission), but also disrupts the system holding him to the outside of the ship – and he floats away, untethered and without an MMU, to his certain death. **In 2120**, **Zia** wakes to find that his body has aged horribly. As the numbness wears off, he starts to feel pain, and passes out when he tries to sit up. But he eventually manages to get up, and finds that most of the other crew have died from the fungal infection. They are now a mere 300AU away from Alpha C, and he realises that the magsail isn't slowing them down as it should, probably because they're entering the local equivalent of the heliopause. Then the magsail fails, probably due to that. And when he looks for the EVA suit to go out and fix it, he realises that it, and Sergei, are gone – though he doesn't know whether this was accident or suicide. So he jettisons the magsail and tries to work out a new way to slow them down sufficiently, through gravity assists with the two suns. He manages it, starts the manoeuvres, writes the log, and goes back to sleep. **In 2125, Rosa** wakes up. Like Zia, she's surprised how old she looks and feels. Zia is dead – he went back to sleep but didn't reattach his stents (deliberate, or an accident?). Rosa refines Zia's orbital calculations, and performs the first burn past Alpha Cent A. The ship gets very hot, but they survive the close encounter, and they've halved their speed. She's done her bit, and goes back to sleep. **In 2126,** Sophie wakes for a second time (see 2043). She's old, and all the others are dead. The mission has failed, but the Alpha C system DOES include one habitable planet (out of five). She completes the braking manoeuvre around the second sun – but they don't have enough fuel, and the ship is still going too fast afterwards to be captured by the gravity of the Alpha C system. She's failed. They've all failed. As they head away from the system into interstellar space once more, she starts to compose poems. Then the radio comes on! It's Earth – they sorted out their problems, and everything is fixed. They salute the mission and say goodbye. And Sophie continues on into infinity.

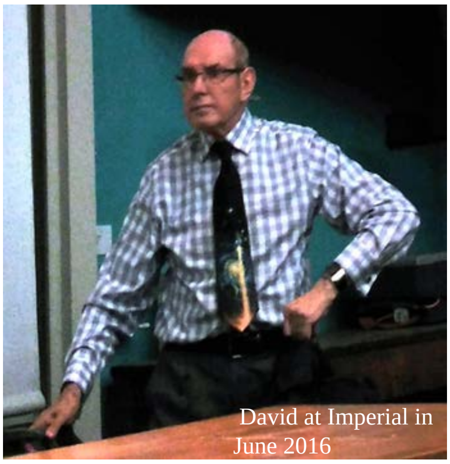
About the reviewer

Patrick Mahon is an i4is member who works in the waste and resources sector. He was encouraged to study mathematics and physics at university after falling in love with astronomy and spaceflight when Sir Patrick Moore gave a talk to his school's astronomy club in 1981, the same year as the first Space Shuttle flight. He now writes science fiction in his spare time.

The art and imagination of David A Hardy

John I Davies

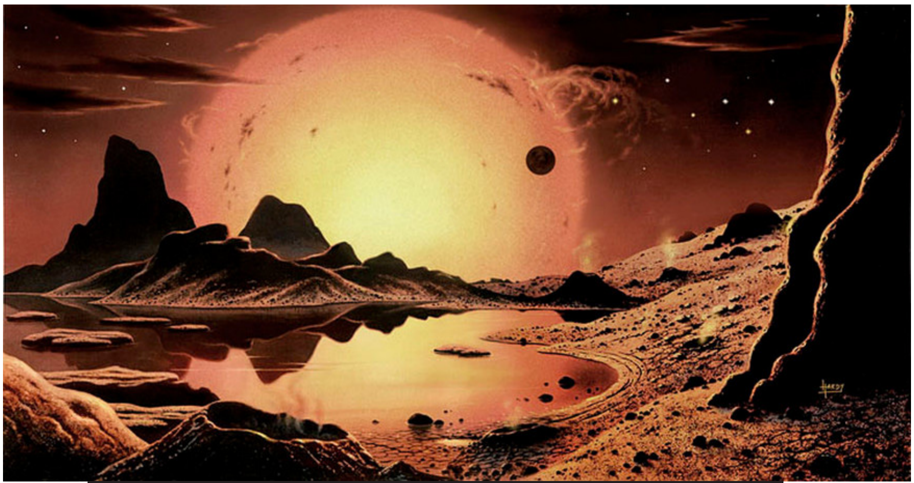
We reported in our last issue that our old friend, the "grandmaster" of space art, David A Hardy, was chief guest speaker at the joint AGM of the Science Fiction Foundation (publishers of Foundation, the Review of Science Fiction) and the British Science Fiction Association (BSFA) at Imperial College, London, 25 June 2016.



