PRINCIPIUM

The Newsletter of the Initiative for Interstellar Studies
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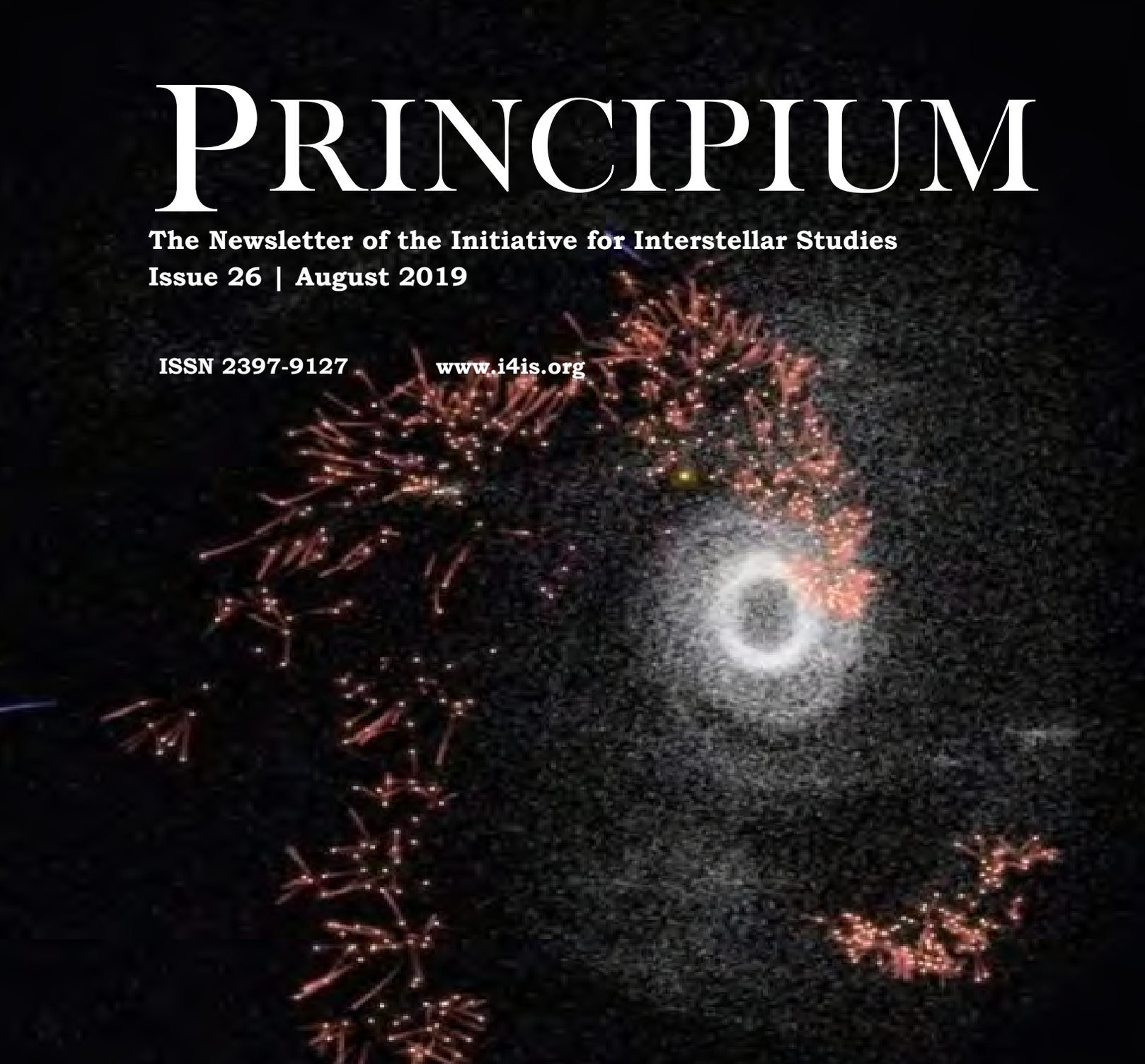

Scientia ad sidera
Knowledge to the stars

Editorial

Welcome to issue 26 of Principium, the quarterly newsletter about all things interstellar from i4is, the Initiative and Institute for Interstellar Studies. This issue is edited by Patrick Mahon.

The front cover image shows a European Space Agency simulation of how humanity might expand to the stars in future, while the back cover shows an extraordinary image of the Apollo 11 landing site, taken by NASA's Lunar Reconnaissance Orbiter.

The Lead Feature for this issue reports on the second *Foundations of Interstellar Studies Workshop*, the final event at i4is's headquarters, The Bone Mill, in Gloucestershire, UK, in late June. Our other main features include the second and final part of Kevin Schillo's essay on *The State of the Art in Fusion Propulsion*, and part one of an article by Terry Regan on building a scale model of the Mariner 2 spacecraft which visited Venus in 1962. i4is Executive Director Andreas Hein reports on a recent interstellar workshop organised by the European Space Agency's Advanced Concepts Team. We have advance notice of papers by members of the i4is team, plus details of other relevant interstellar talks at the 70th International Astronautical Congress, which will take place in Washington DC in late October. We also feature details of the imminent Starship Congress 2019: *Bend Metal*.

We are also pleased to announce the result of our Apollo-themed interstellar poetry competition, along with more on the i4is membership scheme, plus our regular member's page with more about members'-only website content.

As usual, we report on recent Interstellar News, including i4is activities – an ISU ChipSat elective, and Summer Schools at the Royal Institution plus other news: Jodrell Bank is a new UNESCO World Heritage Site, the Planetary Society's LightSail 2, the ESA 'Comet Interceptor' mission and numerous recent interstellar papers in JBIS.

For Members of i4is

Members have access to -

Networking - i4is.org/members/networking-opportunities

Principium preprints- i4is.org/members/preprints

Videos - i4is.org/videos

More in The i4is Members Page - page 28

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And following the feature on the membership team last time, we highlight here the team that puts each issue of Principium together.

And finally, sad news: the closure of i4is's headquarters. together with the departure of co-founder Kelvin Long from our organisation.

Our next issue, P27 in November, will feature the delayed article on *Nomadic Planets and Interstellar Exploration* by T Marshall Eubanks, a new technosignature-based SETI method by Dmitry Novoseltsev and a Report from IAC 2019.

If you have any comments on Principium, i4is or interstellar topics more generally, we'd love to hear from you!

Patrick J Mahon, Editor, patrick.mahon@i4is.org

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

Membership of i4is

Please support us through membership of i4is. Join the interstellar community and help to reach the stars! Privileges for members and discounts for students, seniors and BIS members - details page 32.

More at i4is.org/membership.

Please print and display posters - page 3 (student discount), 21 and 29. Other variants are all at -

i4is.org/i4is-membership-posters-and-video

Keep in touch!

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

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And seek out our followers too!

Contact us on email via info@i4is.org.

