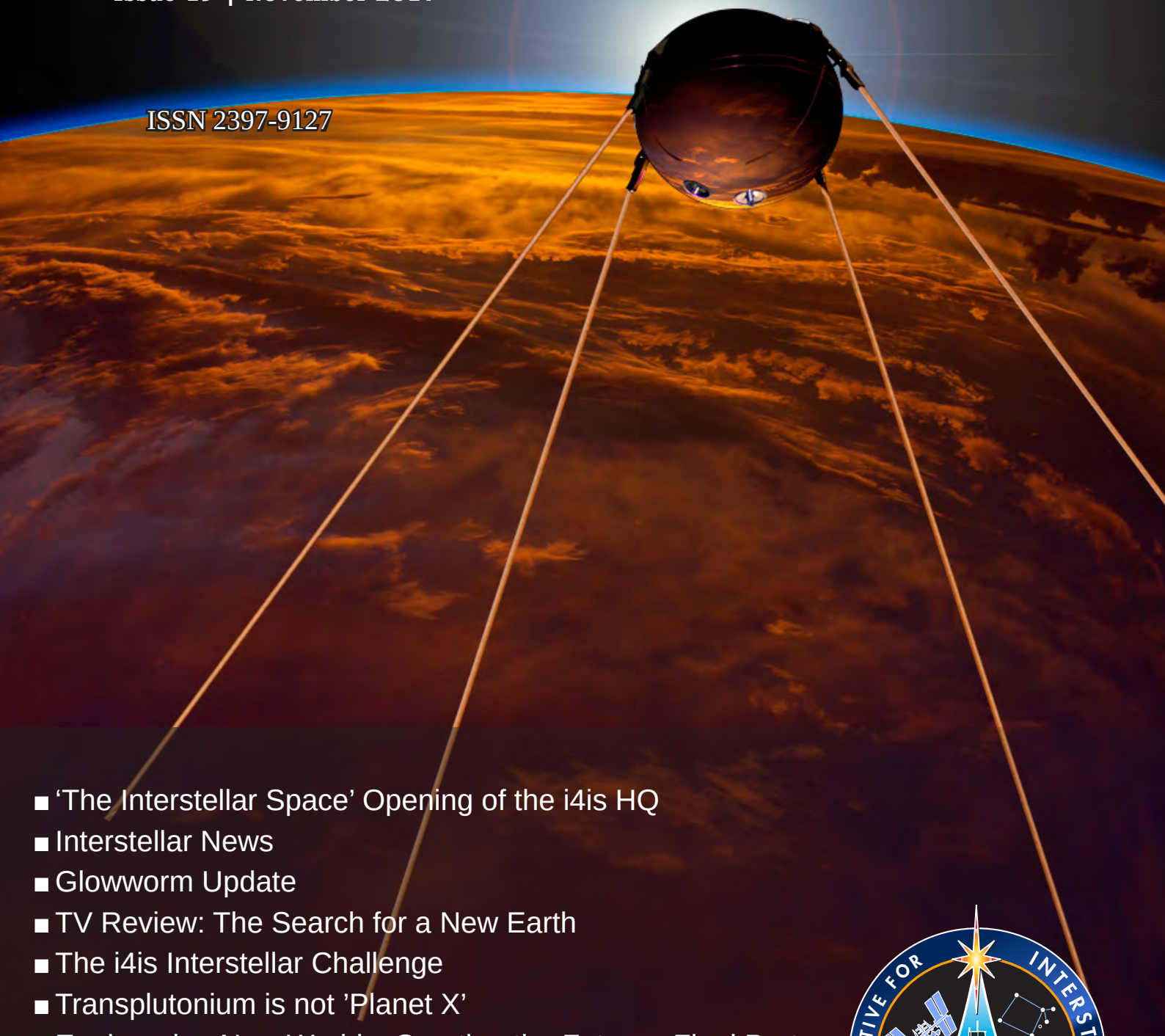
PRINCIPIUM

The Newsletter of the Initiative for Interstellar Studies

Issue 19 | November 2017

ISSN 2397-9127



www.i4is.org

Scientia ad sidera
Knowledge to the stars

Editorial

Welcome to Principium, the quarterly newsletter about all things interstellar from i4is, the Initiative for Interstellar Studies - and our US-based Institute for Interstellar Studies. And a special welcome if you are a new reader - we have added 109 since our last issue. Please tell us if we have your details incorrect (info@i4is.org).

Our Introduction feature for Principium 19 is the opening of the i4is HQ, *The Interstellar Space* reported by our Deputy Editor, Patrick Mahon. This was a momentous event for i4is and, we hope, for human progress towards the stars. Al Worden, Apollo 15 command module pilot gave us a brilliant opening speech and all ages present witnessed a unique occasion. And thanks to our friends at the BIS magazine, *Spaceflight*, for a two page feature about our HQ opening, also by Patrick..

We bring you the third and final instalment of the major new work by Dmitry Novoseltsev, *Engineering New Worlds: Creating the Future*, his vision of the massive prospect of Interstellar Engineering. This month Dmitry examines "Cosmological Natural Selection", considering an engineering approach to the "creation of the world" and a proposed history of the desired future: to create worlds, suggesting that the propagation of intelligent life can be irreversible and auto-catalytic. He concludes with a briefing on the simplest Shkadov thruster, perhaps the largest conceivable propulsion device, Our thanks to Dmitry and his collaborator Anna V Sedanova for a glimpse of possibilities on a truly cosmic scale.

Interstellar News again has much to report including i4is management changes, more outreach, our regular JBIS summary and *Project Lyra: Sending a Spacecraft to the Interstellar Asteroid* - an i4is project which has received worlwide attention.. Keep scanning Google and watching our Twitter and Facebook for more developments on this exciting i4is initiative.

Our feature Art for Interstellar 2017 reports on the visual art event at the i4is/CUNY Workshop in June. Inspirational art is a vital human part of the interstellar vision and we are proud to show this work in Principium.

Our Technical Report on the Foundations of Interstellar Studies Workshop is postponed.

Our front and back covers once more reflect different historical aspects of our outward urge.

Our front cover is an artist's impression of Sputnik 1. We celebrated the 60th anniversary in October 2017. The image was commissioned originally for the 40th anniversary by Robert Kennedy, President of the Institute for Interstellar Studies, our US organisation. For a contemporary view of this historic event see the BBC On This Day page.

Our back cover is a shot taken by the Apollo 15 Lunar Module crew of their Command and Service Module as they returned from the lunar surface. Al Worden no doubt looking forward to welcoming them home for the return trip to their beloved Earth.

Next time we will have -

» Project Lyra: Flying close to our first discovered interstellar object

» Models and Art at The Mill

Later in 2018 we will feature Z-Pinch Fusion Propulsion - An Introduction by Patrick Mahon, based on the Icarus Firefly design led by Robert Freeland

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

Errata and Apologies

In the account of our NYC June conference in Principium 18, Edward Montgomery was wrongly identified as Richard Montgomery. Our apologies to him and our readers.

We are now rescheduling the Starship Engineer course for next year with additional and updated material. Apologies to those who expressed interest in the 2017 course.

And, of course, Principium 19, November 2017, strays into December. We have maintained our quarterly schedule since May 2015, Principium 9, and we aim to continue. There is certainly no lack of things to discuss and report. Interstellar Studies is a fast growing field. Principium will reflect and, we hope, enhance it.

Join in the conversation by following the i4is on our Facebook page www.facebook.com/InterstellarInstitute and in our professional network on LinkedIn www.linkedin.com/groups/4640147 - and check 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.

All issues of Principium are at www.i4is.org/Principium

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

The Initiative for Interstellar Studies

image: ©ALEX STORER

Working towards the real Final Frontier

Help us to realise our mission to reach the stars - we need your help - physics to software engineering, graphic design to project management - and rocket science of course! ...and much more....

We have a great team. But we need more talent in all departments. Come and join us!

Here is just some of our team -

- **Dr Andreas Hein: i4is Executive Director, System Architect & Engineer**
- **John Davies: Project Manager & Editor, Principium, the i4is quarterly**
- **Kelvin Long: i4is President, Advisory Council of Project Starshot, author *Deep Space Propulsion, A Roadmap to Interstellar Flight* (Springer)**
- **Paul Campbell: Software Engineer**
- **Richard Osborne: Rocket Scientist**
- **Rob Swinney: i4is Education Director, Project Leader, Project Icarus**
- **Terry Regan: creator of the BIS Daedalus model and the i4is 2001 Monolith**
- **Tishtrya Mehta: Astrophysics Researcher**

Contact: info@i4is.org

- and let's talk!

Web: i4is.org
Twitter: @I4Interstellar
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tinyurl.com/principium

‘The Interstellar Space’

Opening of i4is HQ, 8 October 2017

Patrick Mahon

Our Principium Deputy Editor reports from The Mill, our first headquarters, on its opening. We have the privilege of being the first dedicated interstellar organisation to have its own headquarters and the opening event was, we hope, an unforgettable one for all who attended.

I was privileged to attend the opening of The Initiative for Interstellar Studies’ new headquarters, ‘The Interstellar Space’, on Sunday 8 October 2017. Our new headquarters occupies part of ‘The Mill’, an impressive early nineteenth century four-storey industrial building located in Charfield, Gloucestershire, a few minutes’ drive from Junction 14 of the M5 motorway and close to Bristol Parkway train station. I drove up from my house in Buckinghamshire, and after parking in Charfield village had a very pleasant ten minute walk to the Mill through pretty English countryside.

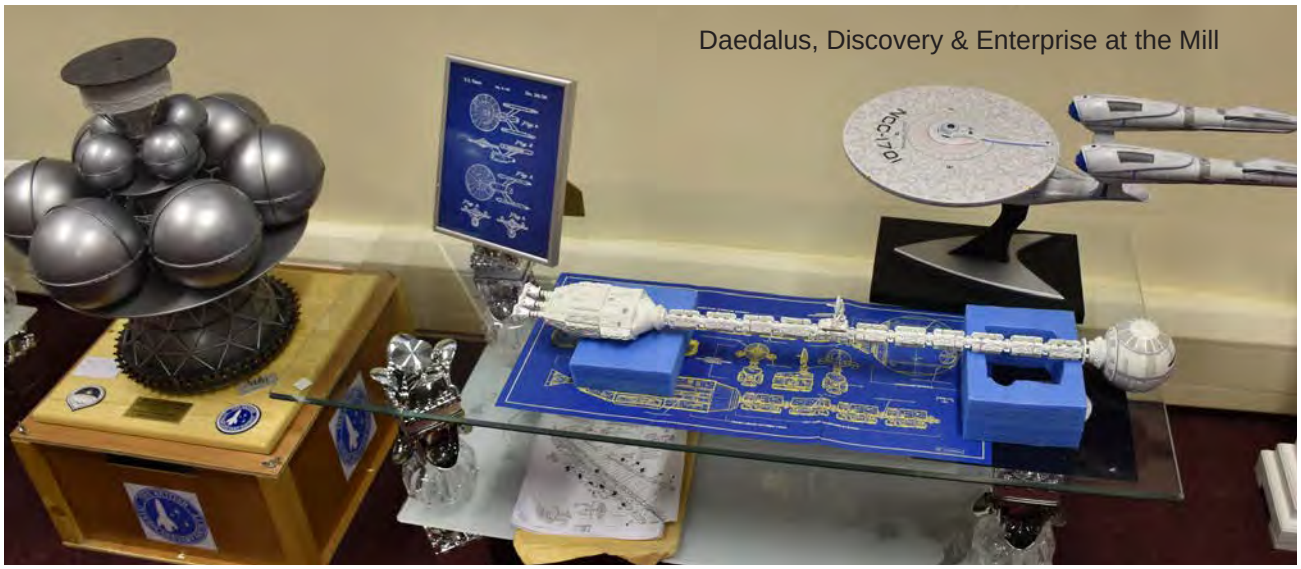
The Mill ready to receive guests. The trestles reserve a space for a disabled visitor
Credit Richard Osborne

The building is an imposing rectangular construction of red stone, set in beautiful countryside, with the Little Avon River running just behind it. Inside, the Interstellar Space is bright and modern, with a reception, a library, a conference room and a kitchen. What really captures your attention, though, is the huge number and variety of space-related items displayed throughout the building. There are too many to list here, but my personal highlights would include the original engineering drawings for the Project Daedalus spacecraft and the wonderful scale model of it made by i4is member Terry Regan, genuine meteorites, NASA mission patches, and many spaceship models from

fact and fiction, including the Space Shuttle, the International Space Station, the Discovery from '2001: A Space Odyssey', the Avalon from the recent Hollywood film 'Passengers' and, inevitably, the Starship Enterprise from 'Star Trek'. The BIS model of Daedalus, still the only detailed starship design, was on loan from BIS HQ.

I arrived a little before the formal start of proceedings, which gave me a chance to catch up with some of the other 'early

Starship Avalon - lit by a decidedly modest light source!



Daedalus, Discovery & Enterprise at the Mill

BIS Project Daedalus Fusion Starship sponsored by i4is built by Terry Regan

birds', which included several representatives of the British Interplanetary Society (BIS): their President Mark Hempsell, Executive Secretary Gill Norman, several members of the BIS council including Rod Woodcock, David Shayler and Richard Osborne, and Odyssey Editor Terry Henley.

The Guest of Honour, Colonel Alfred M Worden, the Command Module Pilot on the Apollo 15 mission to the Moon in July 1971, arrived at about 11 o'clock, accompanied by his ever-helpful UK agent, Vix Southgate, who was instrumental in setting up

Vix and Al chatting at i4is reception
Credit Richard Osborne

Al's attendance. I had not met him before, and was amazed at how friendly, approachable and down-to Earth (no pun intended!) he was, considering that this man is a member of one of the most exclusive clubs in the history of the world: the 24 humans who have travelled a quarter of a million miles to the Moon, and back. Before the formal proceedings began, Al mingled readily with the guests, chatting enthusiastically about the past, present and future of human spaceflight. I joined a conversation where Al was talking about having met Professor Stephen Hawking's children at a World Space Week event at BIS HQ a few days earlier. He was now trying to find an opportunity to catch up with Professor Hawking himself, to discuss the eminent physicist's strong support for humanity becoming a multi-planet species.

The formal proceedings started at 12:30 pm, when the newly elected i4is President Kelvin F

Gill Norman, BIS Executive Secretary, Al Worden and BIS President Mark Hempsell
Credit Richard Osborne

i4is President Kelvin Long welcomes Al Worden and guests
Credit John Twaite

Long welcomed all the guests (in total, 59 adults and 18 children came to the opening) and invited everyone to take a seat in the lecture space. Kelvin gave a brief introduction to the work of i4is and noted that the opening of the new HQ coincided with the organisation's fifth birthday. He explained how pleased he was with the new HQ building, and welcomed in particular the guests from those who share the building with us, Enigma Security and Shipton Bookkeeping & Payroll Ltd. Kelvin then acknowledged several VIP guests, including BIS President Mark Hempsell, before introducing the Guest of Honour, Al Worden, and inviting him to speak.

Al Worden thanked Kelvin for the invitation to the event, and Vix Southgate for arranging it. He noted that England felt like a second home to him, as he had attended the Empire Test Pilots' School in Farnborough in 1964. He also said that he was pleasantly surprised by the number of people he knew at the event.

Al then gave a fascinating talk on the Apollo 15 mission. I won't cover everything he said, but the points that particularly caught my attention follow.

Apollo 15 was the fourth manned mission to successfully land on the Moon, but it was the first of the Extended Duration Missions, lasting 12 days in total, with the other two astronauts, Commander David Scott and Lunar Module Pilot James Irwin spending twice as long, and travelling ten times as far, on the Moon, as previous moonwalkers, due to the uprating of the Lunar Module and the addition of the motorised Lunar Rover. Al also got to do more science than previous Command Module Pilots, whilst orbiting the Moon for the three days when Scott and Irwin were on the surface, 'picking up rocks' as he jokingly said,

Al Worden captivates the company
Credit John Twaite

due to the addition of a new scientific package, located in the Service Module. This allowed him to run investigations of the chemistry of the Moon's surface and atmosphere, as well as to take high resolution photographs of a large proportion of the Moon's surface from just 60 miles above. In passing, Al noted that he worked on these experiments for up to twenty hours a day for those three days orbiting the Moon because, as he said, 'You don't need much sleep when you're in freefall.'

One of the problems with being the first Extended Duration Mission was that NASA's engineers hadn't quite improved the propulsion system sufficiently to make up for the weight of the extra equipment they were carrying. As a result, they didn't have enough fuel to 'do things properly', as Al said, and had to 'cut some corners'. So, whereas Apollo 14 launched to a 103 mile high parking orbit before setting off for the Moon, Apollo 15 could only reach a height of 90 miles. At this lower altitude, the last vestiges of the Earth's atmosphere produce sufficient drag that they had to do a very rapid check-out of the spacecraft's systems, orbiting the Earth only one and a half times before accelerating from 17,500 mph to 25,000 mph to head for the Moon. Had they stayed longer in Earth orbit, they would have risked losing altitude due to drag, re-entering the Earth's atmosphere and burning up!

The Apollo 15 mission landed between the Hadley Rille canyon and the lunar Apennine Mountains, about 26 degrees north and 4 degrees east of the centre of the Moon's near side, enabling it to explore more diverse lunar terrain and geology than had been possible on previous missions, which had deliberately been targeted at flatter areas near the lunar equator for safety's sake. However, this made Al's job as the pilot of the orbiting Command Module more difficult, as the Moon's gravitational field was far from uniform in that area, and played havoc with his navigational tasks.