David at Imperial in June 2016

His work has inspired many of us - starting with his early work with Patrick Moore, still the most important populariser of astronomy and space travel in the UK. Patrick is sadly no longer with us but David is still batting as he enters his ninth decade. This celebration of his vision is based to some extent on his account at Imperial in June but I have concentrated on his early work and his contribution to interstellar studies.

David began producing space art in 1950, age 14, and began work with Patrick Moore four years later (Patrick was in the RAF in the Second World War so was a little older!). More of David's bio at www.astroart.org/hardy-profile.



Proxima 1972

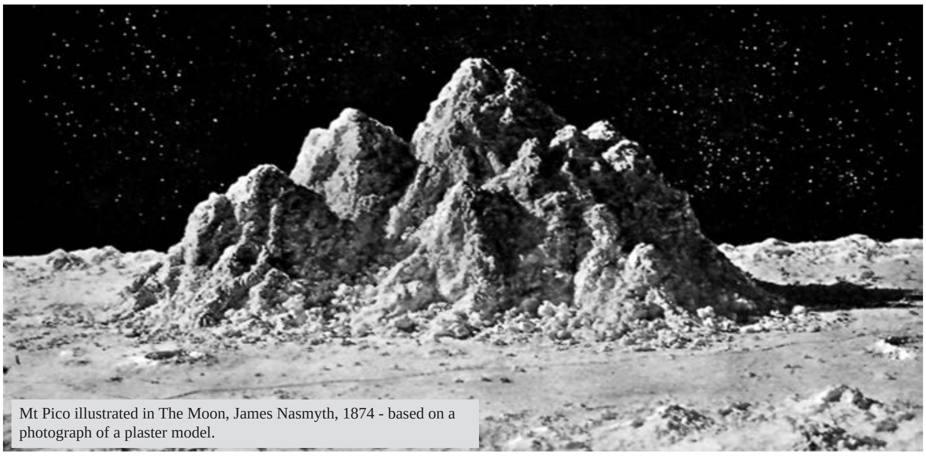
The most effective extrasolar scenes are often those with a red sun, whether a red supergiant or a dwarf. One of the latter is our closest stellar neighbour, Proxima Centauri, a small member of the Alpha Centauri system. This was painted, in acrylics, for The Challenge of the Stars with Patrick Moore in 1972. In order to have liquid water, the planet would need to orbit the red star in 10 days. The constellation Cassiopeia can be see with an extra star - our Sun.

First let's cut to the (interstellar) chase. All images are courtesy of David Hardy (www.astroart.org) Back in 1972 (44 years ago!) David painted the above image of an imagined planet of the nearest star to Earth.

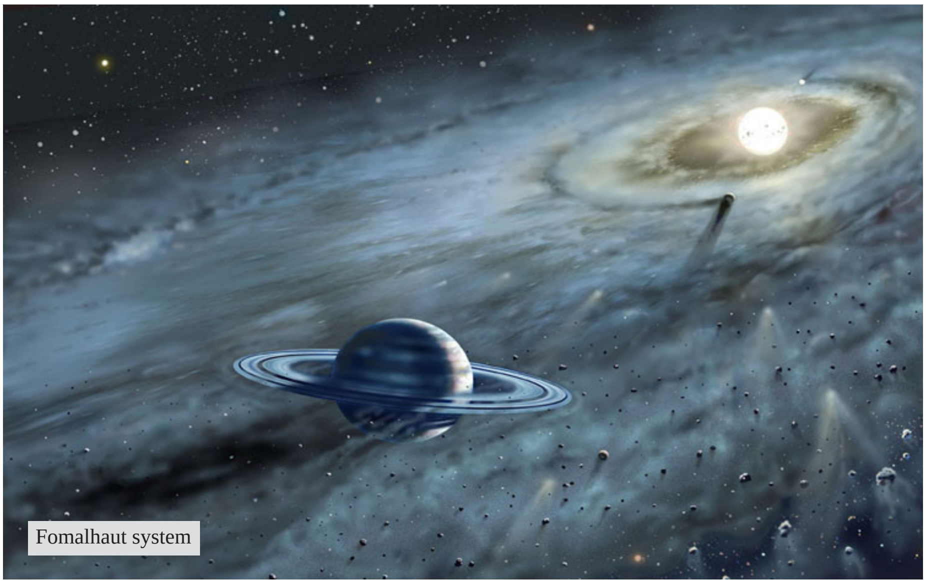
As we now know the period of Proxima b is 11.6 days and "water could be liquid on its surface" (see *A terrestrial planet candidate in a temperate orbit around Proxima Centauri*, Guillem Anglada-Escude, School of Physics and Astronomy, Queen Mary University of London et al, Nature, August 2016). More later about The Challenge of the Stars.