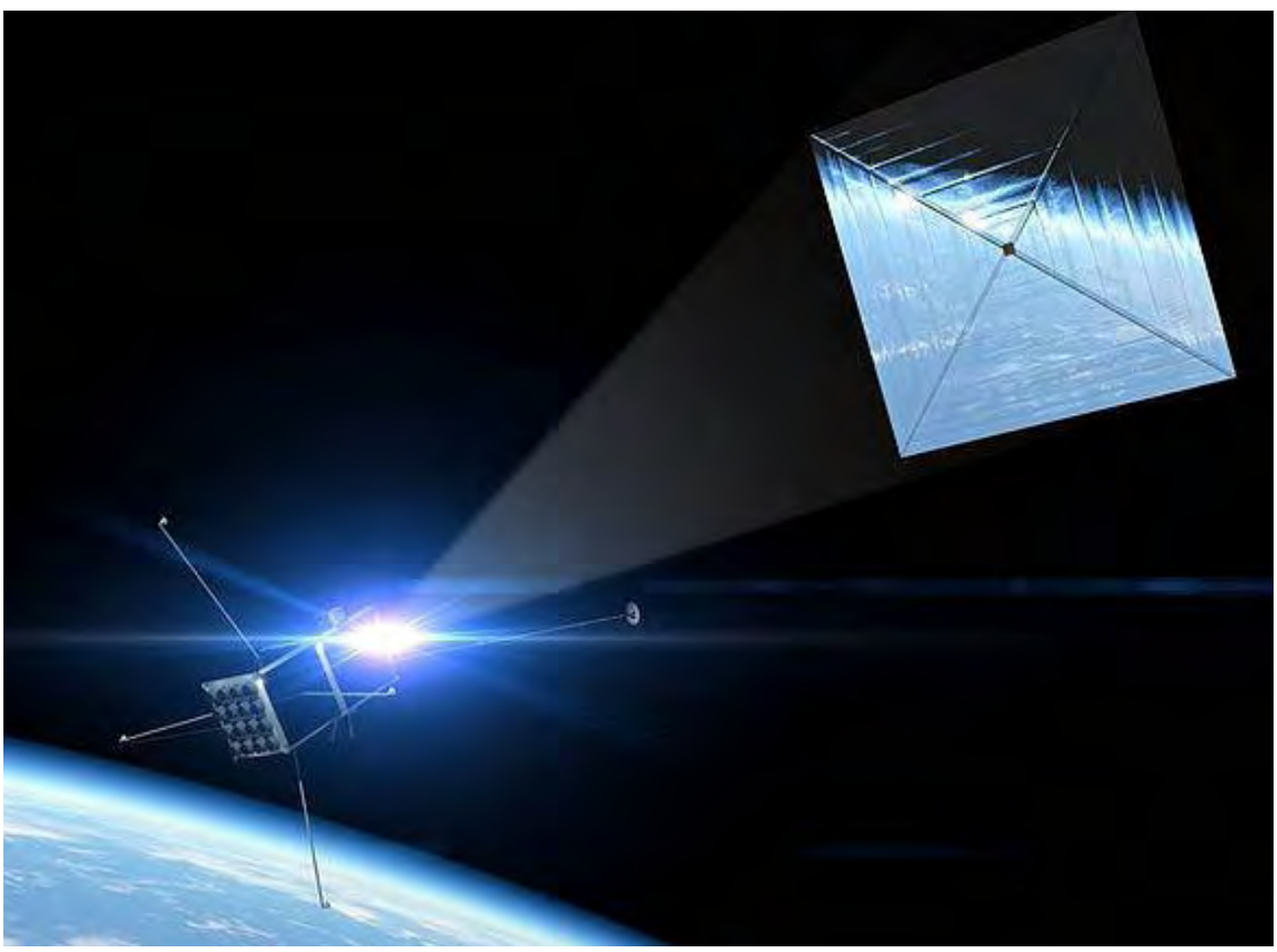
Back issues of Principium, from number one, can be found at www.i4is.org/Principium

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

JOIN I4IS ON A JOURNEY TO THE STARS!

Do you think humanity should aim for the stars?

Would you like to help drive the research needed for an interstellar future...
... and get the interstellar message to all humanity?



The Initiative for Interstellar Studies (i4is) has launched a membership scheme intended to build an active community of space enthusiasts whose sights are set firmly on the stars. We are an interstellar advocacy organisation which:

- conducts theoretical and experimental research and development projects; and
- supports interstellar education and research in schools and universities.

Join us and get:

- member exclusive posts, videos and advice;
- free or discounted publications, merchandise and events;
- advanced booking for special HQ events; and
- opportunities to contribute directly to our work.

To find out more, see www.i4is.org/membership

80 % discount for full time students!

News Feature: Foundations of Interstellar Studies Workshop 2019

Reported by Patrick Mahon

The Second Foundations of Interstellar Studies Workshop took place between 27 and 30 June 2019 in the beautiful surroundings of The Bone Mill, Charfield, Gloucestershire, UK. It followed on from the inaugural FISW meeting, which took place in New York in June 2017.

All pictures credit Samar AbdelFattah unless otherwise stated.

Day 1, Thursday 27 June

The workshop began at 6 pm with an opening reception. Attendees were treated to food, drink and jazz from 'Blue Shift', a three-piece jazz band whose members include i4is member Stephen Ashworth and Simon & Tom Feast, two brothers who both work for Reaction Engines (www.reactionengines.co.uk). The evening provided an opportunity for old friends to catch up, and new friends to be made, and everyone seemed to have a great time. The party broke up at about 9 pm.