Al noted that the Apollo missions were luxurious compared to the earlier programmes, in terms of the living space per astronaut. The Mercury capsule provided its sole astronaut with a rather claustrophobic 45 cubic feet of space, while the two-man Gemini spacecraft afforded the astronauts a more generous 75 cubic feet each. The Apollo astronauts, however, had a relatively large living space of 220 cubic feet each, roughly five times more for each person than during Project Mercury.

The biggest problem that Al had with being in freefall was with getting to sleep for the first two days of the mission. Since you

Al rememebers the parchute that did not open!
Credit Richard Osborne

float around, you need to strap yourself into a sleeping bag that's tied down, so that you don't float away while you're asleep. However, as Al found out, unless you also use something to restrain your head, it lolls around as soon as you fall asleep, and the motion confuses your inner ear, waking you up again! He said that he slept very badly on their first night in space, but got used to it by the third night.

At the end of Scott and Irwin's three days on the surface of the Moon, they blasted off and rejoined Al. Some time after firing their engine to break lunar orbit and return to Earth, when they were 50,000 miles from the Moon but still 190,000 miles from home, Al donned a spacesuit, left the safety of the Command Module and performed the first ever spacewalk in deep space. He had to climb down the side of the cylindrical Service Module to recover canisters containing all the film he had shot while orbiting the Moon, as the Service Module would not be accompanying them all the way home.

The rest of the journey back went according to plan, until the final seconds, when one of the three parachutes intended to slow the Command Module's descent into the sea failed to open properly (see photo on previous page). Thankfully, the system had been designed with some redundancy, and two parachutes were still sufficient to enable a safe water landing.

On the question of manned versus robotic missions, Al recognised the huge value of unmanned scientific probes, but felt strongly that missions of exploration would always need a human presence in order to deal with the unexpected.

i4is activist Kieran Twaites meets Al Worden
Credit John Twaites

Al had some interesting things to say about the impact of spaceflight on human health, noting in particular how it affected his heart rate. His normal, resting heart rate is around 55 beats per minute. Prior to launch, this increased slightly to around 75 bpm. While he was in orbit, it reduced to around 15 bpm, since the heart does not have to work very hard while you're in freefall. However, after 12 days in that freefall environment in space, when he returned to Earth gravity his heart rate was recorded at 125 bpm by doctors on board the aircraft carrier that recovered them from the Pacific Ocean! He concluded his talk by remarking that the issues surrounding the health effects of long duration spaceflight needed tackling before we went to Mars and beyond.

Al then answered some questions from the audience. Asked what the toughest part of his training for the Apollo 15 mission had been, he responded that it was learning geology in sufficient depth. However, this paid off, as observations he made from orbit helped with the selection of the landing site for Apollo 17. In response to a question about how the trip to the Moon had changed his views of Earth, he said that people were the same the world over, and the difficulties largely arose from relationships between governments. His view was that the main purpose of the space programme should be for us to go somewhere else, outside of our own solar system. Asked his view of Elon Musk's recent announcement about SpaceX's future plans, Al wished him luck, noting that Musk had been very successful so far at achieving those things he set out to do. Al's central question about the

commercial spaceflight business was where the profit was going to come from, and he contrasted it with the early history of air travel, which was subsidised by Government-funded transport of airmail. Would an orbiting hotel pay? Where was the profit to be found in returning to the Moon? Asked about the likelihood of aliens existing elsewhere in the universe, Al said that he had known the astronomer Carl Sagan well, and agreed with his conclusion that there were likely to be many extraterrestrial civilisations spread across the universe.

Following an extended round of applause, Kelvin Long invited Al Worden to formally open The Interstellar Space. Al did this jointly with Kelvin by unveiling a plaque on the wall which marks the occasion for posterity. Al signed the plaque, and then recited from memory the whole of his post-Apollo poem 'Oceans', a line from which is quoted on the plaque.

The new Executive Director of i4is, Dr Andreas Hein, then gave a speech, thanking Al Worden for his fascinating talk, and noting some of the key achievements of the Initiative over its first five years. These include:

• the establishment of Principium as a quarterly publication;

• our ongoing collaboration with the International Space University;

• the establishment of the Alpha Centauri Prize; and

• the Andromeda Probe study, produced in just three days as an input to the Breakthrough Initiative's Project Starshot, which is looking at how to send a gram-sized probe to Proxima Centauri at one-fifth the speed of light, so that the mission can be completed in decades rather than centuries.

Andreas went on to outline i4is's plans for the next five years, which include Project Glowworm, a fingernail-sized spacecraft to launch in the next 2-3 years as part of a wider programme to demonstrate the laser sail concept as a practical reality.

A large cake, beautifully decorated with the i4is logo, was then brought out and Al Worden was invited to make the first, ceremonial, cut. A group photograph with Al was then taken, and I was lucky enough that he chose to sit down next to me while this was being done. While the photographers were getting ready, I had time to briefly ask Al how he felt about his Apollo 15 spacewalk. He remarked, with typical understatement, that this extravehicular activity, or EVA – the first one ever done in deep space – was 'easy', as he'd done it over a hundred times in training! Finally, once the main group photograph had been taken, Al signed individual photographs for the children present, to go with

Al Worden with the rising generation
Credit Richard Osborne

a goody bag that each of them received before leaving.

With the formalities at an end, the party resumed. I took the opportunity to speak to Mark Hempsell, the President of the BIS, and asked him what his impressions were. Mark said, 'This is a massively impressive building, containing a great mix of the vision of science fiction and much that will hopefully be science fact to come. I think Kelvin, Andreas and the team have done a fantastic job. I wish i4is all the best, and look forward to i4is and BIS continuing to work together in the future.'

When I left The Mill a couple of hours later to make my way home, I was left with two abiding impressions from the day. The first was a deep sense of respect and admiration for Colonel Al Worden, for the other 23 astronauts who travelled to the Moon some 45 years ago, and for the hundreds of thousands of scientists and engineers who made those missions possible. The second is a feeling of optimism for the future. We may not have returned to the Moon yet, let alone gone on to Mars, but as long as there are people like Kelvin Long, Andreas Hein, and all the other people involved in the Initiative for Interstellar Studies, working hard to build an interstellar future for humanity, then we have much to look forward to.

Kelvin at the front, left to right seated - Gill Norman (BIS), Mark Hempsell (BIS), Rod Woodcock (BIS), Al Worden, Patrick Mahon (i4is), Kieran Twaites (i4is), Angelo Genovese (i4is).
Right to left standing - Richard Osborne (BIS & i4is), John Davies (i4is), Andreas Hein (i4is), Sam Harrison (i4is), Marc Casson (i4is), Stephen Ashworth (BIS & i4is)
Credit John Twaites

About the Reporter

Patrick Mahon is Deputy Editor of Principium, and i4is Programme Manager. He 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. As well as articles like this, he writes science fiction in his spare time.

Interstellar News

John Davies and Patrick Mahon with the latest interstellar-related news

i4is Leadership Changes

The annual general meeting of the Initiative for Interstellar Studies took place at the new Headquarters of the organisation (see the Introduction Feature in this issue) on 7 October 2017. Present were corporate members Kelvin F Long, Andreas Hein, Rob Swinney, Richard Osborne, Terry Regan, John Davies and (by Skype link) Robert Kennedy III. At this meeting our founding Executive Director, Kelvin F Long, formally announced his resignation from that post and proposed that Andreas Hein take on the role of Executive Director. Given Andreas' expressed willingness to take on this role the AGM accepted both of these proposals and our new Executive Director is Andreas Hein. The AGM accepted a proposal to create a new role within the organisation, that of President, and that Kelvin F Long be appointed to this role. The AGM congratulated Kelvin and Andreas on taking on these new responsibilities.

The AGM also appointed two new board members, Sam Harrison and John Davies.

Project Lyra: Sending a Spacecraft to the Interstellar Asteroid

Close watchers of astronomical news will have noticed that a recently detected object is our first verified visitor from interstellar space, the asteroid 1I/'Oumuamua, formerly A/2017 U1 (en.wikipedia.org/wiki/1I/‘Oumuamua). A team from i4is and Asteroid Initiatives LLC have responded with a feasibility design study for a mission to reach this interstellar wanderer. Given the velocities involved, and the fact that the asteroid had already reached perihelion before it was detected on 19 October, this is a considerable challenge. Missions would be substantial and could most usefully demand our largest launchers including the NASA SLS and the SpaceX BFR. However the team, Andreas M Hein, Nikolas Perakis, Kelvin F Long, Adam Crowl, Robert G Kennedy III and Richard Osborne (all i4is) and Marshall Eubanks (Asteroid Initiatives LLC) have "done the math" (as our American colleagues put it) and find that this "stern chase" is possible with a variety of scenarios including direct launch, Jupiter flyby and even laser-push (with significantly less demands than Breakthrough Starshot). This was a very rapid piece of work but Principium readers will remember "How to Design a Starship in Three Days" in Principium 15 describing our Project Andromeda laser-push study - which was even more of a rush job! i4is has the capability to address this sort of challenge and even if we do not achieve a flyby of this interstellar asteroid the study we have done forms the basis to prepare for a subsequent interstellar flyby.

Of course Arthur C Clarke envisaged something larger in "Rendezvous with Rama" and Fred Hoyle anticipated an intelligent visitor on a similar trajectory in "The Black Cloud" but we need to be ready for less daunting objects from outside our solar system.

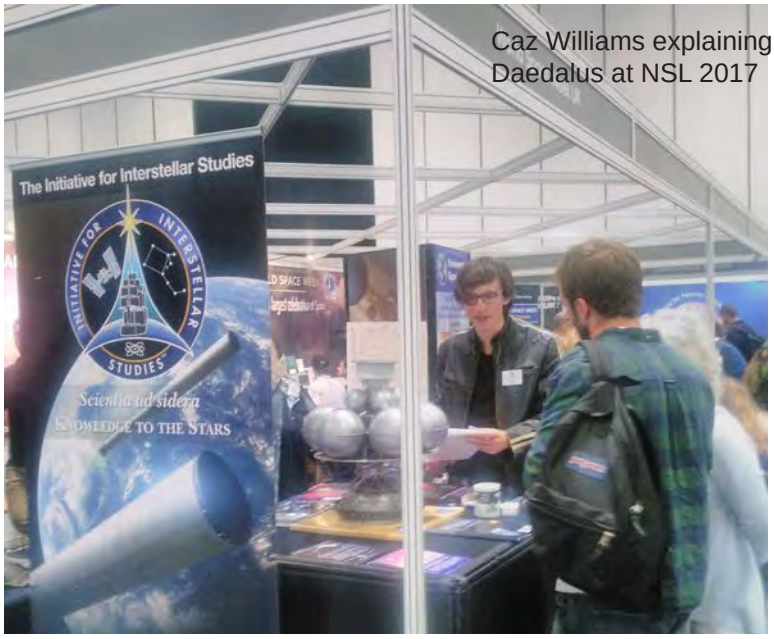
More details of this in Paul Gilster's ever-topical Centauri Dreams "Project Lyra: Sending a Spacecraft to 1I/'Oumuamua (formerly A/2017 U1), the Interstellar Asteroid" (www.centauri-dreams.org/?p=38728) and an academic paper on arXiv with the same title (arxiv.org/abs/1711.03155).

The paper has already been much noticed. It was mentioned on MIT Tech Review in Best of Physics arXiv (Nov 18 2017) and discussed by John Michael Godier on YouTube. Andreas gave a talk at the Paris Observatory on the 5th of December at the invitation of Jean Schneider.

i4is Outreach

i4is has been busy since the last issue of Principium. In addition to our AGM (reported above) and HQ opening (reported in the first item in this issue) we joined the BIS stand at New Scientist Live (NSL) in London and had our own presence at ReInventing Space (RIspace) in Glasgow.

NSL gave an opportunity to meet the scientifically-interested general public - not to mention three astronauts, Al Worden, Helen Sharman and Tim Peake - and the BIS Italia team with their Apollo and Soyuz docking simulators (the former notably enjoyed by a man who used to do this "for real". Al Worden!). The i4is team of John Davies and Terry Regan was very ably assisted by the enthusiasm of BIS member Caz Williams, who began with BIS but ended up



Caz Williams explaining Daedalus at NSL 2017

informing a lot of stand visitors about interstellar technology and especially the Daedalus model, which was on prominent display. Thanks Caz!

RIspace is a BIS event which began as a US-based industry conference and is now in Europe. Many prominent space companies and organisations were present including Clyde Space, SSTL, Airbus, Raytheon, Glavkosmos and ESA. The i4is team was Paul Campbell, John Davies and Tishtrya Mehta. Our thanks to BIS for arranging our presence.

And to all the new Principium readers we met at the two shows - Welcome!

JBIS News

The Journal of the British Interplanetary Society (JBIS) continues to feature significant work in interstellar studies. Since the last issue of Principium in August 2017 we have seen -

Vol. 70 No. 5/6 May/June 2017 Interstellar Studies

Interstellar Communications using Microbial Data Storage: Implications for SETI-Robert Zubrin

Sailships vs. Fusion Rockets: A Contrarian View-James Benford

HERITAGE: A Monte Carlo Code to Evaluate the Viability of Interstellar Travels using a Multi-Generational Crew-Frédéric Marin

Nanobots and Fairyflies-Robert Alan Mole

On the Feasibility of Human Interstellar Flights from Economic, Energetic and Other Perspectives-Jiří Mazurek

On-Board Power for Interstellar Generation Ships: Application of Cassenti's Toroidal Ion Scoop-Gregory L Matloff

A Rationale for Alien Megastructures-Gregory L Matloff

Performance Predictions for

Tishtrya at the i4is stand, RIspace 2017 Credit Tishtrya Mehta

Interstellar Missions using the Special Theory of Relativity-Brice Cassenti and Laura Cassenti

Do No Harm? Cultural Imperialism and the Ethics of Active SETI-John W Traphagan

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Propulsive Forces using High-Q Asymmetric High Energy Laser Resonators-Travis S Taylor

All the founding members of i4is are long-established members of the BIS. Why not join this, the world's longest-established space advocacy organisation (www.bis-space.com/eshop/why-join)?

i4is Interstellar Challenge for Schools

Sadly we have to report that we will not be able to have a new Interstellar Challenge in 2017. We were aiming for a central London venue but this has not been possible. We will widen our horizons for the coming year so please get in touch (John.Davies@i4is.org) if you have a venue for about 50 and connections to local secondary schools. More in *Interstellar Inspiration for School Students* elsewhere in this issue.

NEWS FEATURE - Glowworm Update

Dan Fries

The i4is Glowworm Project is our near-term project addressing the basic principles of laser sail propulsion. Dan Fries, one of the core team on the project, updates on this striking i4is effort.

1. Challenges

The project is to answer needs of Breakthrough Starshot: “A $100 million research and engineering program aiming to demonstrate proof of concept for a new technology, enabling ultra-light unmanned space flight at 20% of the speed of light; and to lay the foundations for a flyby mission to Alpha Centauri within a generation.”

The most likely way to achieve interstellar travel with reasonable transit times and scientific benefits is to use swarms of miniaturized spacecraft (gram scale) driven by a remote propulsion system such as a lasersail. Still, to achieve even 10% of the speed of light under the given constraints, enormous laser powers are required on the order of 100s of Gigawatt. The resulting power densities, diffraction of the laser beam at large distances to the emitter, and the possibility of collisions in the interstellar medium push known physics, materials and project management approaches to the limit. Moreover, attitude and orbit control, communications, and data acquisition become non-trivial due to the extremely large distances from earth and the small size of the spacecraft.