As David told us at Imperial, astronomical imagination is a long established art - quoting the 1874 example below.

David illustrated the imaginings of the British Interplanetary Society (BIS) from the 1930s through to the 50s - adding to the famous R A Smith illustrations of the BIS Moon mission proposal and bursting into print as early as 1952 at the age of 16. He began to be commissioned for SF book covers as well as the popular science works of writers like



Mt Pico illustrated in The Moon, James Nasmyth, 1874 - based on a photograph of a plaster model.

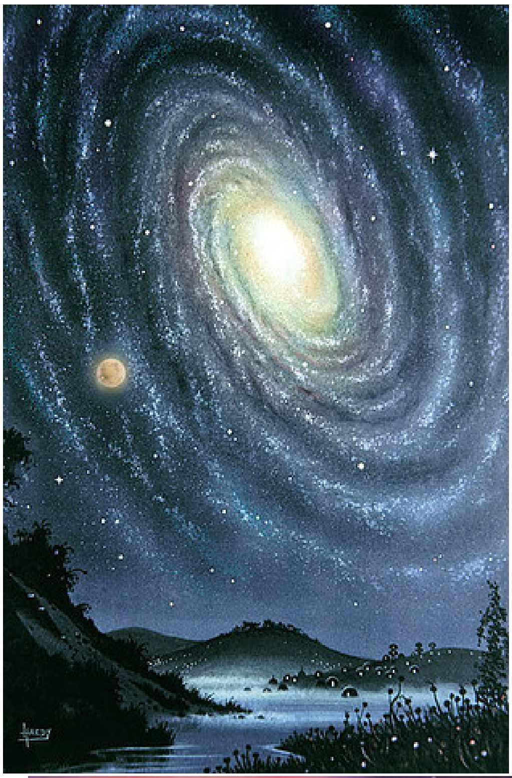


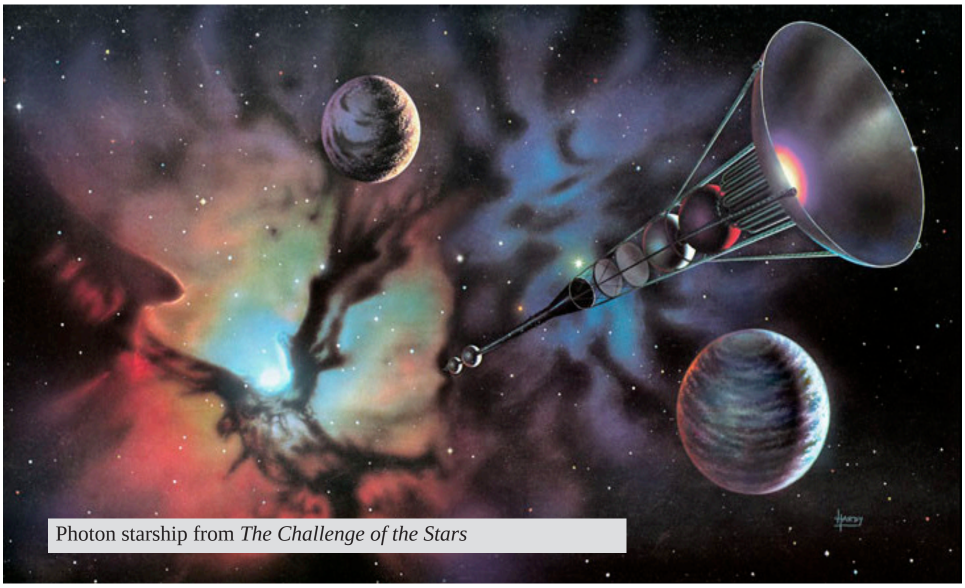
Fomalhaut system

Patrick Moore and he imagined the moons of the outer planets long before we had spacecraft out there.
Getting back to interstellar, David has often envisaged planets, stars and galaxies as they might be. Here's the rather dusty Fomalhaut system with a Saturn-like planet imagined surviving the dust and gas which has been observed around that star.
Even further, what might our Galaxy look like from an earth-like planet whose star had been ejected to a place above the galactic plane?

David began to get joint credit with Patrick for books like *The Challenge of the Stars*. Here he is at the launch in 1972 with Arthur C Clarke, who wrote the foreword to Patrick and David's book.

Back in 1972, Patrick and David were already envisaging exotic forms of propulsion. Below is the Photon Starship from the same book.