Intense conversation at the opening party - left to right

Left standing: Richard Osborne (facing away) and Mark Hempsell

Right sitting: Prof Greg Matloff and Al Jackson

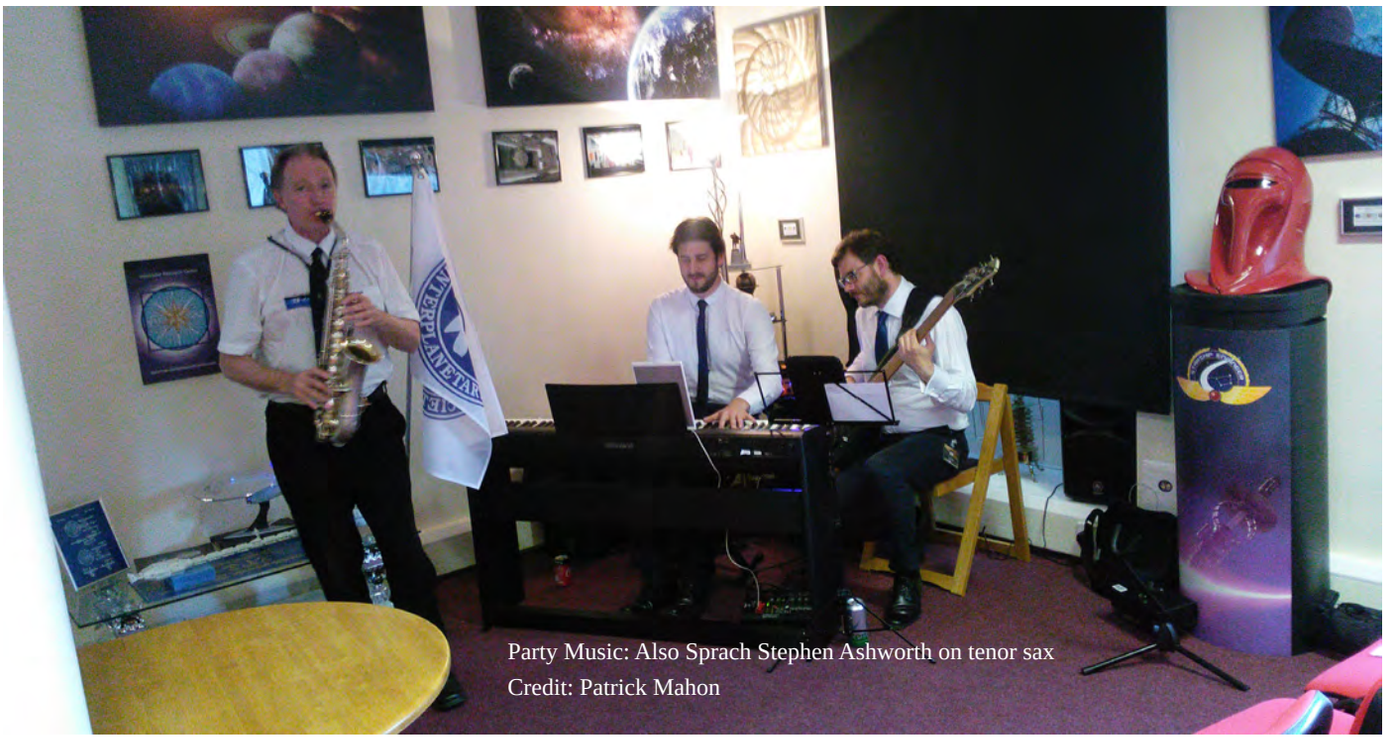
Credit: Patrick Mahon

Day 2, Friday 28 June: Session One, 'Living in Deep Space'

The first full day of the workshop began with introductions from Co-Chairs **Kelvin F Long** and **Rob Swinney**, the latter of whom also acted as Friday's Chairman.

The party in full swing

Credit: Patrick Mahon



Party Music: Also Sprach Stephen Ashworth on tenor sax
Credit: Patrick Mahon

The keynote presentation came from **Professor Philip Mauskopf** of Arizona State University, who was representing ASU's Interstellar Initiative, and who spoke about *Interplanetary & interstellar communications and navigation*. Philip asked and answered two key questions: can we do navigation and communications at interstellar distances? The answer is yes in both cases, although they will be very challenging for tiny Breakthrough Starshot type probes. However, his conclusion was that those challenges are relative ones – there are no absolute challenges just because Starshot probes are very small.

Mark Hempsell of the British Interplanetary Society presented on *Colonies and World Ships*. Mark discussed the fundamental differences between O'Neill-type colony ships, which remain in orbit round the Earth or in the inner Solar System, are economically linked to Earth, and can be resupplied from there, and worldships heading into interstellar space, which can't. He concluded that you can't simply create a worldship by taking a colony ship and putting an engine on the back – the design will need to be fundamentally different.

Following the coffee break, **Kelvin F Long** presented *Calculations for a crewed interstellar Dysonship driven by microwave beam propulsion*. He described a computer model he had built to calculate key quantities for manned spacecraft. He had validated the model against various types of worldships in the literature, to check that it came up with the same numbers. Having done so, he used the model to calculate these parameters for a crewed interstellar Dysonship, and presented his conclusions.

Angelo Vermeulen from TU Delft spoke about *Evolving asteroid starships: a bio-inspired approach to designing generation starships*. He noted that he was a biologist by training, and also an artist, and this work took both disciplines into account. It started from the recognition that the challenges of interstellar travel are complex and subject to deep uncertainty. This means that the solution needs to be a complex adaptive system, where emergent behaviour occurs through evolution and morphogenesis. The project models such a system, based on the idea of converting an asteroid into an interstellar starship

Kelvin Long describing the Dyson ship

questions to Angelo Vermeulen moderated by Rob Swinney

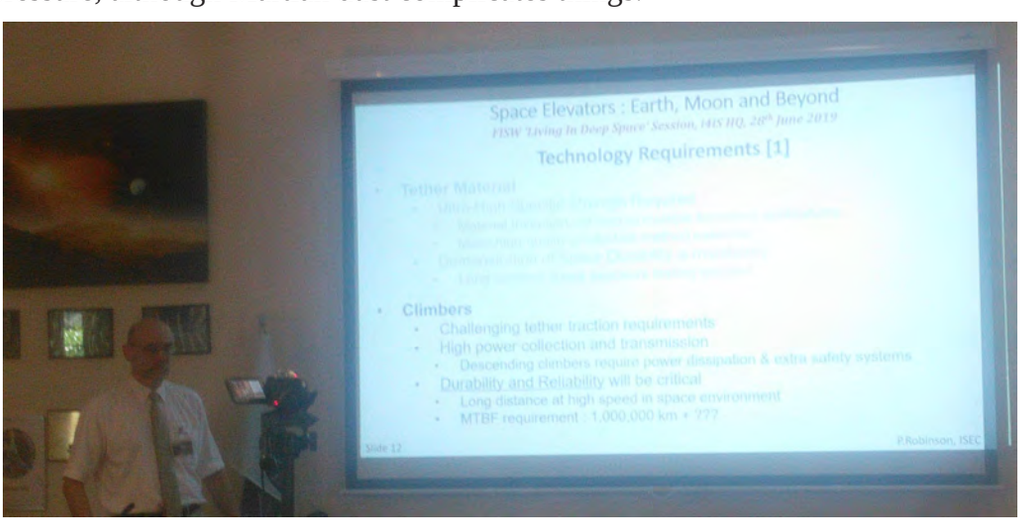
They have done simulations and some experimental work, particularly on a linear induction motor design and on the braking system. Work is ongoing.

Peter Robinson of the International Space Elevator Consortium (ISEC) presented *Space Elevators: Earth, Moon & Beyond*. Peter reminded the audience of the purpose of a space elevator – to provide low cost, safe and simple access to space. He summarised the research that has been done to date, including a major study by ISEC, published by IAA in 2013. Peter discussed the technical challenges of building a space elevator, including the strength & durability of the tether, the reliability & durability of the climber, and the need for active monitoring & control of the tether to move it out of the way of orbiting obstacles. We still don't have any materials strong enough, although single crystal graphene is currently the most promising candidate. ISEC are doing a lot of through the use of 3D printers working in an evolutionary way to respond to the challenges that are encountered on the way.