2. Current goals

» Ground demonstration of thrust

»» "Low power" laser: ~200W in the infrared

»» Characterize different dielectric materials and at least one carbon based “exotic“ material (eg carbon sponge)

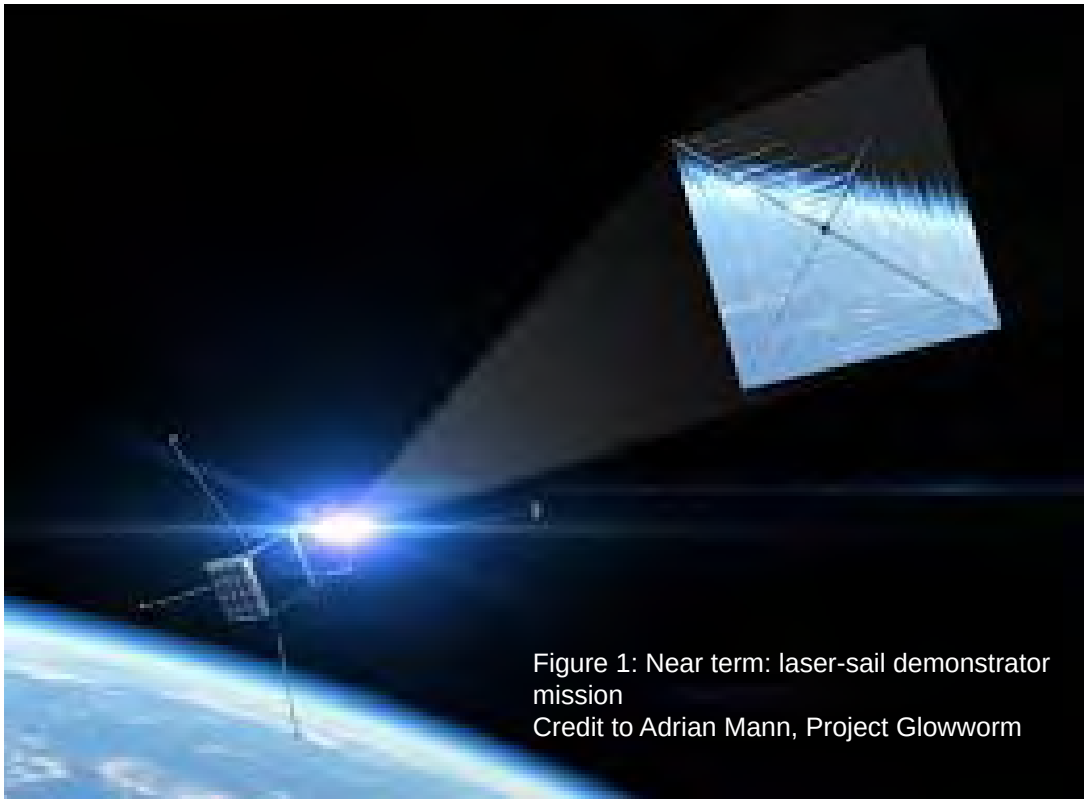


Figure 1: Near term: laser-sail demonstrator mission
Credit to Adrian Mann, Project Glowworm

» Material demonstration
  »» Power density limit
  »» Foldable, extremely thin substrates for dielectrics
  »» Directional dependence of thrust
  »» Thermal management
» Spacecraft miniaturization
  »» Gram-scale or below spacecraft that can perform rudimentary operation
  »» Mass production of such spacecraft
» Demonstrator space mission
  »» Need a measurement that confirms that attitude or orbital change have been achieved by the laser sail in the presence of perturbations (drag, sunlight, etc)

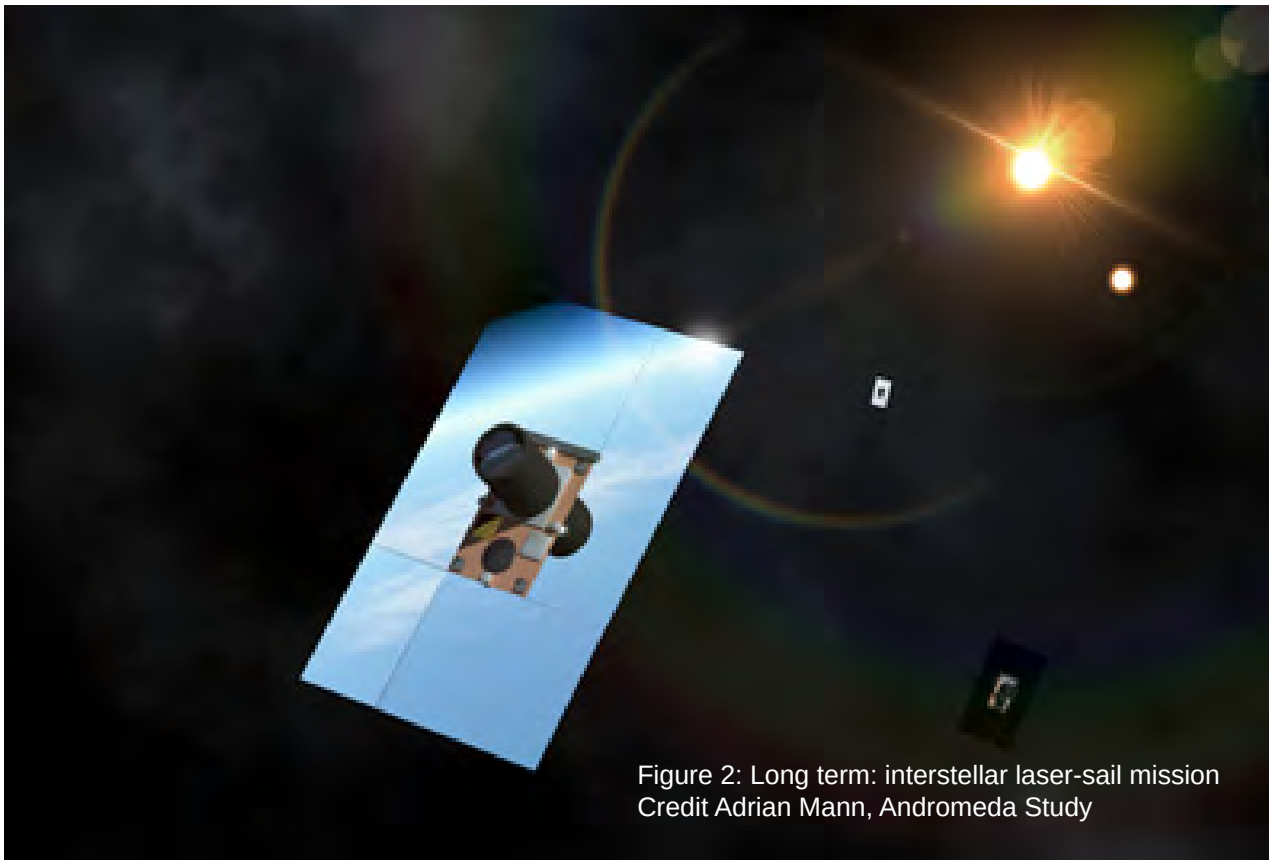


Figure 2: Long term: interstellar laser-sail mission
Credit Adrian Mann, Andromeda Study

3. Final goals

Near term: laser-sail demonstrator mission - Figure 1
Long term: interstellar laser-sail mission - Figure 2

4. Opportunities

After having obtained initial funding for conducting startup work on ChipSats, we are exploring a number of ways to fund our subsequent steps.
These include outside investments to investigate and qualify technologies -
• Looking for labs to collaborate with in experiments
• Looking for interested individuals with relevant skills to push our current goals
• Looking for smallsat launch and space qualification opportunities

About Dan Fries
Dan is currently pursuing a PhD in Aerospace Engineering, dealing with supersonic combustion and turbulence, at the Georgia Institute of Technology. He is interested in advanced forms of propulsion, space utilisation/exploration and systems engineering.

TV PROGRAMME REVIEW: The Search for a New Earth

With Professor Stephen Hawking, BBC2, first screened 11 Sep 2017, UK

Reviewed by Patrick Mahon

A BBC programme asks if we can find an exoplanet to move to - to address Hawking's concerns about our long-term survival on Earth. Our Deputy Editor takes a look.

Over the last few months there have been several programmes on television which will have been of potential interest to i4is members. One recent example is The Search for a New Earth, a ninety minute documentary exploring the challenges of interplanetary and interstellar travel.

The programme features several cameo appearances by Professor Stephen Hawking, who starts things off by explaining why he believes that humanity needs to become a multi-planet species. The rest of the programme considers what this would entail.

The majority of the programme is led by two academics: Professor Danielle George, an electrical engineer who has also studied astrophysics, and who presented the 2014 Royal Institution Christmas Lectures, and Dr Christophe Galfard, a theoretical physicist and science writer whose PhD supervisor was Stephen Hawking.

It's probably worth making clear that this is a popular science programme aimed at the general public. Established Principium readers are unlikely to learn anything fundamentally new here. However, the film does present the various issues clearly and engagingly, so it's still worth watching, even if you already know the subject matter well.

The programme is structured as a series of questions and potential answers, starting from Stephen Hawking's basic premise that humanity needs to move beyond the Earth within the next one hundred years. His rationale for this is that we need to ensure our continued survival as a species against such existential risks as an asteroid impact, a viral pandemic, a global environmental catastrophe or even nuclear war. The presenters then pose the fundamental question: is it possible to meet Hawking's challenge in just a century? If so, how?

To answer these questions, they start by looking for a habitable planet to settle on. It's interesting to note that they don't engage at all with the idea of space colonies, as proposed in Gerard K O'Neill's 1976 book *The High Frontier*, nor with settling Mars, or anywhere else in the solar system. They go immediately to a discussion of planets orbiting stars other than our own Sun – in other words, exoplanets.

After a brief discussion of the kind of exoplanet that might be habitable, they address the problem of distance. Recognising that the stars are very far away, they quickly come to the conclusion that they should focus their attention on the recently discovered exoplanet Proxima B, which orbits our nearest star, Proxima Centauri, a 'mere' 4.2 light years away.

Next comes a discussion of propulsion systems. Since chemical rockets would take tens of thousands of years to reach the target, we clearly need to use something better. The presenters then interview former NASA astronaut Franklin Chang Diaz, who has developed the VASIMR plasma thruster which could theoretically get a spacecraft to Mars in 39 days. However, when asked if his thruster could be used to get to Proxima B, Diaz sensibly says no, arguing that it may instead be the precursor to a next generation plasma rocket that is suitable.

The next interviewee is Philip Lubin from the University of California at Santa Barbara, who talks about using a laser sail to reach Proxima B in 20 years. Nick Rupert from Deepspace then talks about the SIM-card sized spacecraft that would be flown on such a mission, as in i4is's own Glowworm project. Again, the presenters ask if this solution could be scaled up to take humans to Proxima B, and this time they are told that, although it would be difficult, there are no fundamental reasons against doing so. This did raise a question in my mind, since typical mission profile for such laser sail-powered nanosats requires extremely high initial

acceleration rates, well beyond that survivable by humans.

The next topic of discussion is "the Right Stuff". What sort of people will be able to rise to this challenge? Much of the material that follows is similar to that in another recent BBC2 programme in this genre – *Astronauts: do you have what it takes?* – which was fronted by former ISS Commander Chris Hadfield. The presenters talk to ESA astronaut Thomas Pesquet, and former NASA astronaut Mike Barrett, about what qualities are needed by a modern astronaut, and Danielle George even goes camping in the freezing wilds of Norway with polar explorer Anne Daniels to see if she also has what it takes. (She doesn't, she admits!)

Biology is next. How many people do you need for a viable colony? How do you protect their bodies from radiation exposure and the wasting effects of microgravity on the way? One solution to the latter might be to spin part or all of the spacecraft to simulate gravity, as in the Avalon craft featured in the recent Hollywood movie Passengers, see issue 16 of Principium.

Interestingly, the programme suggests that protection against radiation damage might be a side effect of finding ways for the colonists to hibernate whilst on the journey, an idea usually considered purely as a way to reduce food requirements and thus the starship's launch weight. According to Professor Rob Henning of the University of Groningen, the hibernation mechanism used by bears has just this effect. This is something I wasn't previously aware of and it sounds like a very promising line of research.

The final set of questions that the programme addresses concerns what the colonists will do upon arrival at Proxima B. What will the planet's environment be like? Will there be a breathable atmosphere? Will the planet, which orbits very close to its parent star, be tidally locked to it (as the Moon is to Earth), always presenting the same face to that sun? If so, the planet's near side could be very hot while the far side is cold, with a narrow strip of potentially habitable land at the boundary between the two. Will the colonists need to live in domes, generating the oxygen they need from plants? Or, in the longer term, could the planet be terraformed, so that colonists can walk around outside without spacesuits?

The presenters conclude by suggesting that there are potential solutions to each of these technical challenges. So Stephen Hawking's objective is achievable, at least in theory. Professor Hawking has the final word, noting sagely that if we decide to colonise another planet, as he wants us to, we will need to learn from our mistakes first, so we don't just go and ruin somewhere else - an eminently sensible note on which to end.

Professor Danielle George, Professor Stephen Hawking and Dr Christophe Galfard
Credit: BBC

Conclusion

Although most of the points discussed in this programme are likely to be familiar to Principium readers, it is nonetheless an informative and enjoyable programme, and provides a good introduction to the issues for a general audience. It would be worth getting your friends to watch it if they don't yet understand what i4is is all about!

My one real concern about the programme as a whole is that there seems to be a fundamental disconnect between Stephen Hawking's objective – to establish humanity beyond the Earth within 100 years – and the exclusive focus on a solution that involves travelling to our nearest star. As yet, mankind has not managed to send a single human further than the Moon, a mere quarter of a million miles away. Mars is well over one hundred times that far away, and any manned mission to the Red Planet will face significant technical challenges. However, Proxima Centauri is around 700,000 times as far away from us as Mars. Although Breakthrough Starshot has ambitious plans to send chipsats to Proxima B within the next century I'm not sure anyone really believes that scaling up from chipsats to a cargo of human colonists can be done on the same timescale. I welcome the programme's focus on the challenges of interstellar travel but 100 years seems likely to demand options such as settling on the Moon, Mars or the asteroids, or even building Gerard K O'Neill's colonies.

Interstellar Inspiration for School Students: The i4is Interstellar Challenge

John Davies and Aasiya Hassan provide a How To to get you started on your own Interstellar Challenge.

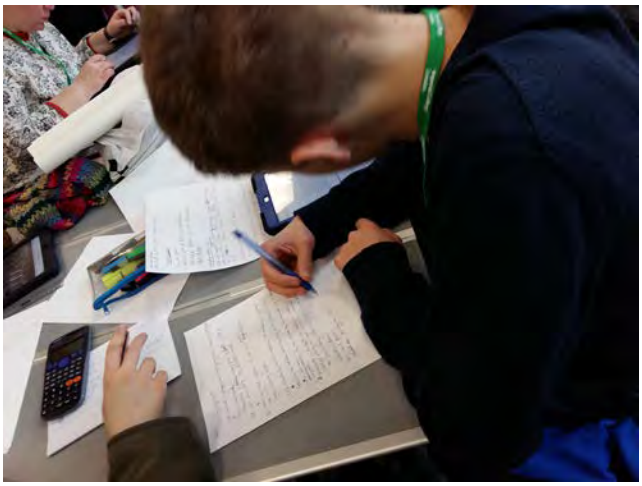
The Initiative for Interstellar Studies (i4is) education team and STEM Learning Ltd delivered the first Interstellar Challenge for London Schools in December 2016 at Imperial College London. In 2018 we aim to widen this to all parts of the UK by working with school educators and STEM Ambassadors to inspire students and raise their aspirations in STEM and other careers by giving an interstellar perspective to a wide range of subjects. We also invite still wider participation - France, Germany and the USA all have active i4is people and we can work with interstellar-minded experts in other countries to deliver the Challenge worldwide.

To organise a challenge day you will need -

- A one-day venue reachable by all schools in your region - in UK your local STEM Ambassador Hub can help you with this
- Experts - initially STEM Ambassadors from the i4is education team can support your Challenge but we aim to bring in a widening circle of teachers, STEM Ambassadors (and equivalent professional STEM volunteers in other countries) and other experts
- Presentation - i4is will provide the briefing material for the Challenge and can provide presenters if you do not have experts available locally (this may require expenses to be paid if i4is presenters have to travel)
- The Challenge Questions – i4is can provide questions for your Challenge
- Organisational guidelines - Work with your local STEM Ambassador Hub in UK or equivalent in other countries to advocate the Challenge Day to local schools. The i4is education team will support you to organise and run your Challenge

How to contact us -

Email info@i4is.org or get in touch with John Davies, Schools Engagement, The Initiative for Interstellar Studies, email: John.Davies@i4is.org phone:020 7226 7190 / +44 20 7226 7190



hard work at the 2016 challenge. Credit Aasiya

The 2016 Challenge

In December 2016 eight London schools came to Imperial College London to participate in the first Interstellar Challenge for Schools. Teams of six year 12 (age 16-17) students invited by STEM Learning Ltd competed to solve problems set by i4is in STEM and beyond to send unmanned probes and people to the nearest stars. This Challenge brings solutions in maths, engineering, physics, biology, sociology and economics to the serious endeavour to take our species to the real Final Frontier. The Challenge is based on course material delivered by i4is at the International Space University (ISU), Strasbourg, in May 2016 as part of the Interstellar Elective for students on the Masters course at the ISU. We have adapted and re-imagined the material for the early year 12 curriculum in UK and equivalent for other countries.

The Initiative for Interstellar Studies

The Initiative for Interstellar Studies team includes world authorities on interstellar science and engineering, has pioneered studies in propulsion and other technologies and is involved in Breakthrough Starshot, a $100 million project to send nano-probes to the nearest stars. i4is President and co-founder Kelvin F Long is a member of the Advisory Committee for Breakthrough Starshot (breakthroughinitiatives.org/Leaders/3). Other Starshot participants include Stephen Hawking FRS, Mark Zuckerberg, Freeman Dyson FRS and Martin Rees FRS, the UK Astronomer Royal.

The winning team Featherstone High with i4is Education Director Rob Swinney
Credit Aasiya

Example Challenge Scenarios

Here are just three possible ways in which humanity might travel to the stars -

Worldship - How can a whole community of humans reach the stars? Imagine a worldship with 10,000 people on board averaging 1% of light speed.

Colony Ship - How can humanity populate a new world with a much smaller "colony" ship? Imagine such a ship with 100 people on board averaging 10% of light speed.

Robot Probe - How can we send a robot probe to another star? Imagine it averages 20% of light speed.

Example Challenge Problems

The Interstellar Challenge presents problems in subjects from maths to creative writing. The emphasis is on STEM subjects but students can display wider talents. Here are just a few possible problems -

Maths: What stars could be reached at the speeds given in the Scenarios and how long would it take?

Physics: What "stuff between the stars" would the ship run into and how much damage might it do? Pick some good places to go given the speed/distance calculation.

Engineering: What sort of propulsion could achieve the required average speed? What are the advantages and disadvantages of each? Assuming humans require normal gravity (1G) how big should your human-carrying ships be and how fast should they rotate? If the ship stopped rotating and you were floating free, would you prefer to be in the swimming pool or the gym?

Biology: How much space would be needed for the people? What genetic diversity would be needed for a healthy population at the destination? How could this be improved by sending sperm and eggs?

Sociology: What ages of people should travel? What would be the issues at the destination if sperm and eggs were carried?

Economics: How much would the ship cost either at current launch costs into low earth orbit or if most of the ship could be built from asteroid material? How might such a sum be found?

Art: What might the ship(s) look like? Imagine the assembled crew in their departure photo.

Creative writing: Given all of the above, write two short stories for one or more of the ships you have chosen. One imagining a failure and one complete success.

The briefing material developed by i4is delivers the starting point to develop solutions to these problems and others. This can be adapted to levels from beginning secondary/high school to pre-university levels.