Photon starship from *The Challenge of the Stars*

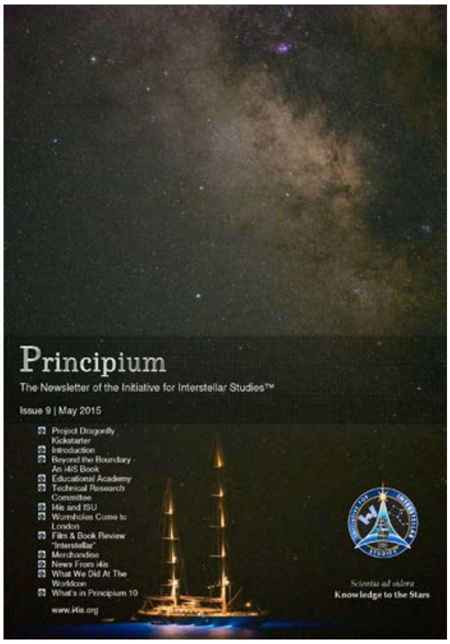
Some of his work has been a little bigger. Here is a 24 by 8 foot mural, another planet of a red star. He's especially fond of stars of this colour.

Again in the early 1970s a short lived UK magazine, Science Fiction Monthly, was published in colour with a newspaper size format and imagination of aliens beyond the "bug eyed monsters" of earlier years.
David envisaged these "lava lamp" like creatures.

And he produced more terrestrial books, for example Energy and the Future in 1979.
But starships could not be kept out. Below is an ion propulsion ship from that book.

Much of his work has, of course, overlapped into fantasy and here's an example that reminds me of the i4is logo...

..which in turn inspired our Principium 9 front cover.
Will our laser spacecraft ever attain the romantic appeal of square-riggers?