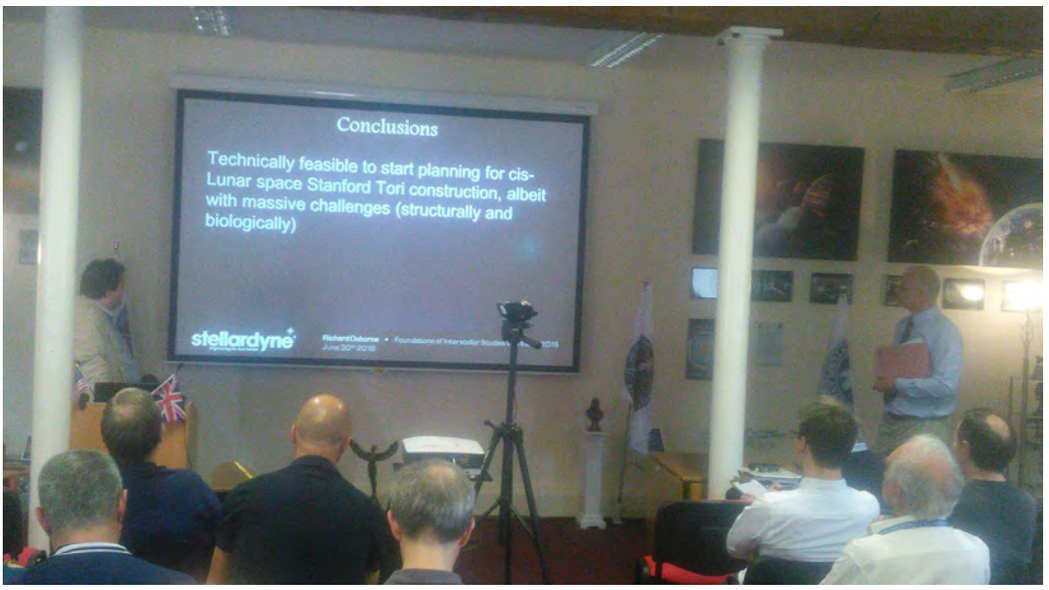
panel : Kelvin Long, Angelo Vermeulen, Professor Philip Mauskopf and Mark Hempsell

The morning concluded with a panel discussion involving all four speakers. This was followed by a buffet lunch and networking.

The afternoon began with a presentation by **Samar AbdelFattah** of Cairo University, who spoke about *Hyperloop: Martian Operations 1*. Samar introduced the Hyperloop concept – a public transport solution involving passengers travelling in a carriage that runs through an evacuated tube, enabling much faster transit speeds. She talked about the work her team are doing to model the use of a Hyperloop on Mars. It's easier to use there, given the low Martian atmospheric pressure, although Martian dust complicates things.



Peter Robinson (ISEC) on 'Space Elevators: Earth, Moon & Beyond'



Richard Osborne on near-term launch systems for a Stanford Torus

modelling work, including of precursors to an Earth-based tether, starting perhaps with a tether on an asteroid.

Richard Osborne from StellarDyne spoke about *The use of near-term launch systems for developing a Stanford Torus*. Richard explained his frustration that today's space stations were still basically 'tin cans in space', and proposed a much more ambitious alternative. A Stanford Torus was chosen as it is the smallest astroengineered megastructure, so would be easier than alternatives and would provide experience of space construction. The Torus is constructed from many near-identical truss segments. These are used to build a central hub first (12 trusses, each 24 metres long), then adding 6 or 12 spokes (each one built from 17 trusses, each 48 metres long), then the station is completed with the outer habitation ring, again built from repeated truss units.

Patrick Mahon of i4is presented on *Worldships – some ecological and resource constraints*. Patrick explained that a large worldship, carrying around 100,000 passengers for hundreds to thousands of years on the way to an interstellar destination, would need a completely closed ecology in terms of material resources. He identified several challenges to this, including the fact that recycling, even at very high levels, will never be sufficient, before suggesting potential solutions for each of these problems. He concluded with some suggestions for early research priorities.

Following coffee, there was a panel discussion involving audience questions to the previous four speakers.

This was followed by another panel discussion, this time focused on *A near-term tactical discussion on the build-up of an interplanetary infrastructure towards the strategic vision of*

Samar AbdelFattah, Peter Robinson, Richard Osborne, Patrick Mahon Asking the question, Mark Hempsell.

interstellar flight capability. The panel comprised **Samar AbdelFattah, Richard Osborne, Angelo Vermeulen, Stephen Ashworth, Harold 'Sonny' White** and **John I Davies** of i4is.

Day 2 finished with a poster session, accompanied by drinks and nibbles.

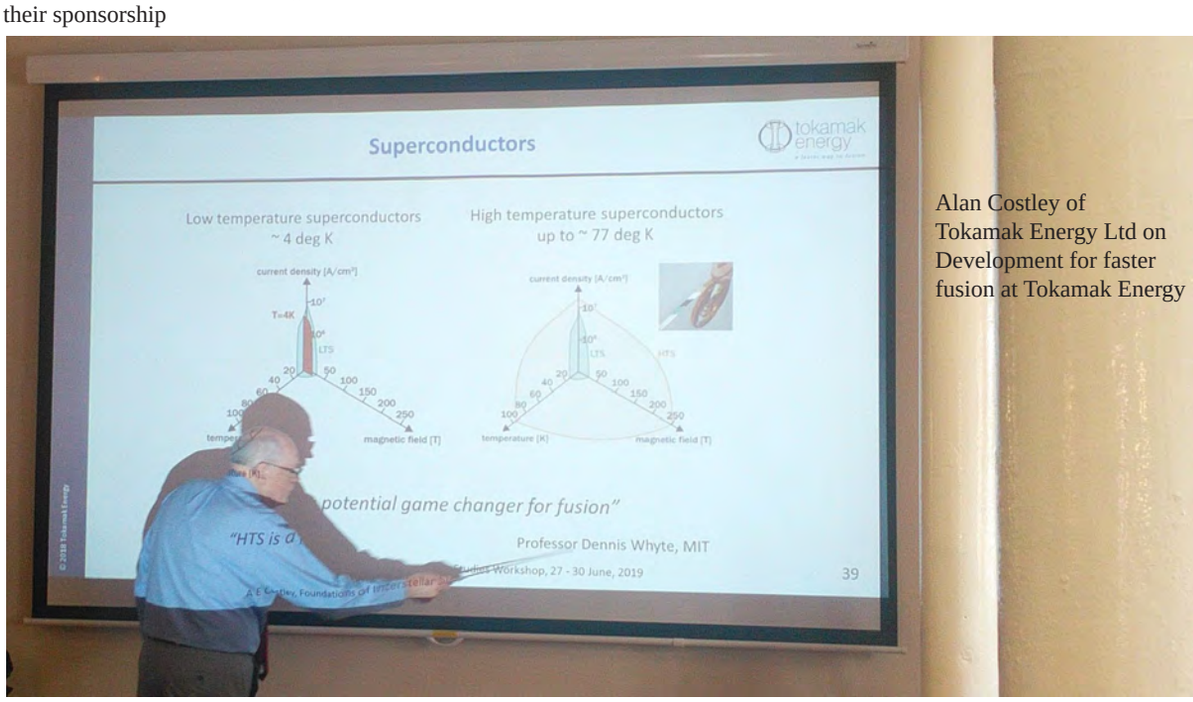
Day 3, Saturday 29 June: Session Two, 'Advanced Propulsion Technology and Missions'

Saturday's proceedings were opened by the day's Chairman, **Harold 'Sonny' White** of NASA.