About John Davies and Aasiya Hassan

John Davies and Aasiya Hassan organised the 2016 Interstellar Challenge. John edits Principium and is schools co-ordinator for i4is Education. Aasiya was with STEM Learning and is now at the Royal Institution (RI), London, venue of the famous BBC Christmas Lectures and of the work of Michael Faraday, engineer and physicist. At the RI Aasiya co-ordinates the Engineering Masterclass network.

Transplutonium is not "Planet X"

Reminiscing and reality-based ruminations on the high cost of nucleosynthesis of propellants for interstellar travel.

Robert G Kennedy III, PE

Our i4is-US President remembers an early encounter with Glenn Seaborg, who used an accelerator to synthesise Plutonium. And how synthesis of elements remains relevant to our interstellar quest.

Background.

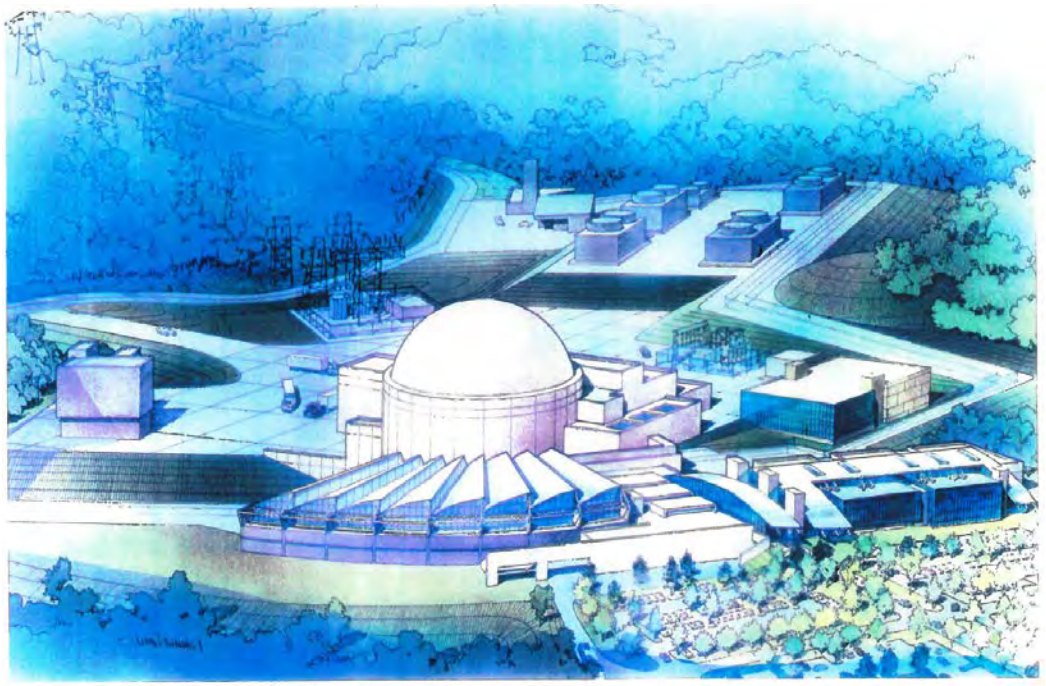
At i4is's Workshop hosted by City University in New York this June, I presented an assessment of the fusion fuel resources of the solar system. While stipulating the feasibility of propulsion with deuterium for interplanetary travel, I pointed out that humankind will need vast quantities of highly energetic fusion fuel, with Isp on the order of a million seconds, if a self-propelled ship is going to get to another star in less than many millennia. This job is far beyond even fission; only fusion (or even more energetic antimatter) will do. However, the ten lightest fusion chain reactions that the human race knows about (some of which have sub-chains, and five of which involve hydrogen) have major, engineering, energetics or logistics liabilities. In 1985's *Interstellar Migration and the Human Experience* ed by Finney (PBUH) & Jones, William K Hartman presented "Resource Base of the Solar System". To honor them, I repeated their approach 32 years later at CUNY. In a completely unrelated event, 24 years ago (21 October 1993) to this day I submitted my final conceptual design for a trans-plutonium

Author (left) and Glenn T Seaborg (right), in 1994, with transplutonium production rod. Credit: author.

Dr Glenn T Seaborg discovered plutonium in 1940, by making some of it in his lab with an accelerator, for which he got the Nobel Prize in Chemistry. He was head of the Atomic Energy Commission under John F Kennedy, and co-discoverer of ten elements: plutonium, americium, curium, berkelium, californium, einsteinium, fermium, mendelevium, nobelium and element 106, which was named seaborgium in his honor. Note the necktie, which he signed "Sg", has not been laundered since.

Funny airport security story about hiding the transplutonium production rod in the picture inside a rolled-up umbrella in 1994. When the sharp-eyed lady screener at the X-ray asked "hey, what is that?" I replied, "It's part of a machine", and was waved thru. Of course, this was long before 9/11. Things would have turned out differently today.

production facility here in Oak Ridge, Tennessee. This is the slender metal rod that was passed around the room at CUNY, as described on page 21 in *Principium* #18. It seems appropriate to likewise observe that anniversary with the time-stamp on this article. My purpose is to illustrate the magnitude of the challenge involved in synthesizing artificial elements via transmutation for nuclear propellants for interstellar travel.
Oak Ridge, Tennessee, 21 October 2017



The Advanced Neutron Source, a $3-billion, 330-MWt, heavy-water-moderated, highly-enriched-uranium (HEU)-fueled, pressurized research reactor that was to have been built in Oak Ridge, Tennessee in the 1990s. ORNL.

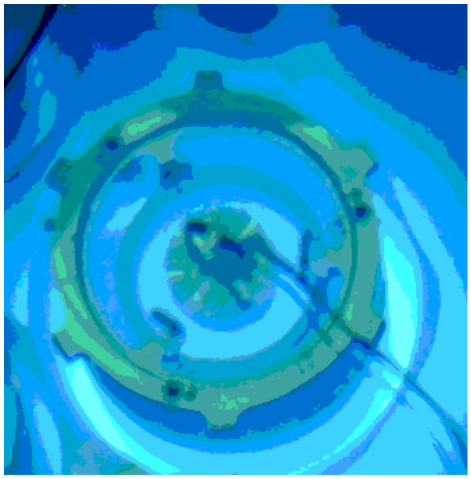
The Advanced Neutron Source (ANS) was optimized for three major scientific and industrial purposes:

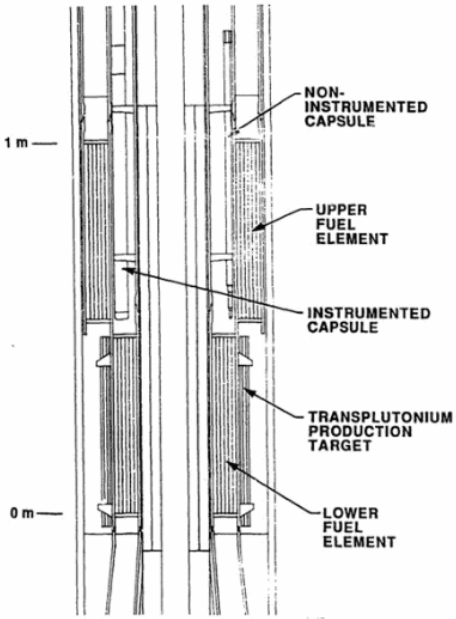
- neutron beam radiography [1]
- production via transmutation of superheavy isotopes beyond plutonium that do not exist in nature
- materials irradiation experiments.

The design flux of the 330-thermal-megawatt (MWt) ANS was on the order of 10-to-the-20th neutrons per m² per second, which was (and still is) an order of magnitude more intense than that available at the highest-flux steady-state[2 reactors in the world— the 58-MWt one at Institut Laue-Langevin (ILL) in Grenoble, France, and the 85-MWt High Flux Isotope Reactor (HFIR) also in Oak Ridge, Tennessee.

The transplutonium production "facility" was to be a bird cage of 30 slender aluminum rods about a meter long, collectively stuffed with a kilogram of plutonium-240, plus small amounts of other actinides like americium and curium, wrapped around the heart of the ANS's annular nuclear fuel assembly.

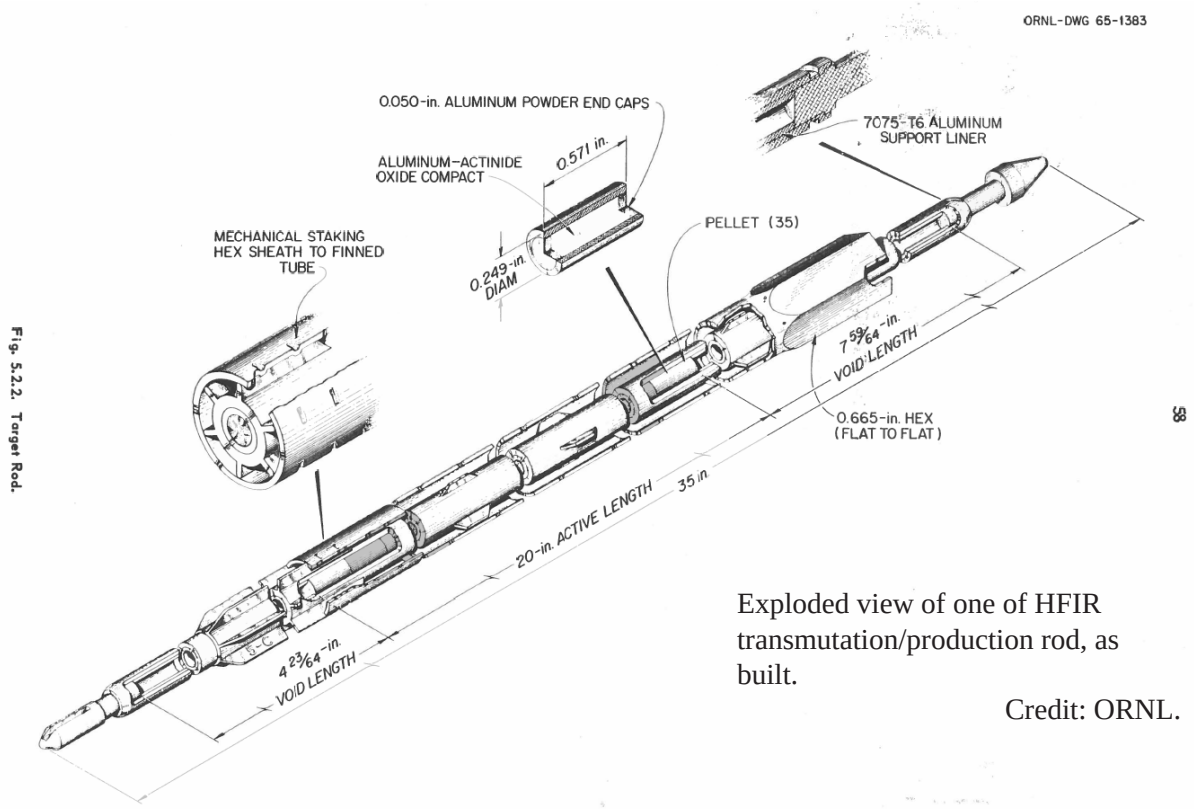
Consider that in an hour, the ANS would have generated about a ***mole*** (10^{23}) of neutrons. Yet in one year's operation, ANS was expected to produce a mere gram or so of californium-252. Luckily, this would have been enough to sustainably fund the enterprise, because the US Department of Energy charged ***$50 million per gram*** of Cf-252 (1990s prices). The stuff, which has many important industrial and security uses around the world, was so intensely radioactive that it required its own dedicated flatbed trailer with a





(left) One of HFIR's fuel assemblies cooling off in a pool after a production campaign. Credit: ORNL.

(right) section elevation of ANS's core showing position of transplutonium production targets. Credit: ORNL.



Exploded view of one of HFIR transmutation/production rod, as built.

Credit: ORNL.

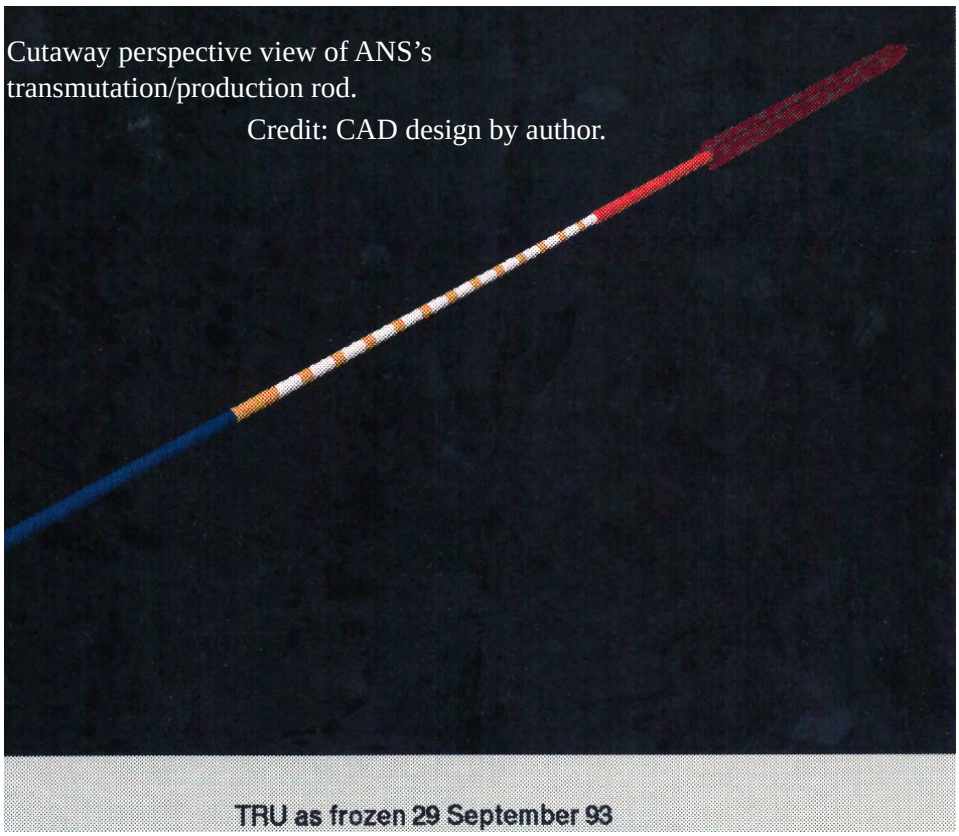
25-metric-tonne shipping cask just to deliver that one gram to a customer. ANS would have also produced microgram-quantities of einsteinium-254 and picograms of fermium-257, with rather more exotic applications. I do not know what DOE charged for these two, but the invoice surely would have been expressed in scientific notation. Avogadro's Number is a very large one by anybody's reckoning, but the effort necessary to synthesize fuels for interstellar travel via fusion propulsion based on physics we know about would be a billion-fold greater yet.

The idea behind artificial nucleosynthesis is to submerge selected actinides in an intense bath of neutrons, for transmutation via neutron capture and particle emission along a dozen steps up the periodic table. The vast majority of the time (99.7%), the progenitors simply split into useless (and dangerous) daughter nuclei. Based on actual production numbers from Savannah River, only a tiny fraction (0.3%) of precursors survives the nuclear cooking at the heart of the reactor to become Cf-252. Es-254 and Fm-257 require another half-dozen transitions with yet more "shrinkage".

The major reasons that the unit cost of superheavy synthesis is so high are that:

- the bulk methods are so inefficient (see the Sankey diagram below), and
- the market is so small, grams per year (which can be thought of like NASA's flight rate problem).

One of the engineering challenges that comes with such inefficiency is disposing of the waste heat

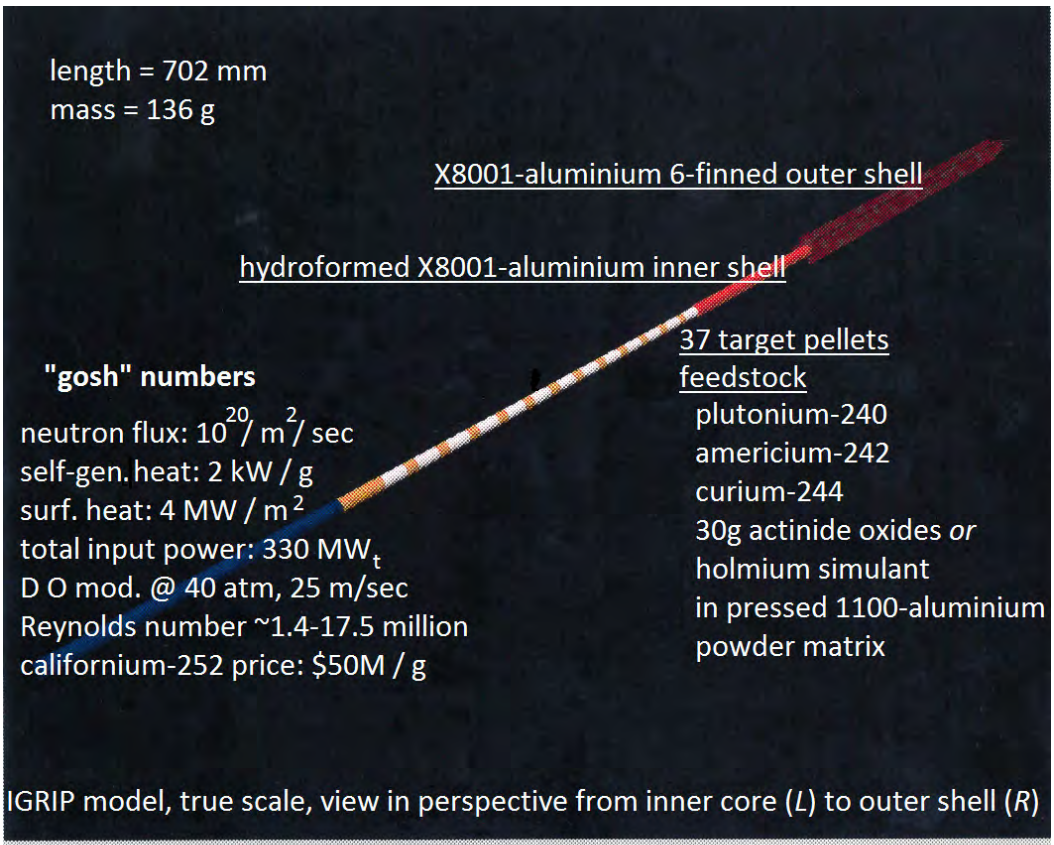


Cutaway perspective view of ANS's transmutation/production rod.