Principium

The Newsletter of the Initiative for Interstellar Studies™

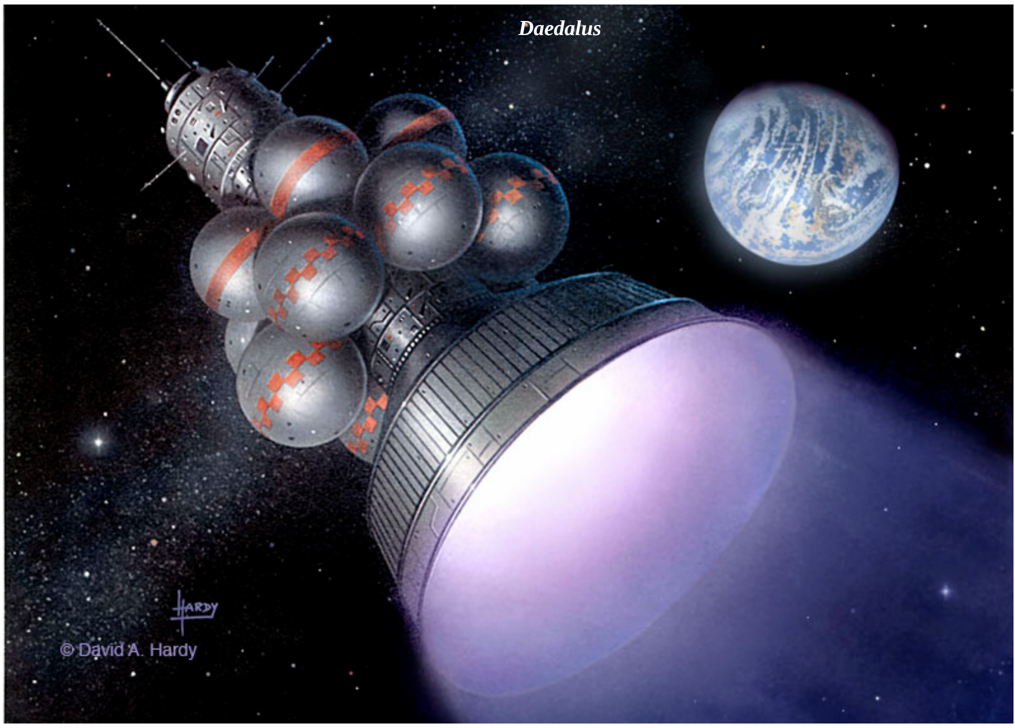
Issue 9 | May 2015

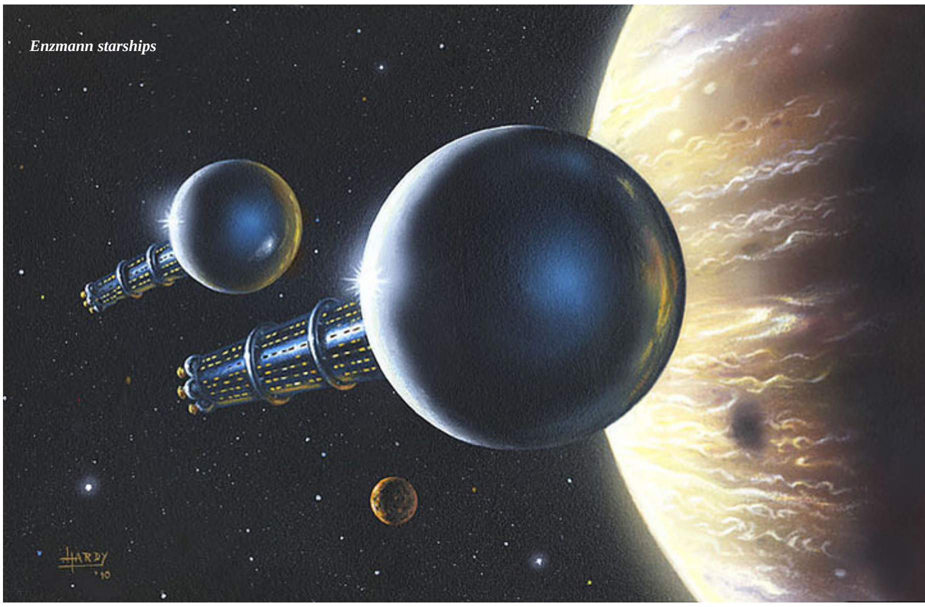
- Project Dragonfly Kickstarter
- Introduction
- Beyond the Boundary - An i4iS Book
- Educational Academy
- Technical Research Committee
- I4is and ISU
- Wormholes Come to London
- Film & Book Review "Interstellar"
- Merchandise
- News From i4is
- What We Did At The Worldcon
- What's in Principium 10

www.i4is.org

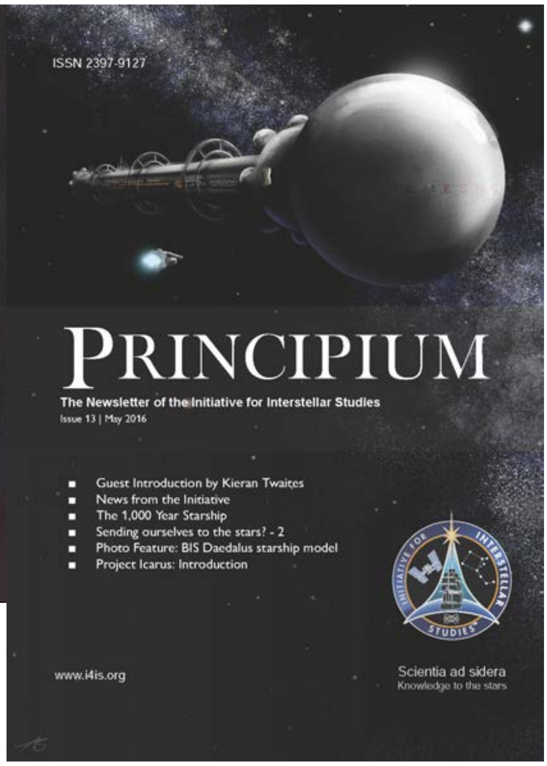
Scientia ad sidera
Knowledge to the Stars

We can't leave out the BIS Daedalus, of course, below is David's illustration from a Marshall Cavendish book in the 1980s.