The keynote address was given by **Alan Costley** of Tokamak Energy Ltd, on *Development for faster fusion at Tokamak Energy*. Alan started his talk with a primer on fusion physics and engineering, explaining the importance of the triple product. He noted that there had been rapid progress in increasing the triple product between 1970 and 2000, but this had slowed more recently, as international collaborative projects got delayed. Most recent fusion experiments have been based on large, expensive, high aspect ratio tokamaks (eg ITER costs $20 billion), but recent theoretical analysis suggests that the use of low aspect ratio spherical tokamaks may be more promising than previously thought. Tokamak Energy Ltd has been set up to pursue this development approach towards commercialisation. Alan summarised their progress to date, including the use of high temperature superconductors, which are a potential game-changer. They are doing conceptual work, experiments and R&D. They are currently meeting their milestones on the way to commercial production of electricity by 2025-2030. Such a fusion powerplant could be compact and powerful enough to be used on an interstellar spacecraft.

Sonny White opens the day by thanking Bill Cress and SpaceExcess.com for their sponsorship

Rob Swinney of i4is spoke about *Project Icarus Fusion Starship Concept Design Solutions*. Rob summarised the history of Project Icarus, initiated in 2009 with the intention of revisiting BIS's Project Daedalus four decades on. The project ran a design competition, the results of which were five competing designs for a fusion-powered unmanned starship heading for Alpha Centauri: Firefly, Ghost, Resolution/Endeavour, Zeus and UDD. Of these, the Ghost design won the competition, but later ran into problems. At the present time, the most developed design is the Firefly, which uses a Z-Pinch fusion engine. (Editor's note: the Firefly



Alan Costley of Tokamak Energy Ltd on Development for faster fusion at Tokamak Energy

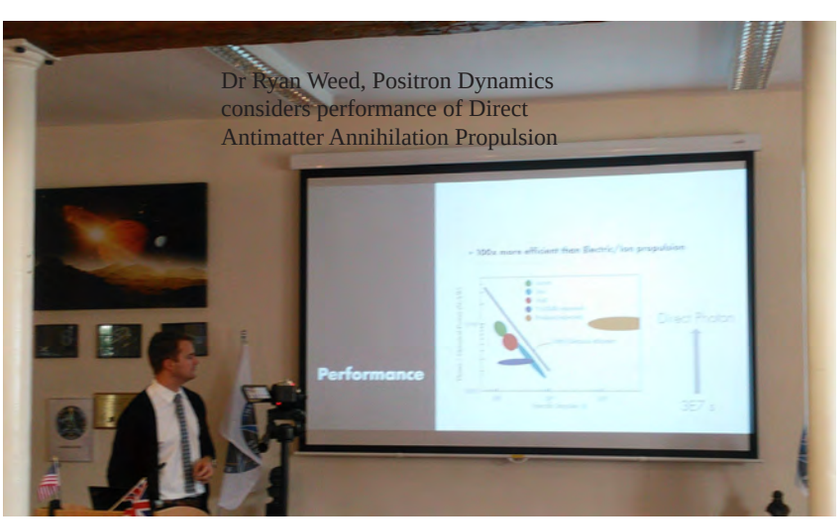
Rob Swinney on the vital radiators for the Icarus Firefly design

design was the subject of a review article, the lead feature in issue 22 (August 2018) of Principium, available at i4is.org/wp-content/uploads/2018/08/Principium22.pdf).

Dr Ryan Weed of Positron Dynamics presented *Towards Direct Antimatter Annihilation Propulsion*. Ryan summarised the history of antimatter research, and noted that the key problem, from the point of view of its value as a propulsion technology, is how to convert the energy to usable thrust. He outlined various potential solutions, although each has its own drawbacks. His company are currently investigating the use of radioisotopes of krypton as part of the conversion process; they believe this may deal with some of the drawbacks of previous proposals.

Day 3 Chairman **Harold 'Sonny' White** presented a talk on *Direct Fusion Drive (DFD) for the Gravitational Lens Mission*, on behalf of **Charles Swanson** of Princeton Satellite Systems, who unfortunately couldn't attend the meeting. Sonny explained that Princeton were developing a novel form of fusion engine, called the Princeton Field-Reversed Configuration (PFRC). This uses Deuterium and Helium-3, but the configuration is simple, small and clean, meaning it could potentially be ideal for many space missions. The mission that Charles had used to illustrate this potential was a solar gravitational lens mission, sending a probe 650 AU from the Sun, at which point the Sun can be used as a gravitational lens. This would, for example, enable a 1 metre telescope to take pictures of an exoplanet 100 light years away, with a resolution of 3 km, while the DFD would enable the spacecraft to get there in just 13 years!

Angelo Genovese of i4is spoke about a *Laser-powered electric propulsion precursor mission*. Angelo reminded the audience that chemical rockets were far too slow for interstellar missions. An alternative is electric propulsion such as ion thrusters. These have higher specific impulse than chemical rockets, but generally the thrust is tiny. Angelo explored various different ways of increasing the thrust from electric propulsion, and demonstrated the potential advantages of laser-powered electric propulsion (LEP, using large, space-based lasers beaming power to photovoltaic panels on the spacecraft), particularly for interstellar precursor missions – LEP should be able to get you to 200 AU within 30 years, and 1,000 AU within 50 years.