Credit: CAD design by author.

arising from all the unwanted fissions. My rods were designed to dissipate a specific heat of 2 kilowatts ***per gram***. The necessary surface heat removal rate was 4 MW per m², equivalent to 4 ***thousand*** suns at the Equator. The whole bundle liberated enough waste heat to raise the temperature of a metric tonne of highly pressurized (40 atmospheres, or 4 MPa) heavy water rushing past (25 meters per second) by 40°C in just ***40 milliseconds***.

Transplutonium production rod, design as frozen 29 Sep 93, with "gosh" numbers.
Credit: CAD design by author.



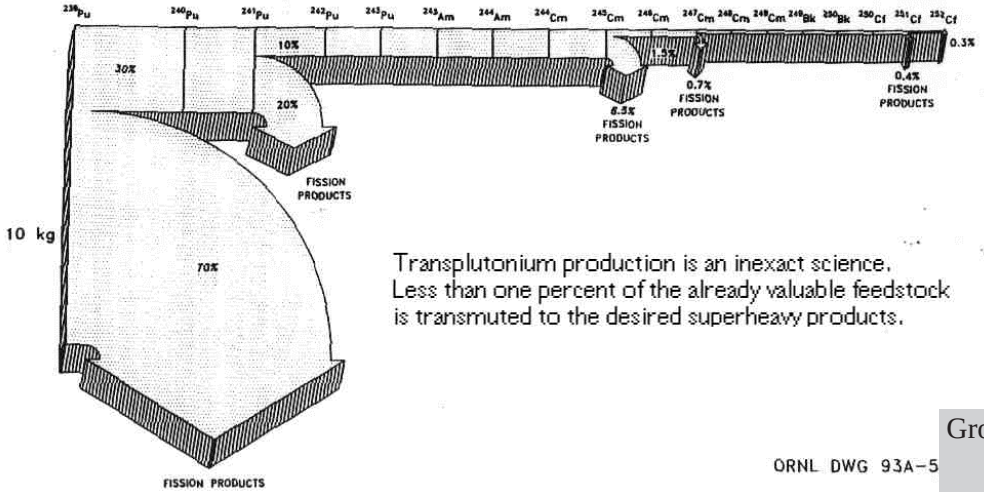
The extreme flow was necessary to prevent the rods changing phase from a solid to a gas in something about a second. Unbeknownst to the early designers before the author got involved, this put the longitudinal flow well within "transcritical" (Reynolds number ~107), a regime in which there is little experience, thus earning the slender rods an unpromising (but fortunately internal) sobriquet "violin strings".

Fission fuels are at the heavy end of the mass spectrum. The opposite end, wherein lightweight fusion fuels lie, is fraught with comparable problems, which may be likewise summarized:

- the inefficiency of most fusion reactions for propulsion, ie the fast neutron problem, and
- like heavy fission fuels, the present economic and engineering inefficiency of synthesis, and
- the miniscule availability in nature of most (but not all!) of the easiest fusion fuel candidates.

The useless neutron challenge. Getting a self-propelled object to another star in under a millennium calls for Isp on the order of a million seconds. This is far beyond even fission; only fusion (and even more energetic antimatter) will do. Fusion is all about binding energy – small but weakly-bound nuclei such as deuterons combine into more tightly-bound nuclei, like alpha particles (He-4), which is very tightly bound indeed.

The difference shows up as energy, usually in the form of very fast-moving reaction products. The most troublesome of these is the charge-less fast neutron. While a complete discourse on a-neutronic fusion reactions is beyond the scope of this article, recall that Isp



Gross inefficiency of transmutation.
Credit: ORNL.

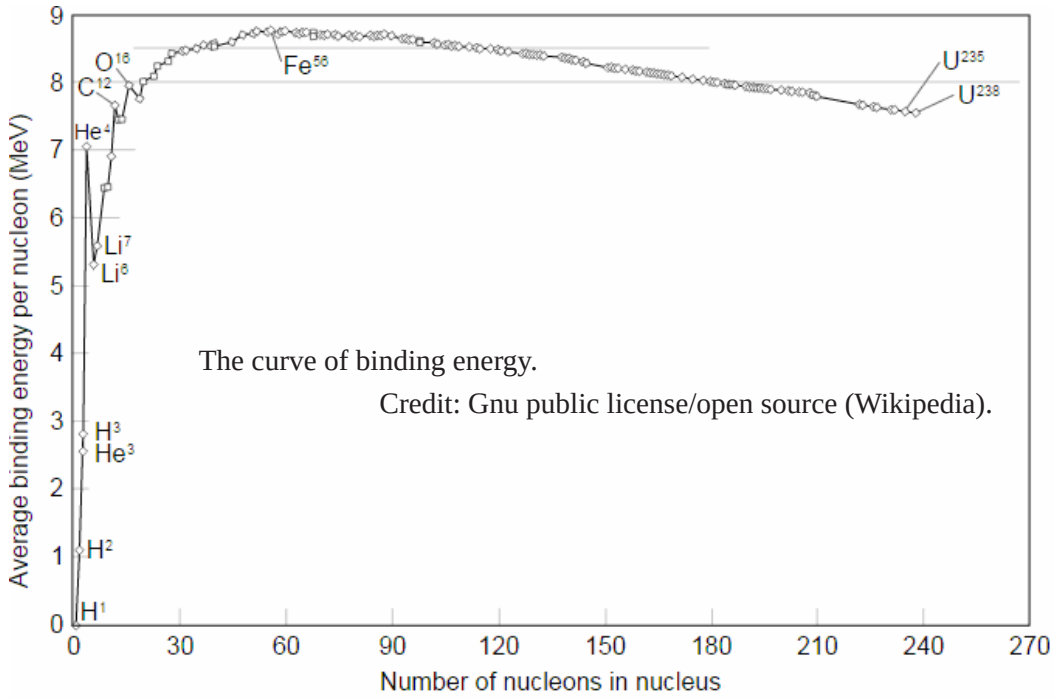
is in the exponent of the Rocket Equation.

$$\left(\frac{m_o}{m_f}\right) = e^{\left(\frac{\Delta v}{I_{sp} g_0}\right)}$$

In every mission that slows down at the target instead of just flying fast by it, fuel for deceleration becomes the predominant component of the "payload", which is a second stage sufficient for rendezvous. The trouble with most light fusion reactions is that neutrons are produced in similar numbers and proportion to other desirable reaction products like protons and alpha particles. This is especially bad when there is a large disparity in mass between the products. Since momentum is conserved, having a light product (eg a neutron) and a heavy product (eg an alpha particle) with equal momenta means that the neutron goes away with X times as much velocity, hence that particle escapes with X/(X+1) of all the energy. Since neutrons lacking in charge, they cannot be pointed, directed, manipulated or controlled, and radiate outward isotropically. A beryllium reflector that captured some of this momentum by subtending a portion of the emission sphere would harvest but a small fraction of this flux. Since neutrons are much faster than the useful products, a majority of the precious energy of the deceleration fuel dearly-bought and dragged across light-years, is thrown away, carried off by a useless neutron!

Can't make it. As an example of the second challenge, there are only about 30 kg of helium-3 in human hands over the entire world. Project Daedalus called for a million times as much of it: 30,000 tonnes. Where will it come from? (See next challenge below.) Although He-3 is a stable nuclide, which is both primordial and also continually produced in the sun therefore present in the solar wind, its abundance is 1/10,000 that of He-4. Being "noble", it is immune to natural chemical processes that concentrate other elements for our use and convenience. Being a very light gas, it almost immediately escapes the Earth when released. Therefore, its terrestrial abundance and its practical availability is still extremely low.

But at least He-3 is stable. Tritium (aka hydrogen-3), another oft-cited fuel for interstellar travel (eg Icarus), decays into helium-3 in just 12.3 years, which is why it does not naturally occur on the surface of the Earth, and why tritium is utterly unsuitable for an interstellar fuel. Tritium is an essential component of thermonuclear weapons, so, based on known experience with it during the Cold War, we can roughly imagine the cost of synthesizing lightweight fusion fuels for interstellar travel. Due to the fact that the tritium at the heart of the tens of thousands of H-bombs had to be continually replaced, the USA had to synthesize it (via spallation also) in a giant complex of production reactors at Savannah River (now decommissioned and demolished). Over the entire 33-year history (1955-1988) of that program (which cost $2B a year to run) the USA made 225 kg of tritium. At the same time, Savannah River and the World War II-era production complex at Hanford churned out about 100 tonnes of plutonium for nuclear weapons. (Total plutonium in existence worldwide is 500-1000 tonnes, mostly embedded in spent fuel rods from nuclear power plants.) While it would be unfair to burden tritium with the entire cost of the production complex, the absolute necessity to have tritium drove its design. From this known experience, we



The curve of binding energy.

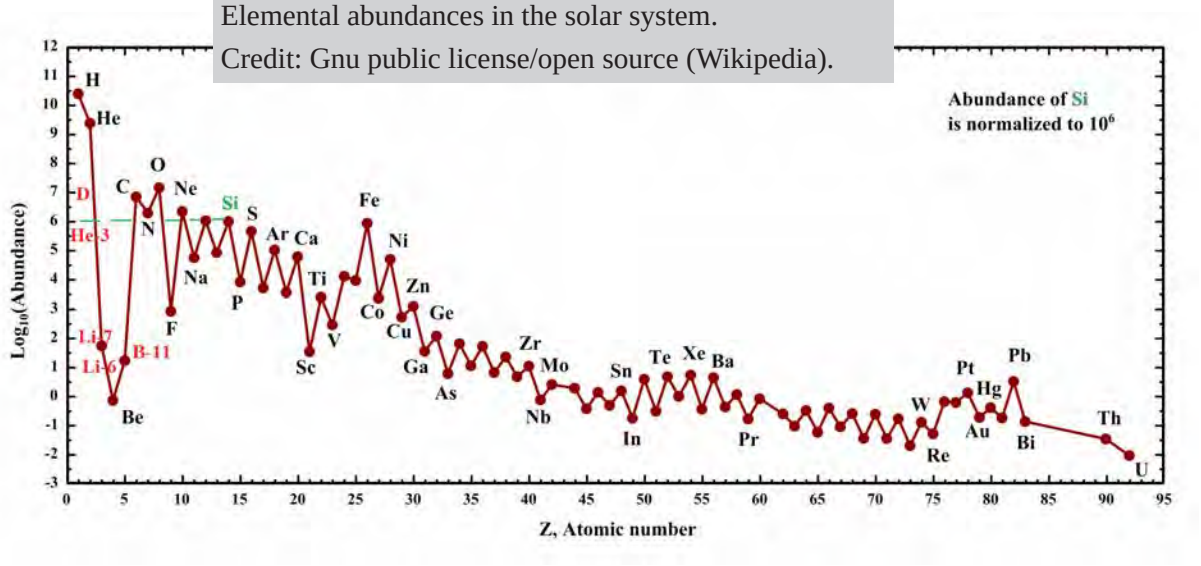
Credit: Gnu public license/open source (Wikipedia).

can set an upper bound of $300 million per kg (or $300,000 per gram, in 1990s dollars) on the fully burdened delivered cost. While this is much better than $50 billion per kg for californium, the comparison is not exact because:

• the cumulative production of californium is about four orders of magnitude less than tritium, and one would expect substantial benefits from economies of scale, and the learning curve; and

• nobody ever proposed using Cf-252 as a propellant. Plutonium is far more abundant, easily produced, and cheaper, about $1M per kg.

Elemental abundances in the solar system.
Credit: Gnu public license/open source (Wikipedia).



Can't dig it challenge. A naïve retort to the third challenge might be: if light fusion fuels are so hard to make, why not just mine them? That won't work because (other than deuterium which is just fine for interplanetary travel hence not the problem here) Mother Nature didn't give us any.

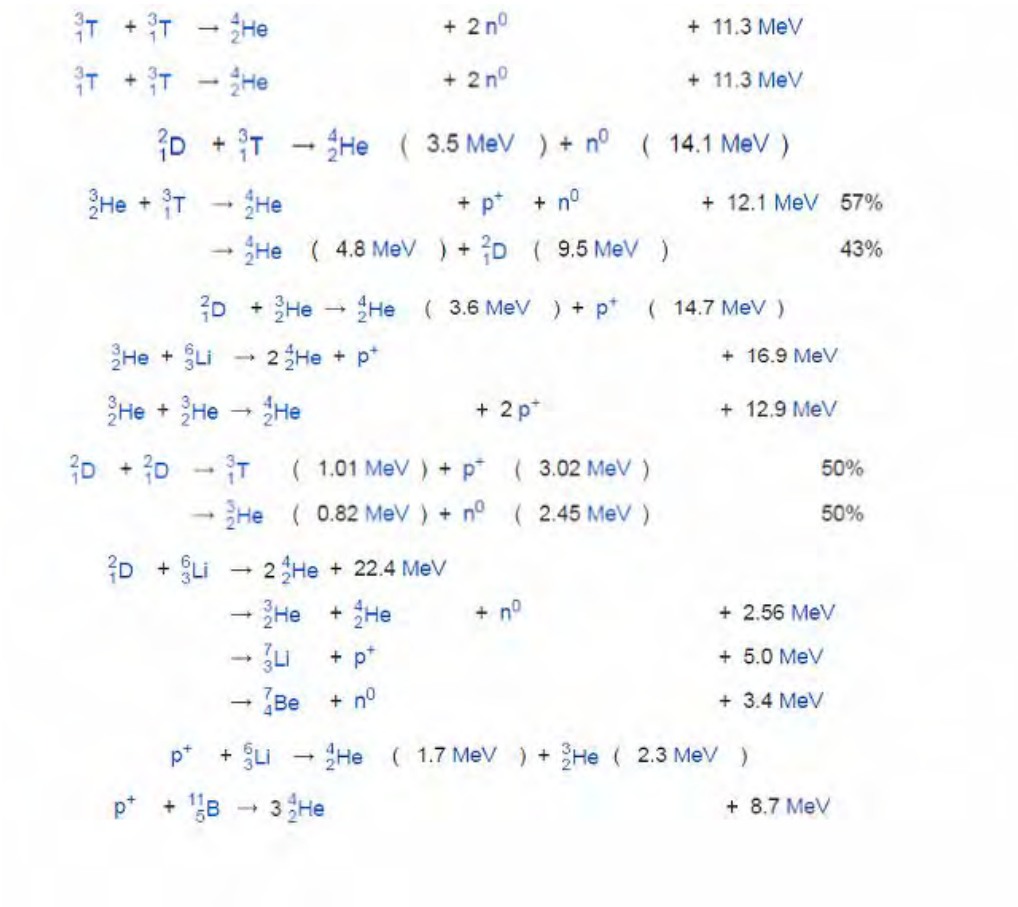
Lithium is an important, valuable metal used in electric vehicles and the renewable energy sector. Lithium was used as a "dry" fuel in thermonuclear weapons almost as soon as radiative implosion was discovered. Lithium-7 is the most common isotope at 92.5% occurrence. Unlike boron-11, the fusible isotope (Li-6) constitutes less than 8% of all lithium, which practically puts this fuel into the same category of cosmic abundance as boron-11. In addition to hydrogen and helium, lithium is the only other primordial element made in the Big Bang (primordial nucleosynthesis). 13.7 billion years ago (GYa), the BB stopped after 20 minutes, at lithium, A=7. Like boron and beryllium, lithium's abundance in the Earth's crust due to its light weight belies its extreme rarity in the cosmos—all three are about as rare as noble metals. Like boron, lithium is not made in stellar nucleosynthesis, nor in supernovae (neither S-process nor R-process). Stars tend to consume whatever lithium, beryllium, and boron they are born with, so you won't see it in the wind from stars or planetary nebula. Some lithium is produced by spallation of carbon and oxygen atoms struck by galactic cosmic rays (GCR, which are bare energetic nuclei stripped of all their electrons) in deep space, but the macroscopic flux of lithium into the solar system is miniscule. There is no boron in the solar wind, neither ours nor anybody else's. Since boron was made neither in the Big Bang nor stellar processes, the reader can see why the cosmic abundance of boron is even lower than lithium. Once it's gone, it's gone.

A few promising exceptions to the challenges discussed above, hence (and hopefully) a limited answer to the problem, will be presented in a future issue of this magazine, once a certain paper has passed peer review.

Endnotes

[1] ***neutron beam radiography*** like X-rays, but with neutral neutrons that bounce off the nuclei at the heart of atoms, not just the electron shells like every other form of radiography

[2] The Russians do have a pulsed reactor made of enriched uranium surrounded by two giant counter-rotating beryllium forks. Beryllium is the best neutron reflector we know of. Most of the time, their reactor lollygags along at a mere 2 thermal megawatts, but when the beryllium forks line up, about twice per second, the nuclear reaction briefly runs away for a few milliseconds to multiple gigawatts. Most people would not purposely "tickle the dragon" in this way, but everyone knows that Russians are crazy. I'd heard tell decades ago that they planned an upgrade to increase the pulse rate to 5 hertz.



Light Fusion Reactions.