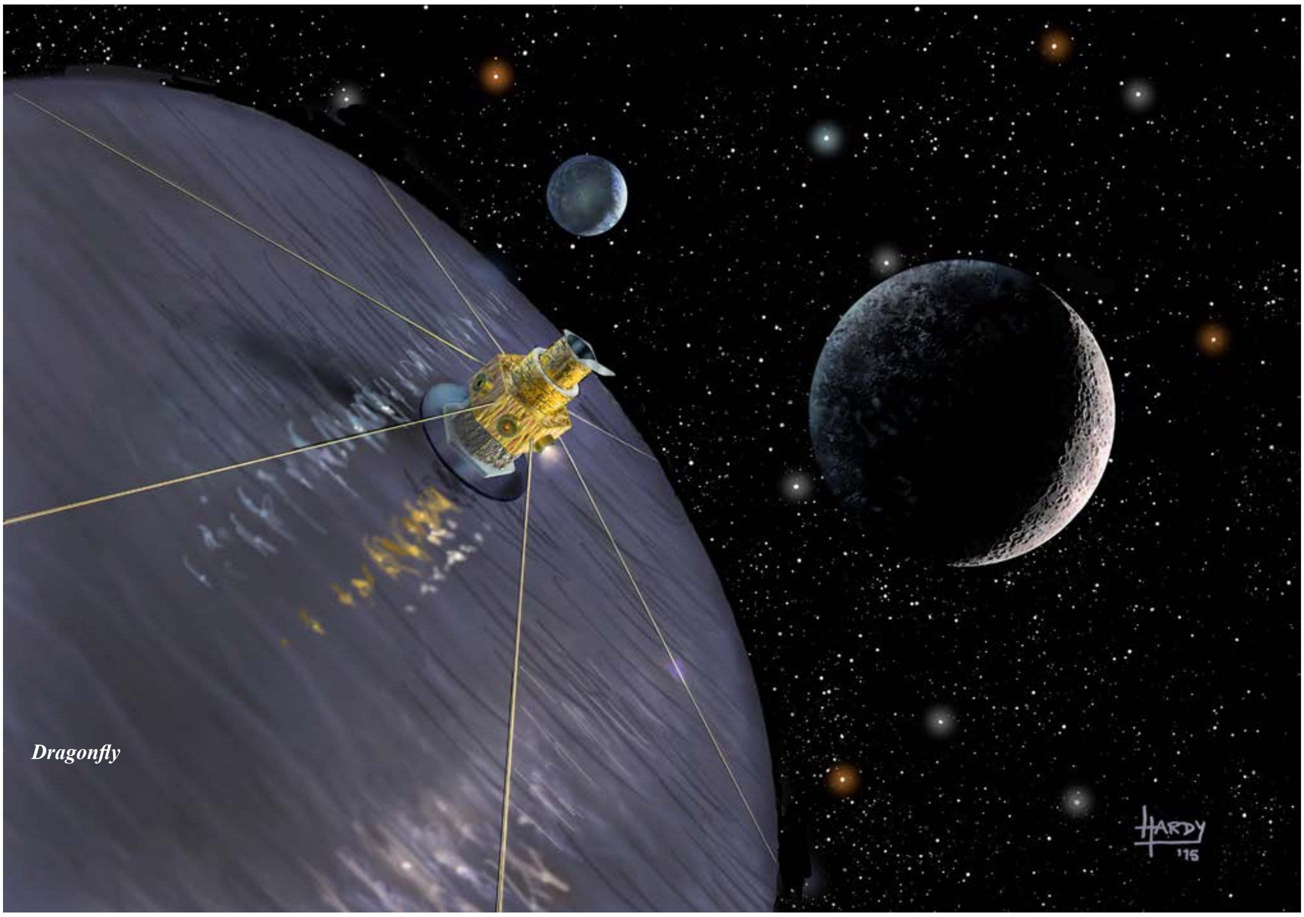
Enzmann starships



And very different designs inspire us. Here's an Enzmann starship painting which i4is Executive Director Kelvin Long commissioned from David.

You may recall Alex Storer's interpretation of an Enzmann from our P13 front cover David has long been an inspiration to younger artists like Alex.

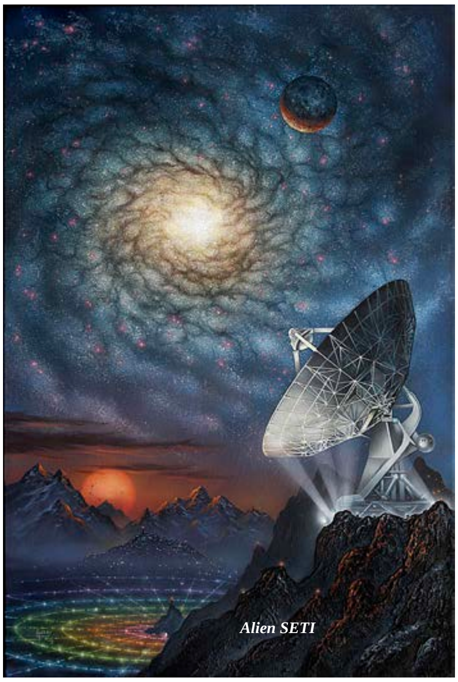
More about Enzmann in *Retrospective: Art, Science and Lollipops:the story of the Enzmann Starship* in Principium 7 (www.i4is.org/Publications#Principium).



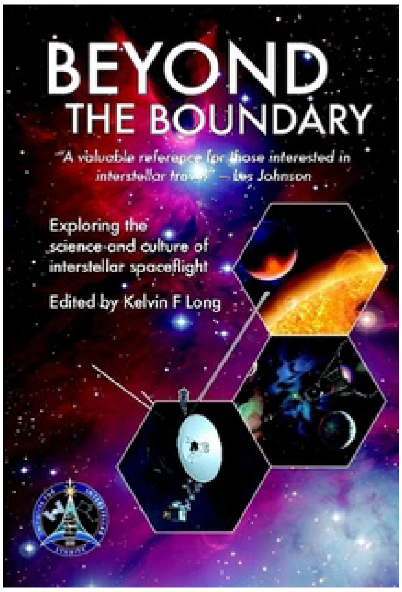
Dragonfly

David continues to inspire us with images like this - the heading of Andreas Hein's piece on the i4is Dragonfly laser push project - showing the winning entry of the 2015 competition from the Technical University of Munich team.