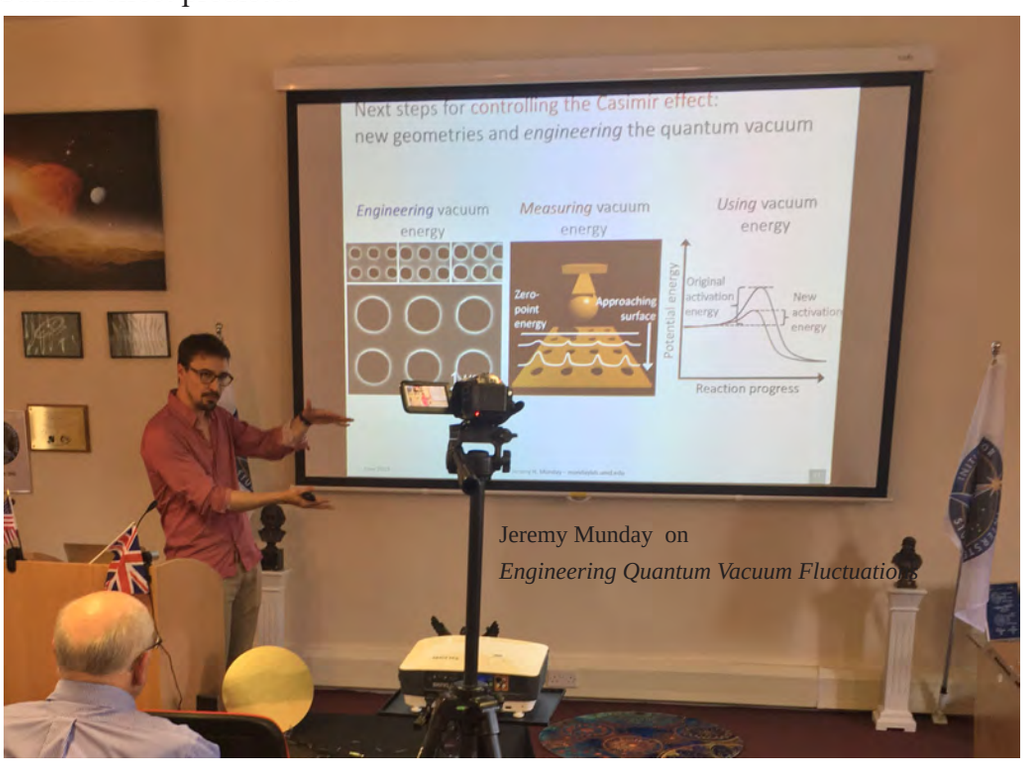


Dr Ryan Weed, Positron Dynamics considers performance of Direct Antimatter Annihilation Propulsion

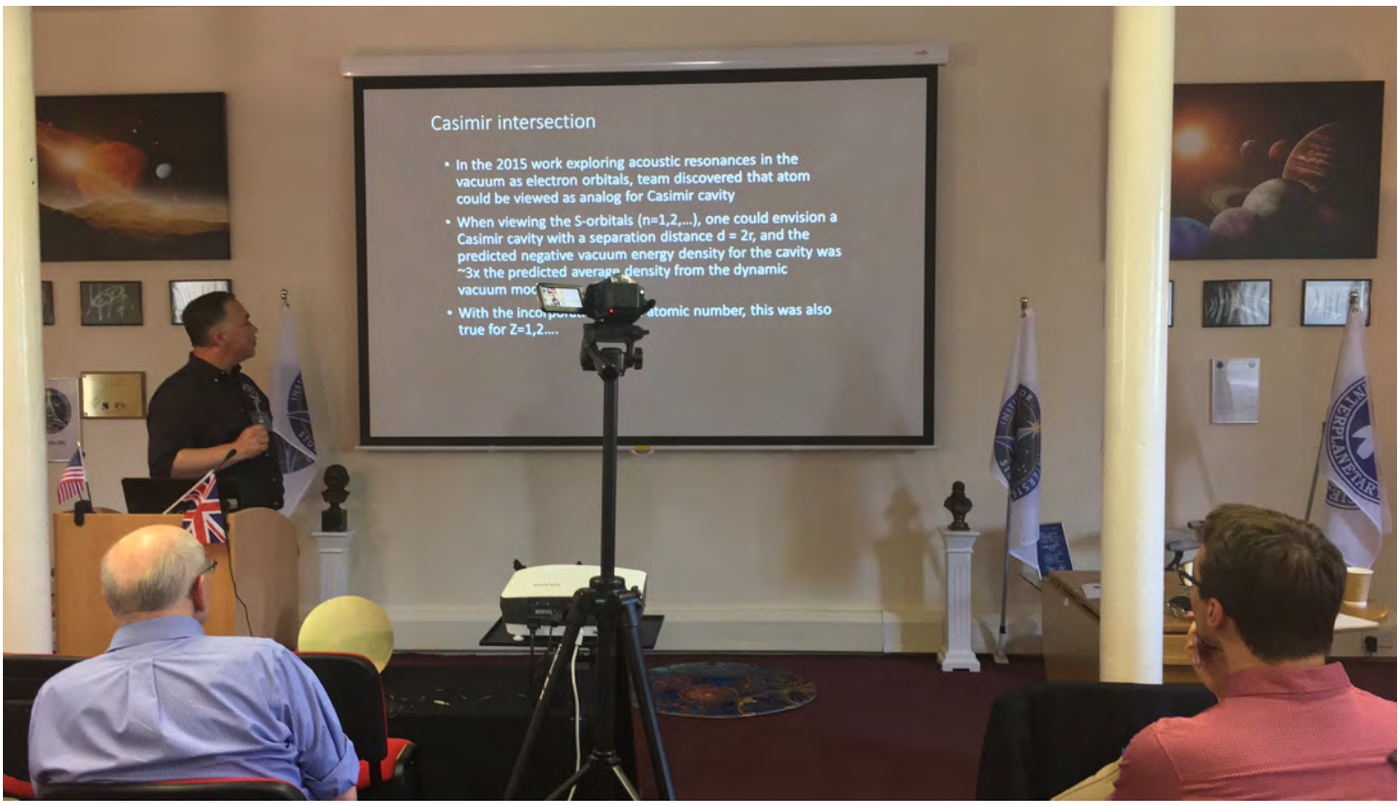
Angelo Genovese on
Laser-powered electric propulsion precursor mission

Following lunch, there was a panel discussion, including audience questions, on the morning's topics. Greg Matloff was invited to join the panel, given his knowledge of the subject areas, to replace Ryan Weed, who unfortunately had to leave for another meeting.

Next, **Jeremy Munday** of the University of Maryland spoke about *Engineering Quantum Vacuum Fluctuations*. Jeremy explained how quantum mechanics predicted that a vacuum is actually a 'sea' of quantum fluctuations, which have a positive 'zero point' energy. This has interesting implications, including the Casimir effect predicted in 1948. Casimir suggested that if you brought two parallel metal plates together, you would find an attractive force, pulling them together, purely because empty space is quantised. The effect is difficult to measure, and has large error bars, but Jeremy's team have been experimenting with different geometries to see if they can change the magnitude and even the polarity of the Casimir effect between two shaped metal objects, with the intention of finding out how to control and use the effect. Further, if you use anisotropic materials, such as optically polarised plates, you can turn the force into a torque. Again, the effect is very small and difficult to measure. However, if this can be controlled, it could have interesting space-related applications, such as in muon-catalysed cold fusion – for details, see his paper in Nature (Vol. 570, pp.45-51, 2019).