About the Author

Robert Kennedy is a consulting senior systems engineer at Tetra Tech who does green energy all over the world for interesting people: eg USAID- and DfID-funded geothermal development in Ethiopia, Tanzania, and Uganda; US DOE-funded gigawatt-scale solar for the Navajo. He was educated in the classics and foreign languages since boyhood (Latin, Greek, Arabic, and Russian). He studied mechanical engineering at California Polytechnic (Pomona, B.S. 1986), with emphases in robotics, machine design, optical physics. Fresh out of school, he designed industrial robotics systems at the Douglas Aircraft Company (1987-1991) in Los Angeles, conducted research in artificial intelligence at Oak Ridge National Laboratory (1987), while earning a special master of arts in national security studies (1988). Robert founded the Ultimax Group, Inc. (1992-present, www. ultimax.com), a Russian-American trading and publishing company in Oak Ridge, Tennessee. He is a published commercial artist and author (nonfiction), and has written about space-based solar power, shell worlds, world ships, SETI, climate change, geoengineering, linguistics, and various security topics. In 2011 - 2016, he co-organized and sponsored the Tennessee Valley Interstellar Workshops in Tennessee and Alabama and went on to be a co-founder of the subsequent non-profit TVIW. He has lectured on geoengineering in Moscow for the Russian Academy of Sciences Rosgidromet (their national weather service), and also at the International Academy of Astronautics in Aosta, Italy. His work has also appeared in the Journal of the British Interplanetary Society, Acta Astronautica, the Whole Earth Review and a cover story on Soviet Star Wars in the Smithsonian Air & Space magazine. He has patents and trademarks pending for a number of optoelectronic, robotic, security, and space system inventions as well as the concept of Tetrageneration(TM). As the American Society of Mechanical Engineer's 1994 Congressional Fellow, he spent his year working for the Subcommittee on Space in the U.S. House of Representatives; before and after, he also designed military and nuclear robotics and devices for superheavy nucleosynthesis at ORNL (1993-96). He presented at i4is's Foundations of Interstellar Studies Workshop at CUNY this past June, participated in the First Interstellar Robotics Conference at NYU, and was a technical consultant on "Deep Impact" (ParamountDreamworks major motion picture released May 8, 1998). Most recently, he has been appointed president of the "American branch" of i4is.

Engineering New Worlds: Creating the Future - Parts 4 and 5

Dmitry Novoseltsev

Dmitry Novoseltsev (Дмитрий Новосельцев) is Deputy CEO of the Siberian Mechanical Engineering, Non-Profit Partnership (www.npsibmach.ru). His article, which is appearing over three issues of Principium, considers a number of different approaches to increasing the likelihood of intelligent life developing anywhere else in the Universe. The first three parts appeared in the last two issues. In Part 1, *The current state of play: an "uncomfortable" Universe* he pointed out that the structure of the Universe does not make it a particularly encouraging place to generate intelligent life. In Part 2, *"Catalysis": the spread of life*, he outlined a two-step project intended to increase the probability of intelligent life forming in the proto-planetary systems around stable stars in our galactic neighbourhood. And in Part 3, discussed the Shkadov thruster, "star machines" and the architecture of galaxies.

In this issue, Part 4, *Cosmological Natural Selection*, discusses an engineering approach to the creation of a world starting from the ideas of theoretical physicist Lee Smolin. Finally, in Part 5, he suggests *A history of the desired future* – to create worlds, followed by a short briefing on Shkadov thrusters, which complements these final two parts of his work.

All visualisations are by Dr Anna V Sedanova (Анна В Седанова)

4 - "Cosmological Natural Selection": an engineering approach to the "creation of the world"

Finally, we should consider the following, the most ambitious and, in this case - absolutely altruistic version of "engineering of the worlds."

The original concept by Lee Smolin (Perimeter Institute for Theoretical Physics) is known as the «fecund universes» theory, also called the theory of "Cosmological Natural Selection» (CNS). According to this hypothesis, "the other side" of a black hole is a new universe in which fundamental physical constants may differ from the values for the universe containing the black hole. Reasoning observers can appear in those universes, where the values of the fundamental constants favour the emergence of life. The process resembles the mutations in biological natural selection. A detailed description of the Smolin hypothesis was published in his book, *The Life of the Cosmos*, 1997 ([1], [2]). According to Smolin, his model is better than the anthropic principle in explaining the "fine-tuning of the universe", necessary for the emergence

of life, as it has two important advantages:

- In contrast to the anthropic principle, Smolin's model has physical consequences, which are amenable to experimental verification.

- Life in the multiverse there is not random, but natural: more "offspring" in the selection of those universes are parameters which give rise to a greater number of black holes, and the same parameters on his assumption favour the possibility of the origin of life.

However, the latter assumption is not quite reliable. From this position, the optimal situation for these "fecund universes" would be an “r–strategy” of reproduction [Editor’s Note: see Part 2 in Principium 17] – which, in this case, means the occurrence of the maximum number of black holes in the minimum time. This would correspond to the early formation of a large number of first-generation stars, absorbing almost all the hydrogen and rapidly evolving within a few tens of millions of years to the stage of gravitational collapse. In such a universe there would be an extremely small amount of "non-stellar" substance, which would be a negligible amount of metal and extremely high levels of radiation. The formation of complex molecular structures, not to mention any biological objects, would be unlikely, and its evolution would be completed very rapidly.

Thus, Lee Smolin’s "fecund universes" concept requires adjustment, in this author’s opinion.

As noted earlier in Part 3 of this Article, the author previously proposed a modified, or an electric Shkadov thruster (EST) [3], which is a set of unmanned spacecraft with electric solar (photon-ion) sails (perhaps replicating the principle of von Neumann machines created from material mined from asteroids) which together form an ellipsoidal reflector with a star at one focus, in a polar orbit round that star. The scheme of creating such an object is susceptible to various reflector configurations, including fragmentary ones, and to a certain extent similar to the concept of “Dyson Dots” proposed by Robert Kennedy III et al [4]. As with the original version of the Shkadov thruster, and its previous versions [5], it can be used by a technological civilization to reduce the distance between the stars and thus accelerate the formation of habitable artificial star clusters, which could possibly encourage intensive interaction of cosmic civilizations (CCs).

At the same time, this technology allows for more large-scale projects, including the controlled collapse of such star clusters with the formation of supermassive black holes.

It should be noted that the implementation of such astroengineering designs, contrary to first impressions, does not require ultra-high energies and technological levels. If for the creation of such structures as Shkadov thrusters and artificial star clusters time is not an issue, they may be implemented through the creation of a small group of self-replicating spacecraft with electric solar sails, similar to the concept of the "Astrochicken" by Freeman Dyson [6] which is launched into space, like modern combat aircraft missiles, on the principle of "fire and forget". The cost and complexity of creating the first prototypes of such devices, in the most preliminary estimates, could be comparable to such projects as the construction of the International Space Station, the Large Hadron Collider or the ITER experimental fusion reactor, but it is not an emergency situation.

An earlier theoretical possibility for the creation of artificial universes as the black holes of the elementary particles, with an energy of 10^{15} GeV, for which "we would need energy particle accelerators only a hundred billion times more powerful than now achievable ...", was pointed out by Y N Efremov [7], with reference to the paper by I D Novikov [8], which "showed that if the compression of ordinary matter to the size of the gravitational radius - the creation of a black hole - gives the surface an electric charge, the interior of a hole swells and begins to expand to another space. To start this process with the experimenter outside the hole, nothing changes, the hole is a hole - but the scale of the universe, he created a new universe", and E Harrison [9] has covered similar ground. This provides an opportunity to mention Carl Sagan [15] with reference to one of the publications by Andrei Linde [16]. However, it is clear that for the CC the interest is not to create universes with arbitrary general characteristics (as, in this model, happens all the time through the natural processes of gravitational collapse and the collision of super-high-energy particles), but the purposeful creation of a universe with a given set of fundamental constants, optimal for the emergence and development of intelligent life.

Such a problem can be solved by the controlled artificial gravitational collapse of a star cluster formed by means of

the Shkadov thrusters, with sufficiently precise provision of the necessary mass distribution of stars (and using a modified Shkadov thruster - and electric charge). For "exo-humanitarian" reasons, an uninhabited galaxy or star cluster can be chosen for this purpose, the installation of the Shkadov thrusters and the resultant machine "quasi-civilisations" can be functionally managed on the basis of organized groups of self-replicating unmanned vehicles ("Builders of the Universe") with electric solar sails as described above. (In the general case, this may create more complex machine ecosystems, including, for example, analogues of detrital organisms – ie specialized machines for the processing of defective machines, which are upgraded or otherwise utilized).

The key issue in this case is the following: can the known laws of nature, with the necessary accuracy, predict the distribution of mass and electric charge through to the gravitational collapse, to uniquely identify the physical conditions in the emerging universe and determine their constants?

Thus, a modified version of Lee Smolin’s concept of "Cosmological Natural Selection" (with a positive answer to this question) can be formulated as follows:

- Naturally, in most of the existing universe in which gravity acts as a result of gravitational collapse to form black holes, secondary universes arise with different sets of fundamental constants;

- In some of them, reaching the stage of technological development sufficient to start, with the help of self-replicating devices, the implementation of

astroengineering activities to create objects such as Shkadov thrusters, there will be at least one CC (today, obviously, we know of at least one such Universe, and one such civilization (the modern Earth) is in it, tending to this level);

- Any arising CC then creates, in the artificial manner described above, secondary universes with a given set of fundamental constants, favourable for the occurrence of similar civilizations;

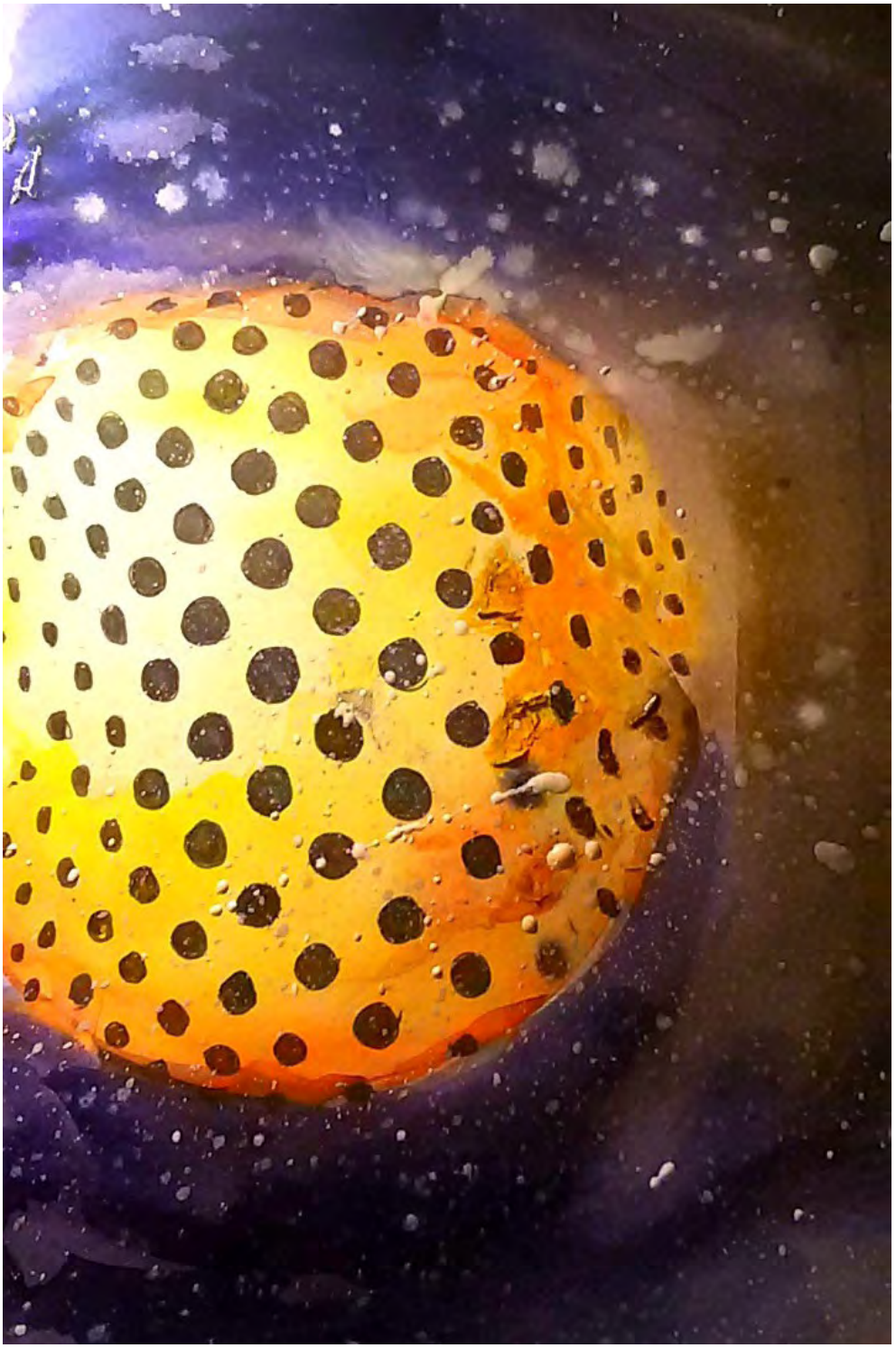
- So that the process becomes autocatalytic in nature, the number of inhabited universes increases in a continuous, nonlinear fashion and they become more routine cosmological objects.

This concept implies the possibility of an artificial origin for our known Universe. Such an approach has a right to exist, and can be verified by analysing the physical traces of the events related to the early stages of the universe (eg according to the programme of the WMAP [11] and at the subsequent, higher resolution), by known methods, used in the programs of the SETI, including with the help of new mathematical and software techniques developed within the project Breakthrough Listen [12]. It is assumed that the creators of an artificial universe may provide for the possibility of including in it a kind of "signature" of the author (and possibly the "instructions for use").

For example, in a recent paper by . Penrose and V G Gurzadyan [13], the authors highlighted a group of anomalies in the temperature distribution of the CMB (Cosmic Microwave Background, relic radiation), interpreted as possible traces of astroengineering activities by supercivilisations preceding the Big Bang.

Nevertheless, we can assume that the answer to this question is negative.

Among more than a thousand reliably identified exoplanets, as well as the planets and moons of the Solar system, so far it is not known of any planet, with the exception of Earth, suitable for the development of civilization. Although some of them, starting with the Moon, could become long-term bases for a technological civilisation, today it is a fairly complex task, which at best will be realized by the fourth decade of the XXI century. Moreover, maintaining a reasonable life on Earth at present, and especially in the past, remains a problem, and its maintenance and further development is still not guaranteed. There is every reason to assume that the distance between civilizations in the known Universe is big enough -



and the proposed technology [3] is aimed primarily at reducing these distances.

It is hard to reconcile this with the notion of an artificial universe which is optimally set up for intelligent life. Probably, such a universe would remind us of the old Sci-Fi books of the end of the XIX and early XX century, in which Mars, Venus and the Moon are inhabited, near-Earth space is filled with alien spaceships and the Fermi paradox does not exist.

There are plenty of examples of the existence in the mountains of natural caves, within which reasoning inhabitants have been fighting for survival for thousands of years (eg the Denisova Cave in the Altai). However, the deliberate construction of a city in which there is only one relatively habitable apartment in every few high-rise buildings seems highly unlikely.

Thus, the possibility of creating artificial universes today, which we have discussed, can be seen primarily as a vision for the distant future. If the cosmological models of the Big Rip [10] or multiple re-Big Bang [13] turn out to be true, it could be of value for technological civilizations, including ours, for the future ability to ensure that even if you do not own "immortality", there may be some continuity and "non-senselessness" of existence (just as modern people solve the problem of the finiteness of their lives through the birth and raising of children).

The technical aspects of these artificial universes, using different types of engines, are similar to the Shkadov thruster detail previously discussed [3] in part 3 of this article in the case of artificial habitable stellar clusters. Their study may be started as early as today.

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5 - A history of the desired future: to create worlds

In general, writing the future history is mainly the traditional occupation of the classic Sci-Fi authors. Their own versions of these stories were almost all by well-known authors. However, I will try to briefly introduce my own history leading to the desired future, based on the assumptions set out above.

For most of the history of the existence of intelligent life on Earth, a hand axe served as a basic tool. Originating as a simple flake pebble – a chopper, over time it has become a universal Acheulean hand axe, and then acquired a handle, turned into an axe and a hammer, then through material change become a metal chisel – but, in fact, it remained the same tool. And with the help of these simple tools, people over time have created such great structures as the Egyptian and American pyramids, Indian cave temples, Inca roads and the Great Wall of China. This required only time and sufficient motivation.

We will similarly assume that by using a fairly simple technical device - a solar sail in its various versions - people over the next few billion years, with sufficiently modest resources, will radically change the surrounding universe, making the propagation of intelligent life irreversible and autocatalytic.

A brief history of the desired future might look like the following:

1) The first half of the XXI century:
- Start of the "Catalysis" project. Creating standard spacecraft
- "Sowers" and "Keepers". Collection and systematization of the total volume of available information by mankind for entry into the "Keepers". Selection of stable stars with protoplanetary disks as the targets for the “Fleet of Life”.
- Creating and testing the first prototypes for elements of the Shkadov thruster.

2) The 2nd half of the XXI century:

- Mass start of the “Fleet of Life” and “Fleet of Memory” in the "Catalysis" project.
- Mastering automatic production of elements of the Shkadov thruster from material mined from the asteroid belt and the beginning of the assembly of its main reflector.
- Identification of stars which might be a potential base for technologically advanced CCs.