David has provided front cover images for Principium and the first i4is book, Beyond the Boundary.
Below is *Alien SETI* - which we used on the cover of Principium 5.



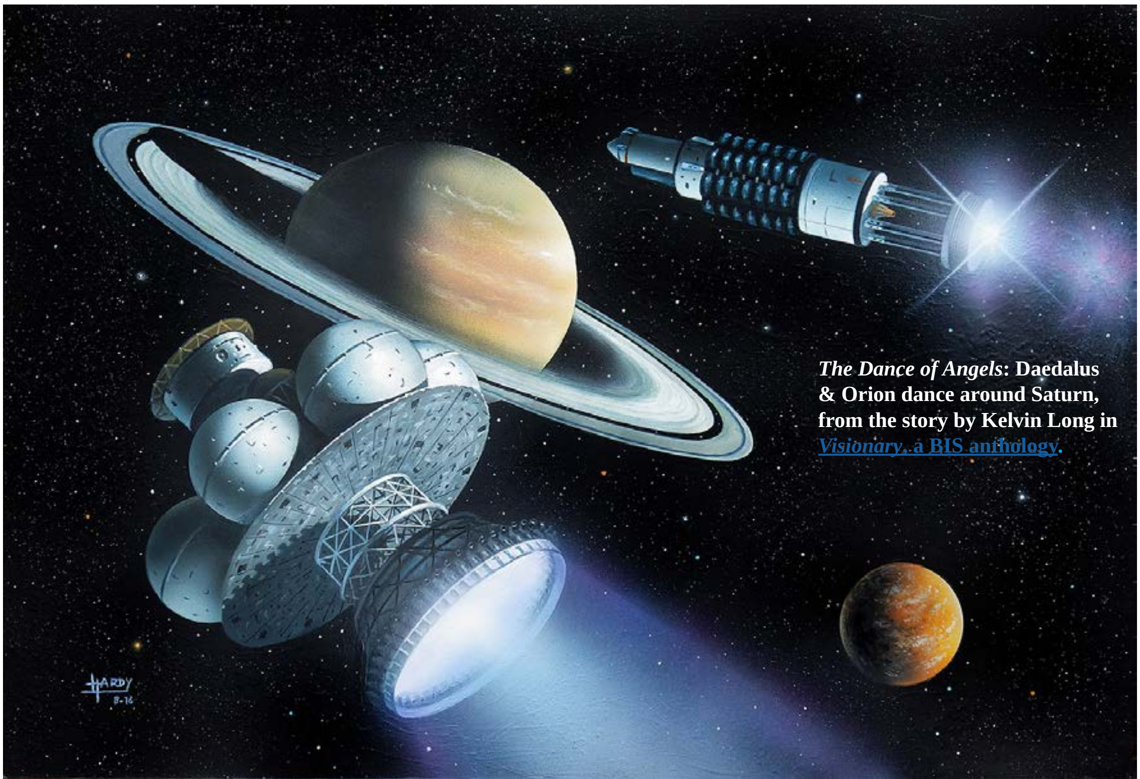
Alien SETI



And here is the [Beyond the Boundary]() front cover.
And David has kindly provided our back cover image for this issue, the Liberator from that favourite 1970s space adventure, Blake's 7.
And finally David's Daedalus and Orion "dancing"!

More

See more about David and his art from the 1950s to the present on his site [www.astroart.org](). And look for *Hardyware: The Art of David A. Hardy*, with text by Chris Morgan, Paper Tiger, 2001. For a fuller list of David's author credits see the Summary Bibliography: David A Hardy in the *Speculative Fiction Database* [www.isfdb.org/cgi-bin/ea.cgi?21486]()



***The Dance of Angels*: Daedalus & Orion dance around Saturn, from the story by Kelvin Long in [*Visionary, a BIS anthology*]().**

About the writer
John Davies, editor of Principium, was first inspired to take an interest in space by the brilliantly drawn *Dan Dare, Pilot of the Future*, strip in his weekly *Eagle* in the early fifties. The originator and artist, Frank Hampson, born 1918, inspired many people, not least Alan Bond of the Daedalus project and Reaction Engines. John is privileged to present this sample of the art of David Hardy, another inspiration to both newcomers to space science and technology and those of us who have seen so much progress in the many decades of David's career.