Jeremy Munday on
Engineering Quantum Vacuum Fluctuations



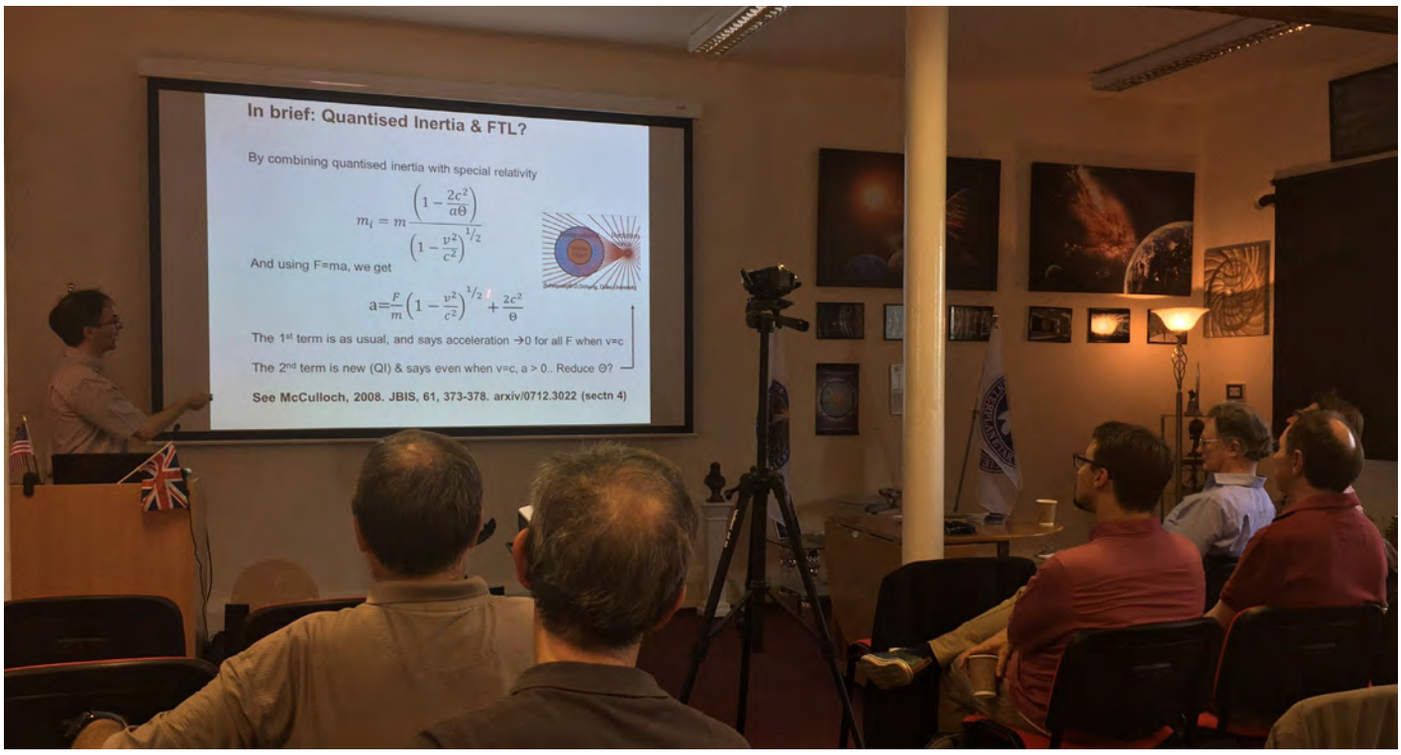
Sonny White explains his Casimir work in *Dynamic Vacuum Model and Casimir cavity experiments*

Harold 'Sonny' White of NASA presented on *Dynamic Vacuum Model and Casimir cavity experiments*.

Sonny described the 'pilot wave' interpretation of quantum mechanics, and discussed the mathematical formalism behind this approach. He showed how this could be applied to a hydrogen atom and a hydrogen molecule, getting results which agreed with experiment to within 1 %. He explained that he was now exploring the implications for a radioisotope decay experiment, and noted the potential analogy between this model and some aspects of the Casimir effect described by the previous speaker.

Following coffee, **Professor Heidi Fearn** from California State University, Fullerton, spoke about *Advances in Mach Effect Gravitational Assist (MEGA) Drive Experimentation*. She explained that they were working, courtesy of NASA Institute for Advanced Concepts (NIAC) phase I and II funding, on experiments to create a force on the basis of Mach's principle on the origin of inertia. They have built a small test rig – the MEGA drive – to try to measure the small force they have predicted. Heidi explained how you could derive the effect from the equations of General Relativity, and then presented their results and discussed the many suggestions they have received for ways in which to reduce potential sources of experimental error. They are continuing to refine their experiment with the aim of increasing the size of the force created by the MEGA drive.

Professor Heidi Fearn explains her torsion balance pendulum

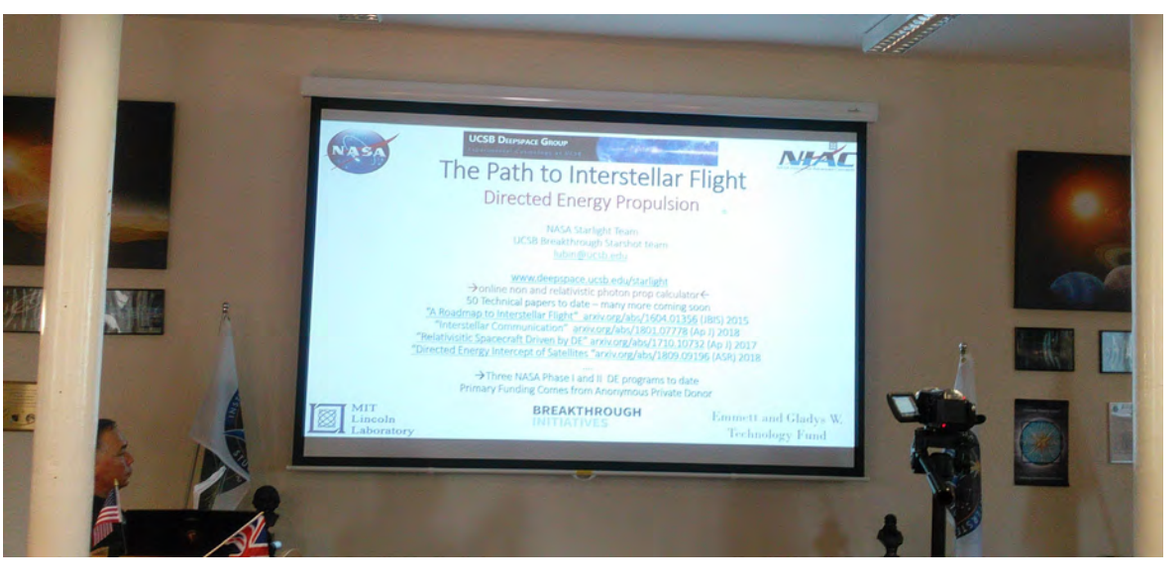


Mike McCulloch on quantised inertia and FTL

Dr Mike McCulloch of Plymouth University (UK) presented on *Quantised inertia, propellant-less thrust and interstellar travel*. Mike presented his theory of quantised inertia, which proposes that inertia is caused by interactions between accelerating objects and distant horizons caused by two effects: an information boundary to one side which generates so-called 'Unruh' radiation, and the quantised nature of reality (as discussed earlier in relation to the Casimir effect). Mike showed how his theory can explain the energy that's been ascribed to dark matter, as well as various other anomalies such as the Emdrive and the Mach effect. He explained that if his theory is correct, it could be used to get to Alpha Centauri in just ten years, although the Emdrive that did this would need 29 GW to produce the required thrust. Mike has recruited a team to test this experimentally.