3) The next few centuries:

- Continuation of the mass start of the "Catalysis" project.
- Automate the building of the Shkadov thruster. Select the direction of movement of the Solar system with reference to the possibility of the presence in the Galaxy of other technological CCs.
- Systematic attempts to find signals from "beacons", presuming these to be artificial star clusters which feature the signature of extragalactic Shkadov thrusters.
- Attempts to colonize the nearest habitable exoplanets and using these to form "anthropogenic” CCs.
- Creation of the first prototypes of autonomous von Neumann probes – the "Builders of the Universe" – and launching them towards remote uninhabited star clusters.

4) 5-10 million years:

- Achieving the goal of the “Fleet of Life” and “Fleet of Memory”. Getting the "Sowers" started on biocatalysis.
- Maintaining the performance of the Shkadov thruster in the Solar system.
- Development of "anthropogenic" technological CCs. Construction of their Shkadov thrusters and the beginning of a coordinated convergence of stars with habitable planetary systems.

5) The next 2-3 billion years:

- Completion of the activities of the "Sowers". Formation of habitable exoplanets.
- Creating an artificial habitable star cluster outside the galactic arm.
- Achieving the goal of the "Builders of the Universe", and the beginning of self-replication and the construction of Shkadov thrusters from local matter in star clusters.

6) The next 4-5 billion years:

- Increasing the number of potentially habitable planetary systems in our Galaxy, when it merges with the Andromeda Galaxy.
- The emergence of the next generation of "anthropogenic" CC as a result of the activities of "Sowers". The development of CCs of information from the "Keepers" and the establishment of links between CCs. By starting their own unique "Catalysis" project, the beginning of autocatalytic propagation of intelligent life.
- Creating a "beacon" outside the artificial star cluster.
- Controlled artificial gravitational compression of the inhabited star cluster and the "acceleration of external time."
- The organization of a managed gravitational collapse of the stellar clusters by the "Builders of the Universe", and the formation of many new universes, more suitable for intelligent life than the existing ones...

This is probably the limit of the author's imagination. However, the beginning of this process goes beyond the imagination and, of course, it can be started in the coming years.

Briefing - The simplest Shkadov thruster: the possible design

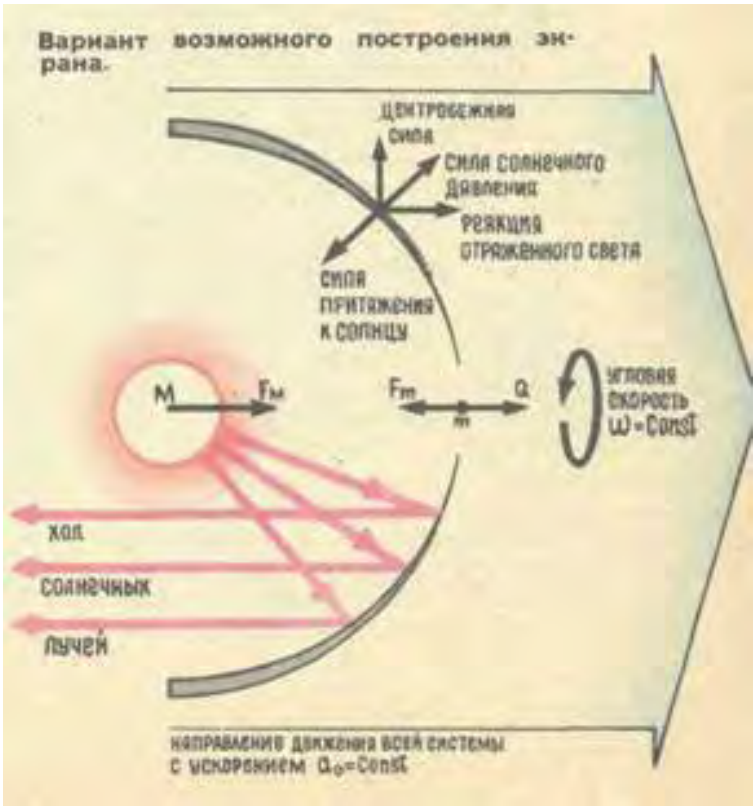
One of the first designs of star machine, known today as the Shkadov thruster, was proposed by students and leaders of the "Space Design" group in the Moscow Palace of Pioneers in 1979 under the name "Farah"[1] (Fig 1). Since then, such structures are all depicted as a monolithic structure with the technical aesthetics of the railway bridge. It is obvious that such a construction, like a classic Dyson sphere (a fragment of which, in fact, it is), is not feasible for reasons of material intensity, strength and stability. In addition, it is difficult to make this structure remain stationary near one of the poles of the star, which is necessary to maintain a constant directional thrust.

The solution to these problems requires the establishment of a construction of a different type – a mild, dynamically stable system, as a combination of identical, interchangeable, easy and cheap elements with a sufficiently long service life and easy and reliable construction. Taking into account the time required for the purposeful movement of stars (up to billions of years), it is advisable to make the system self-regulated through the use of simple analog devices.

Consider the simplest version of such a scheme.

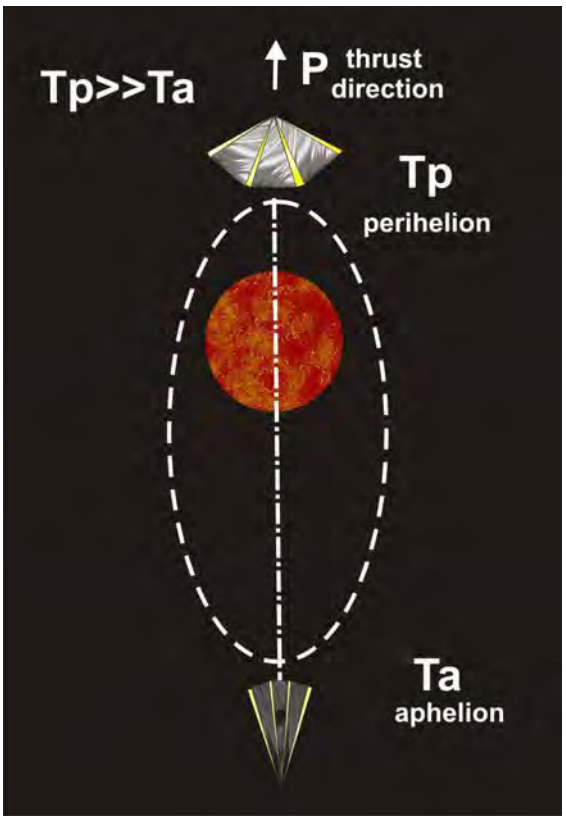
First, consider a single spacecraft with a solar sail that rotates around the sun in a highly elongated polar orbit with a low perihelion and a very distant aphelion (Fig 2). In general, the location of the apparatus near perihelion is determined by the law of Newton-Lebedev – ie the ratio between gravitational attraction and light pressure on the sun-facing surface of the sail.

Figure 1 - Shkadov thruster design from *TO THE STARS ON ... THE SOLAR SYSTEM*, Technology - Youth No. 12 1979, VIKTOR BOROVISHKA, GENNADY SIZENZEV, engineers [1]



But due to its elongation, the orbit of the spacecraft as a whole will be close to the Keplerian one. Obviously, in the region near perihelion - especially if it is located close enough to the Sun, for example, inside the orbit of Mercury - the light pressure will be very significant, creating a noticeable reactive force applied to the sail [2]. If the spacecraft is gravitationally balanced in a stationary orbit, the reactive force is applied to the "Sun-and-sail" system in the direction of the sail. In connection with the fact that the light pressure weakens proportionally to the square of the distance to the source, near aphelion the undesirable reactive force, directed in the opposite direction, is negligible.

Figure 2 - a single spacecraft with a solar sail that rotates around the sun in a highly elongated polar orbit



If in this polar orbit there are a large number of identical solar sails with a small separation between them, some will always be close to the Sun, creating a continuously directed thrust (Fig 3). This "conveyor" is a small permanent element of the reflector of the Shkadov thruster, but its thrust is negligible.
To significantly enhance the overall thrust it is expedient to arrange a large number of similar polar orbits with a very small angular displacement of many of these "conveyors". To exclude the possibility of collision of individual sails, orbits are also arranged with a small (on the order of kilometers) axial displacement (in the direction of the Sun's pole), so that the "conveyors" are spirally arranged like a clam shell. In this case, a mobile surface is formed around the Sun in the shape of an ellipsoid, the longitudinal axis of which is perpendicular to the plane of the ecliptic (Fig 4). The part located in the region near perihelion forms a delicate, movable, but permanent reflector of the Shkadov thruster, in the form of an elliptical concave mirror, in the focus of which is located the Sun.

In principle, for the simplest task of ensuring a relatively long directional movement of the Sun this is enough. However, it would be desirable to completely eliminate stray thrust from the aphelion side, as well as considering the possibility to provide structural stability during long disturbing influences. The giant planets of the Solar system are located in the ecliptic plane far enough from the polar orbits of the reflector elements, and their gravitational influence is negligible. However, non-stationary oscillations of solar activity could in principle violate the established order of motion of the reflector elements.

This problem can be solved by making the sails foldable, on the principle of an umbrella - with reinforcing straps of a shape memory material, for example, Nickel-Titanium (NiTi) (Figs 2, 5).

In the working position, with the maximum design heating of the structure (at perihelion), the sail is almost completely (but not completely) opened, so the area of the reflecting surface is close to the maximum. Conversely, as the distance from the Sun increases, the cooling sail is folded, and at aphelion the reflective surface is minimal, so that it eliminates parasitic thrust fully. The mechanism for regulating the shape of the reflector is quite simple in this case. Suppose, during solar activity oscillations, the reflector elements are moved closer to the

Figure 3 - solar sails, some will always be close to the Sun

Figure 4 - "conveyors" are spirally arranged like a clam shell

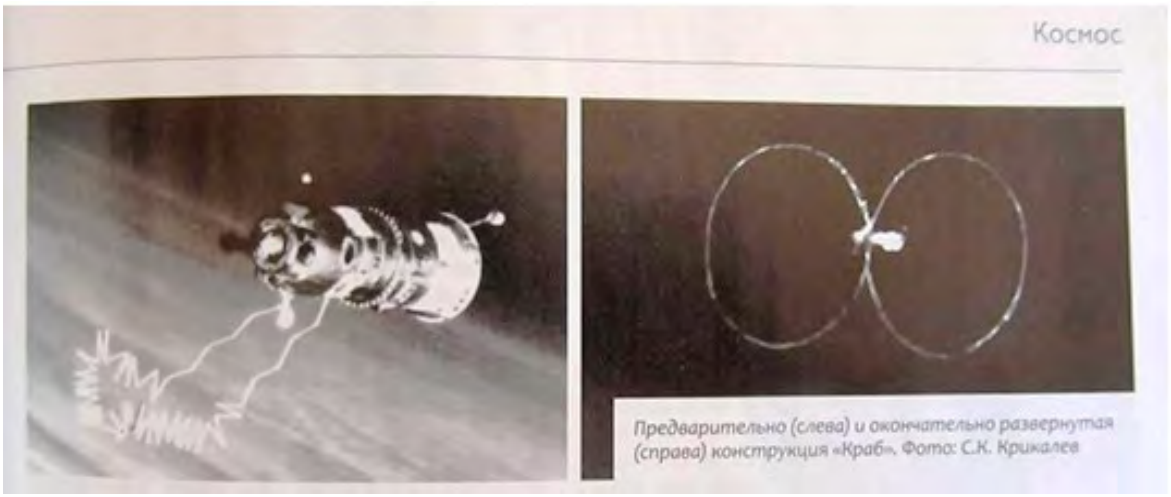


Figure 5 - Demonstration of the deployment of shape memory material in the 'Crab' experiment from the Progress-40 resupply craft to the Mir space station, March 1989 [3]

Sun. With increasing temperature, the sail opens completely and its reflecting surface increases, which in combination with the nonlinear growth of the solar light flow creates an additional thrust that returns the device to the design orbit. At a distance from the design orbit, the surface of the sails is reduced and returns to the reflector element of the orbit of the uncompensated action of gravitational attraction. Thus, the reflector of the Shkadov thruster constantly "breathes" within certain limits, but on the whole remains in shape.

The shape memory effect can persist for millions of cycles, while the cycle time (depending on the degree of elongation of the orbit) for an individual sail can be hundreds or even thousands of years. This ensures high stability for the system as a whole.

Sequential filling of the "conveyor" in polar orbits is advisable through the introduction of new elements from automatic factories in the asteroid belt in the plane of the ecliptic in the region near perihelion. This will ensure the complete design thrust of the Shkadov thruster is achieved long before the full completion of the construction.

The total mass of the ellipsoid, depending on its elongation, may be up to one or two orders of magnitude greater than the mass of its working part (reflector) from the poles of the Sun. But in general, it is relatively small in connection with the design of the structure, and can be fully provided for by the raw stock of the inner asteroid belt.

Obviously, it would be possible for highly developed cosmic civilizations from other stars to create similar structures. For an external observer, they would be quite spectacular. Finding such objects could be one of the tasks of "Dysonian SETI".

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About the Author

Dmitry Novoseltsev (Дмитрий Новосельцев) is Deputy CEO of the Siberian Mechanical Engineering, Non-Profit Partnership (www.npsibmach.ru). He has a PhD in Technical Sciences, awarded by Omsk State Technical University, for his thesis "Vacuum, compressor technics and pneumatic systems". He is a regular contributor to the Space Colonization Journal (jour.space).

About the Illustrator

Dr Anna V Sedanova (Анна В Седанова) is a Senior Researcher in the Institute of Hydrocarbon Processing, Siberian Branch of Russian Academy of Sciences, Omsk, Russia, www.иппу.рф

Art for Interstellar

Bringing art, technology and science together in New York

Cosmos Imaginings was a social-cultural event organized by the Institute for Interstellar Studies (i4is) in affiliation with City University of New York (Recall that, for UK legal reasons, i4is is, for the time being, the Initiative in the country where it is based.).
The event took place on 17 July 2017 at the Harvard Club in New York City as part of the Interstellar Workshop at New York City College of Technology, the designated college of technology of The City University of New York..
A major part of the event was the display of art. The catalogue is available on request from i4is (contact info@i4is.org) Here we present a sample with a little about each of six of the artists. Much more in the catalogue.
All images are credit to the artist unless otherwise specified.

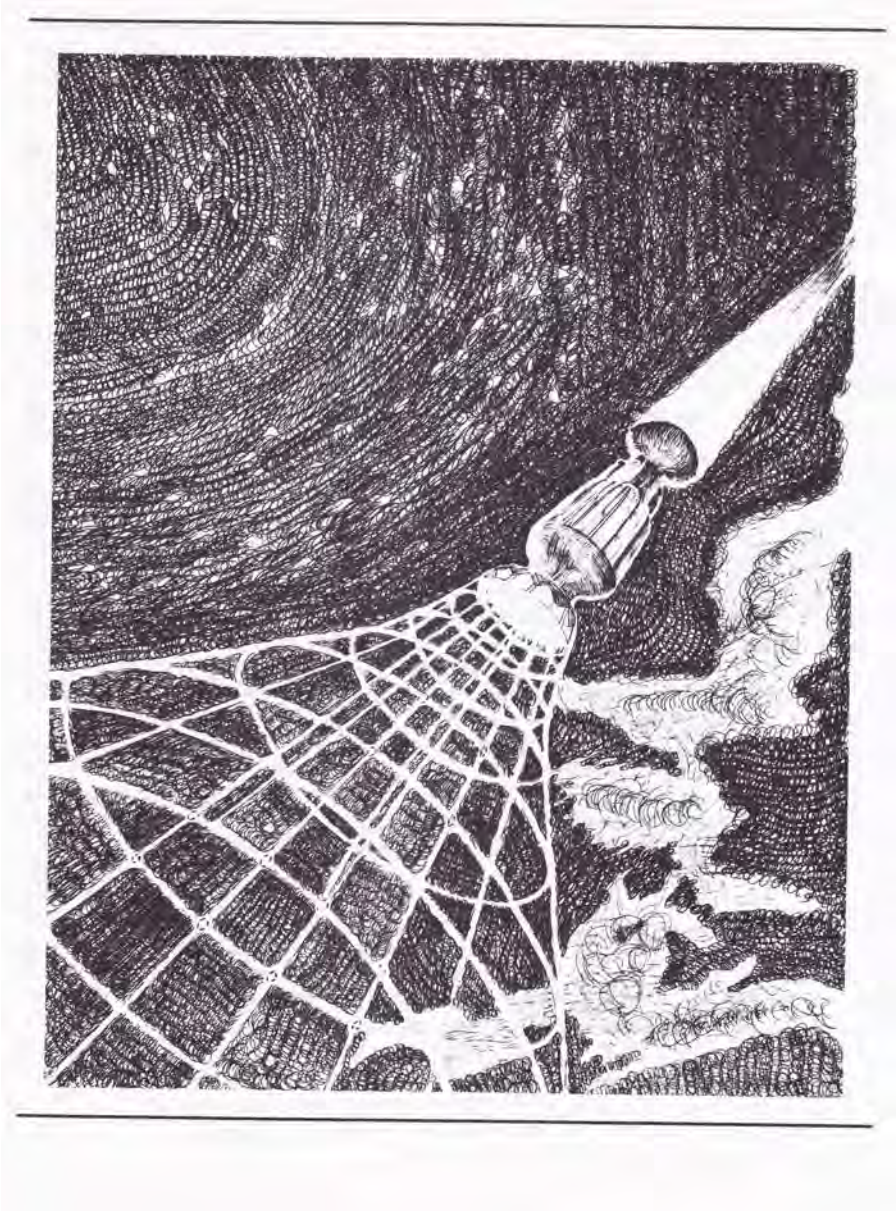
The logo of the Initiative/ Institute for Interstellar Studies was envisaged by Kelvin Long, Adrian Mann and collaborators and executed by Adrian Mann. For a full account of this and its iconography see i4is.org/who-we-are/founding-articles.