NEXT ISSUE

In the February 2017 issue we'll have more from the May 2016 i4is/ISU course *Interstellar Studies*. We'll report from the *Interstellar Challenge for London Schools* and outline our plans for taking it to other parts of the UK, Europe and the world. We'll also report from our Starship Engineer course at BIS in November. And we'll be reviewing those two interstellar-themed films, *Arrival* and *Passengers*. And more, of course!

Mission

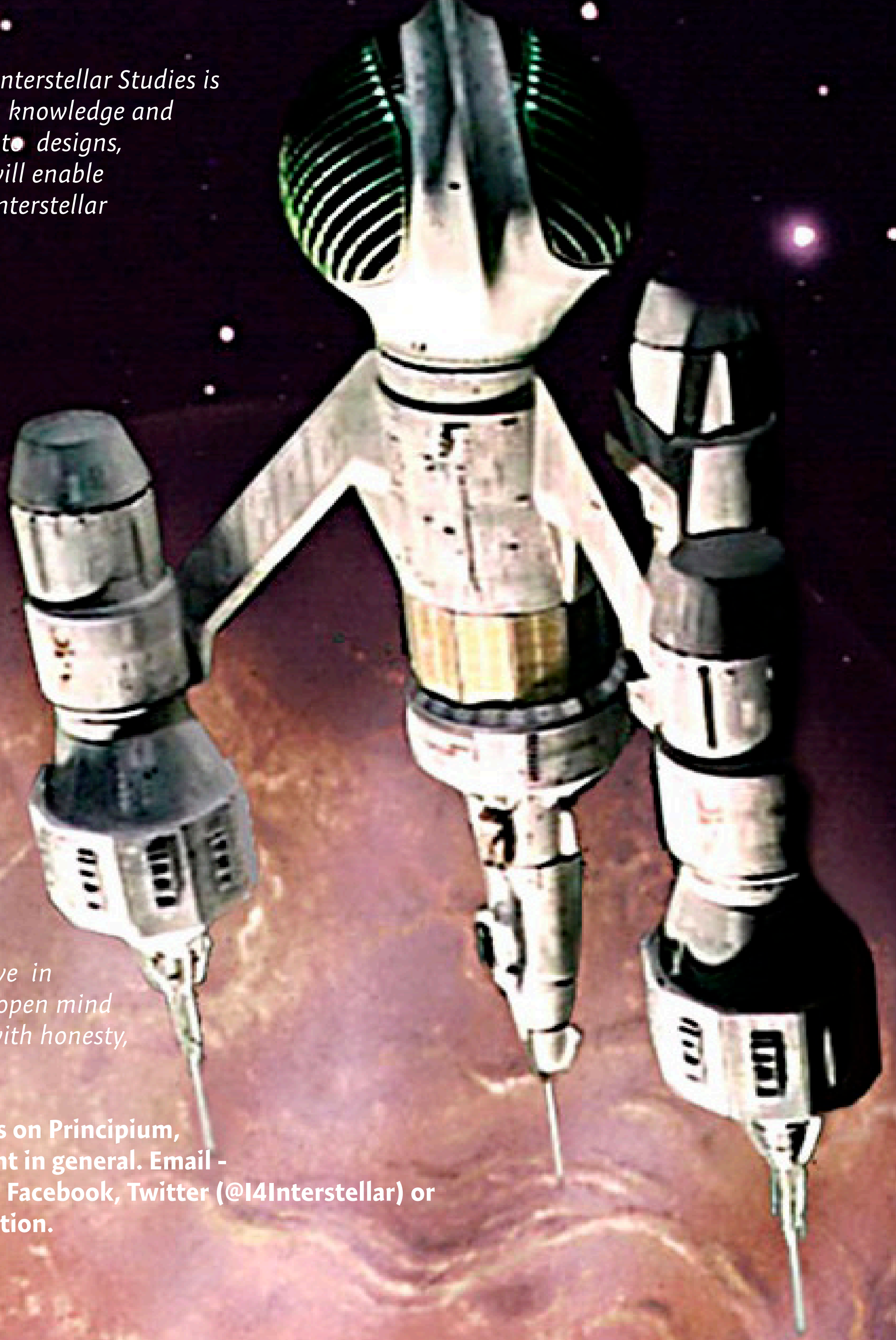
The mission of the Initiative for Interstellar Studies is to foster and promote education, knowledge and technical capabilities which lead to designs, technologies or enterprise that will enable the construction and launch of interstellar spacecraft.

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.

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

The Initiative For Interstellar Studies is a pending institute, incorporated in the UK in 2014 as a not-for-profit company limited by guarantee.

Front cover: Andromeda project - spacecraft approaching target star. Credit: Adrian Mann
Back cover: Starship Liberator from the TV series Blake's 7. Credit: David A. Hardy

INITIATIVE FOR INTERSTELLAR STUDIES™

i4is.org