We start with a Daedalus / Icarus like figure, a metal sculpture by Alexandra Limpert. Alexandra produces both metal sculpture and animatronics. She is based in New York City where she also works with the Rush Philanthropic Arts Foundation, teaching her skills to inner city youth across New York City.
See more about Alexandra at www.alexandralimpert.com and about Rush at rushphilanthropic.org.

Alexandra Limpert.

C Bangs gave us our front cover in P18, our August 2017 issue which reported the conference. We include here a less obviously space-related image. Yet this is a visualisation of the Casimir effect. C Bangs' art investigates frontier science combined with symbolist figuration from an ecological feminist point of view. Her work appears in public and private collections, books and journals including the NASA Marshall Spaceflight Center, and the British Interplanetary Society. More about her and her work at www.cbangs.com

C Bangs
photograph credit Mark Lee Blackshear mark@markylee.com



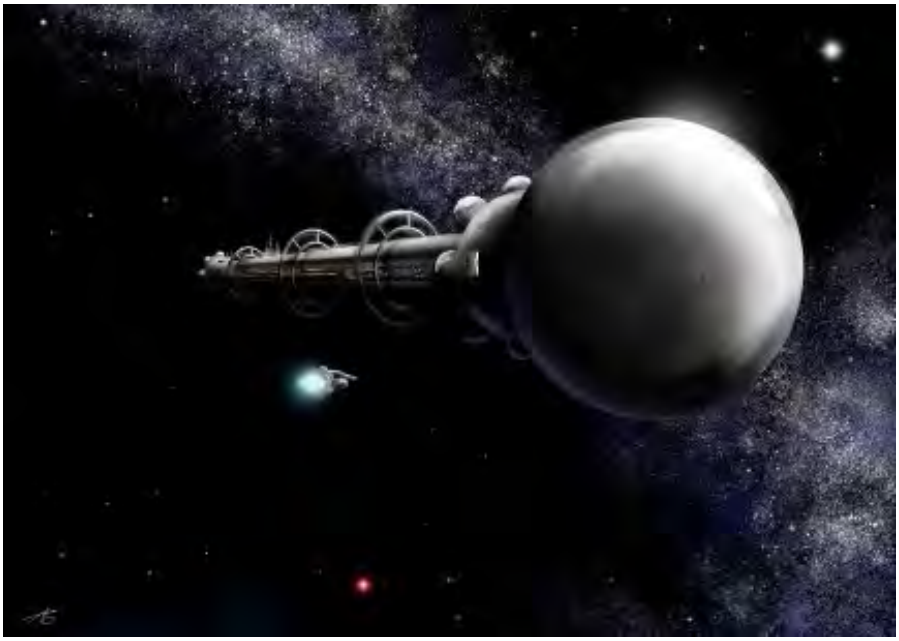
C Bangs visualises a Bussard ramjet. First described in *Galactic Matter and Interstellar Flight*, Robert W Bussard of Los Alamos Scientific Laboratory in 1960 www.askmar.com/Robert%20Bussard/Galactic%20Matter%20and%20Interstellar%20Flight.pdf. Its feasibility has been much debated and the design adapted in a number of ways - see en.wikipedia.org/wiki/Bussard_ramjet and for a recent extension of the idea i4is.org/what-we-do/technical/black-hole-engine.

Bussard's original idea has inspired much science fiction, most notably, *Tau Zero*, Poul Anderson first published in 1967 as a short story in Galaxy magazine. The title was adopted by our interstellar colleagues in the Foundation of that name.

Alex Storer at the keyboard.
Credit David Hardy

Alex Storer is a freelance digital artist and illustrator based in Sheffield, UK. He also composes and performs music. He is honorary musician for the Initiative for Interstellar Studies and he has produced several albums in association with i4is.
See more about Alex at www.thelightdream.net and about his i4is work at i4is.org/who-we-are/interstellar-artists/alex-storer

Alex Storer provided the front cover image for the exhibtion catalogue. *Waiting*. A visualisation of a lonely space station orbiting Mars. More about this image at www.thelightdream.net/art/space/waiting.html

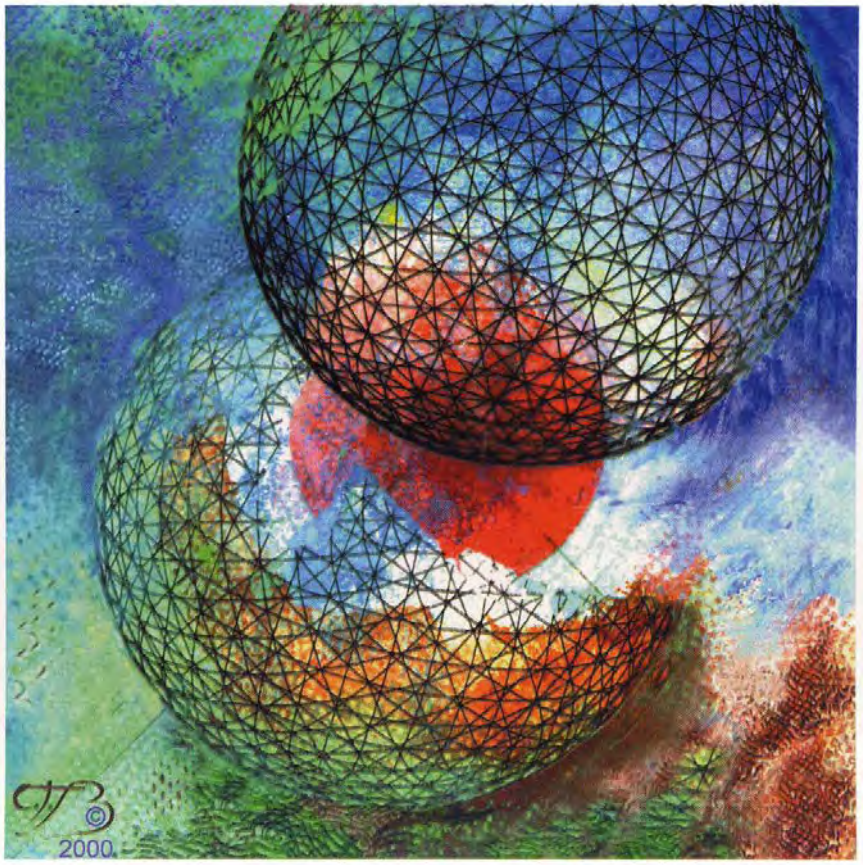


Alex Storer's visualisation of an Enzmann starship, *Demesne*, featured on the cover of Principium 13 in 2016. Here a smaller vessel is approaching - more at www.thelightdream.net/art/space/demesne.html.

Adrian Mann has contributed much to our imagination of space and interstellar in both still and video forms. He has enhanced the pages of Principium since its beginning and was also our layout artist in the early years. He has an extensive portfolio of commercial work for companies including Rolls-Royce, BAe Systems and Reaction Engines. Anyone who has seen his video of the Reaction Engines Skylon mission cannot fail to have been moved by the vision of the company and Adrian's visualisation of it. His work has appeared in 'All About Space', 'Spaceflight', 'Focus' and many more publications. Find his starships at www.bisbos.com spacecraft_starships.html and his other work at www.bisbos.com

A dramatic image of the second stage of a Daedalus spacecraft soon after ignition of its fusion rocket. Adrian has produced many images of Daedalus, www.bisbos.com/space_n_daedalus.html. Terry Regan's Daedalus model at the headquarters of the British Interplanetary Society was inspired and informed by Adrian's work.

The Apollo lunar module seen from above. Adrian has produced many images of spacecraft, old and new, real and imagined. He has also designed a 3d printed model of the BIS Moonship based on the images of R A Smith. You can see that 1930s design alongside the LEM as built at www.bisbos.com/space_bis_moonship.html.



Carmela Tal Baron is a New York-based poet, songwriter, vocalist, set designer, video artist and writer with background and training in interior and architectural design and drafting, painting, drawing, illustration, installation and 2D & 3D design. She savours interdisciplinary collaboration working with poets, writers, dancers, musicians and architects. More about Carmela and her work at www.carmelatalbaron.com.

Being Whole Again is also Carmela's cover illustrations for Paradigm Shift and Other Poems and the eponymous musical collaboration with jazz pianist John di Martino

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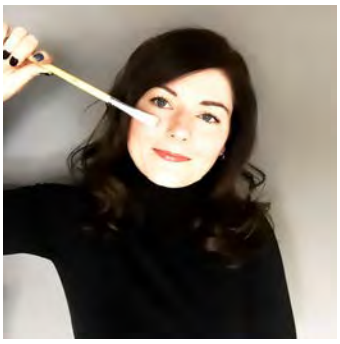
Here Kari gives us a surrealistic image of astronaut, nebula, butterfly and waterfall. This is a commissioned work on canvas titled 'Discovering Hope'.

Kari Weatherbee is a self-taught Canadian artist based in Nova Scotia. She has been creative since her childhood and



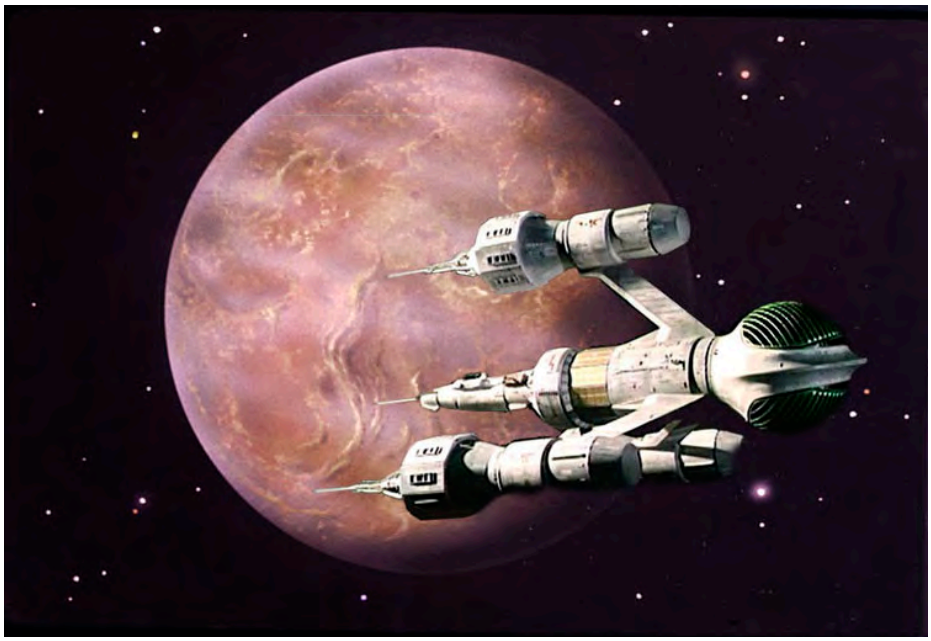
has most recently moved to work in fine arts, specifically using oils. She tells us "The universe is my main source of inspiration." Kari aims to bring the beauty of the cosmos to a broad audience building on her personal perspective and on nebulae, galaxies and stars. Her work has been displayed at the Winding River Art Gallery in Stewiacke, Nova Scotia and The Corridor Gallery in Truro, Nova Scotia. Much more about Kari and her work at www.theoldmillyard.com

Another work in oils. *Starry Shores* www.theoldmillyard.com/gallery?lightbox=dataItem-j6s9z7uh
Lighthouses may be redundant in an era of digital navigation but they remain a powerful metaphor - do those unknown shores have lighthouses set by species other than ourselves?

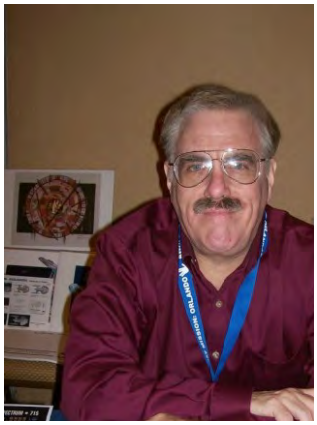
David's illustration of the moonship as envisaged by the BIS in the 1930s was commissioned for the 2008 International Astronautical Congress in Glasgow. The moonscape is deliberately retro and echoes the work of Chesley Bonestell.

David Hardy was influenced in 1950 by Chesley Bonestell's Conquest of Space, and became an astronomical illustrator in 1954 with a commission for book illustrations for now-legendary astronomer, Patrick Moore. David's

career now spans more that 60 years - books and magazines, factual and fictional. His work is in the US National Air & Space and has been owned by Arthur C Clarke, Carl Sagan, Wernher von Braun, Isaac Asimov, Stephen Baxter, Brian May, amongst many others including our own Kelvin F Long. Whilst still painting with acrylics and oils, he now also uses Photoshop. And he has an asteroid named after him, 13329 Davidhardy, news.ansible.uk/a189.html. More of David's work at www.astroart.org .



David produced backgrounds for the legendary Blake's 7 TV adventures. Here the starship Liberator approaches a red planet - which David kindly contributed as a cover image in Principium 15. www.astroart.org/sf--fantasy?lightbox=image_es1



Rick Sternbach has been a space and science fiction artist since the early 1970s with clients including NASA, Sky and Telescope, Smithsonian, Analog and The Planetary Society. He has twice received the Hugo award for best professional science fiction artist. He is perhaps most famous in the interstellar field for his illustrations for the Carl Sagan TV series, Cosmos. i4is founder Kelvin Long celebrated this contribution to our outward urge Cosmos: A Personal Voyage in Principium 14. You can find more about him at www.ricksternbach.com/

All of Sternbach's pictures at the NYC conference were included in Kelvin's piece in P14 so we have not repeated them here.

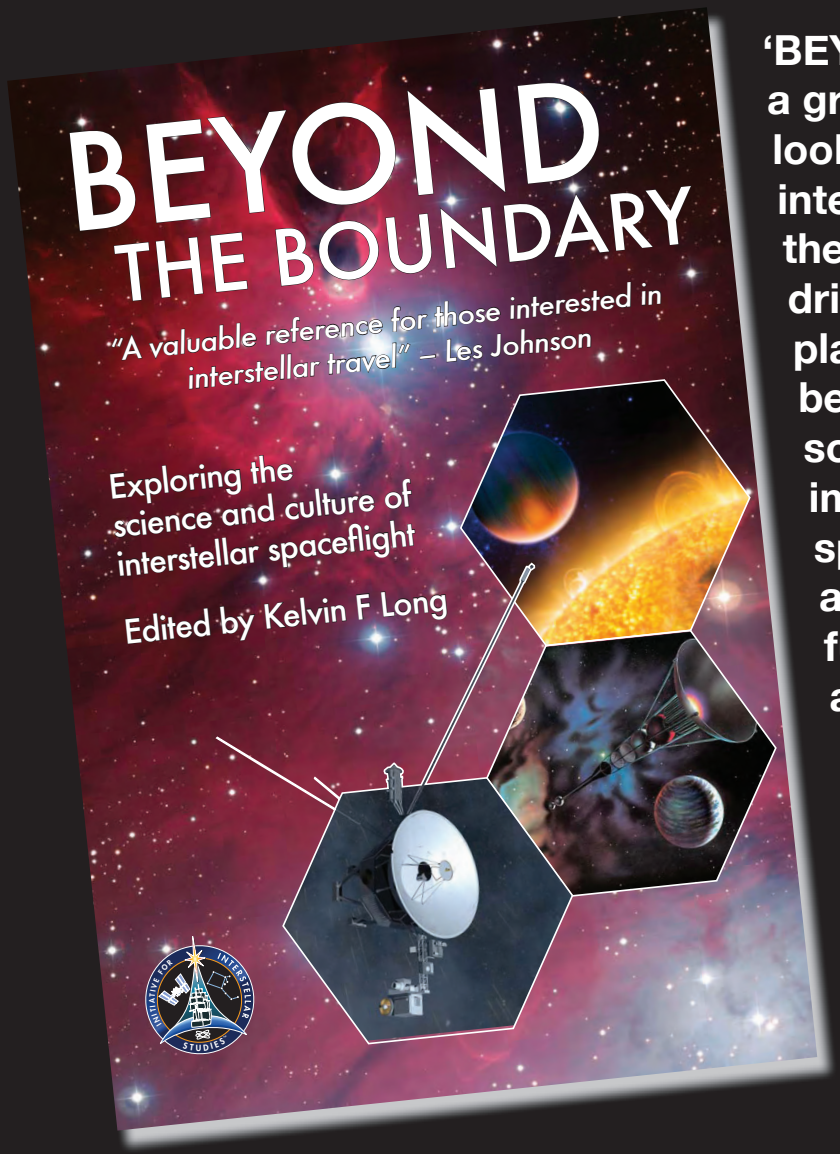
NEXT ISSUE

Models and Art at The Mill
Project Lyra: Flying close to our first discovered interstellar object
...and much more!

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(InterstellarInstitute),
Twitter (@I4Interstellar) or
LinkedIn to join in the conversation.

The Initiative for Interstellar Studies

PRESENTS



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

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

www.i4is.org

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.

Editor: John I Davies
Deputy Editors : Andreas Hein, Patrick Mahon
Layout: John I Davies

The Initiative for Interstellar Studies is a pending institute, established in the UK in 2012 and incorporated in 2014 as a not-for-profit company limited by guarantee.
The Institute for Interstellar Studies was incorporated in 2014 as a non-profit corporation in the State of Tennessee, USA.

Front cover: Sputnik 1, Credit: Robert Kennedy & Ultimax Group
Back cover: View of the Apollo 15 Command Service Module in lunar orbit, Credit: NASA

i4is.org

Scientia ad sidera
Knowledge to the stars