Philip Lubin of the University of California, Santa Barbara, presented via video on *Directed Energy Propulsion – the path to interstellar flight*. He started by asserting that, in his view, if the interstellar research community wanted to be taken seriously by the wider space research community, it needed to be careful to put forward serious, testable, verifiable and transparent propositions that were evolutionary, as well as revolutionary, evolving our capabilities in a realistic, staged manner. We needed to produce technologies which also had parallel, non-interstellar, uses if we wanted to attract serious funding. And we need a long-term, dedicated programme to achieve all this. That was the

Sonny White listens to Philip Lubin on video from UCSB



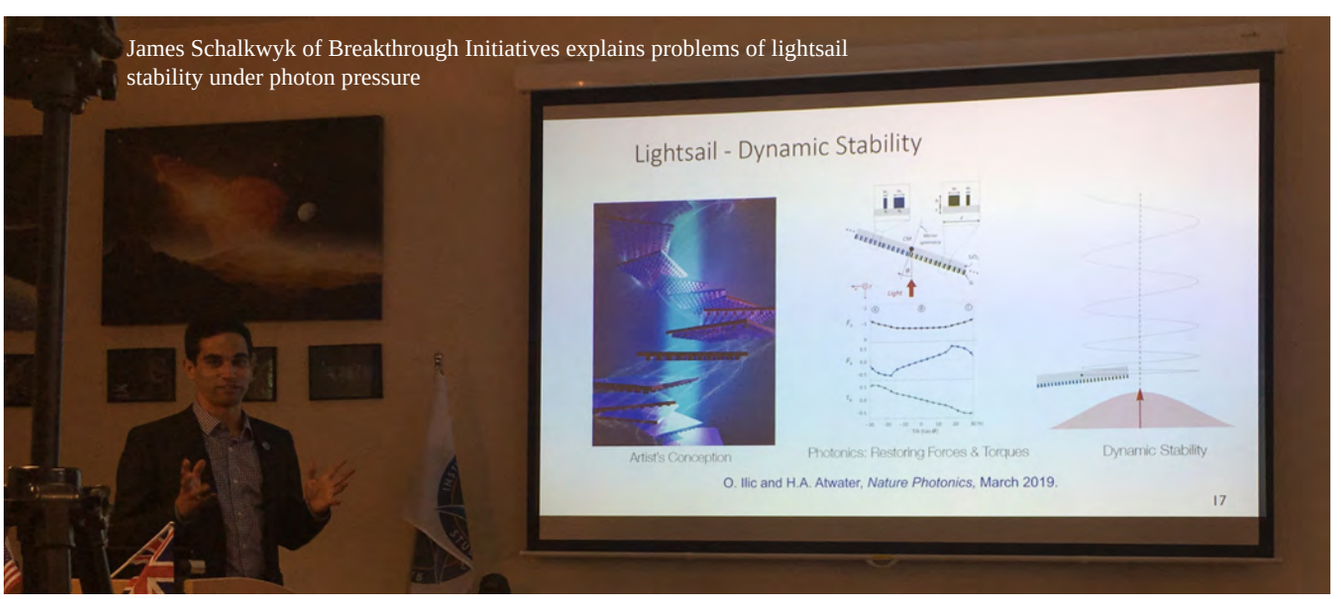
reasoning behind his roadmap to interstellar flight, recently published in JBIS (Vol.69, pp.40-72, 2016).

Turning to the main topic of his presentation, Phil noted that chemical propulsion was clearly not up to the task of travel at relativistic speeds, while nuclear power encounters difficulties getting above 10 % of light speed due to low yield. He was therefore focusing instead on directed energy propulsion (eg laser sails) as well as indirect energy propulsion (eg ion engines powered by photon-electric conversion). He proposed a parallel system of laser sources, as opposed to one large one. This did not only have to be about gram-scale probes – Phil also showed the calculations applicable to a 1 kg and 100 kg probe. Given that slowing such probes down at the destination would be very difficult, Phil proposed instead that you send hundreds of probes, separated in time, and build up your data from hundreds of flybys following one after another. After showing some of their experimental equipment, Phil concluded by noting that he was not personally keen on manned missions, as humans were very high maintenance. He suggested that if we wanted to investigate the effects of interstellar flight on living creatures, we might instead send tardigrades, as they can easily be put into suspended animation for the entire trip, and equally easily revived at the other end.

Day 4, Sunday 30 June: Session Three, 'Building Architectural Megastructures'

The Chairman for the final day of the workshop was FISW Co-Chair **Kelvin F Long**.

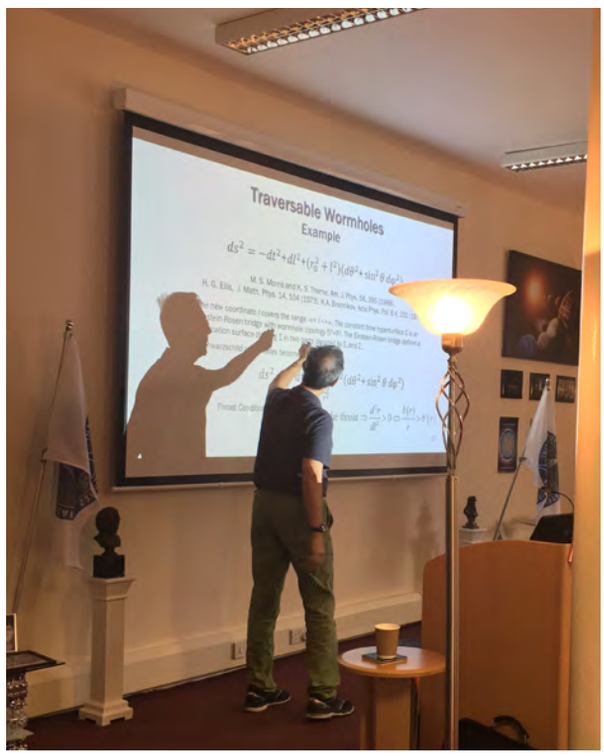
Following a brief introduction from Kelvin, the day opened with a talk from **James Schalkwyk** of Breakthrough Initiatives, who spoke about *Building Breakthrough Starshot*. James summarised the various projects being undertaken by the Breakthrough Initiatives, then focused in on Breakthrough Starshot's plans for sending a gram-scale spacecraft to a habitable exoplanet within five parsecs of Earth, at 20 % of the speed of light, within thirty years. The ideal rocket equation makes this very challenging for any form of spacecraft carrying its own fuel, so they are focused on solutions involving solar or laser sails. Given the high speed required, they are looking for a low mass, miniature spacecraft – and to illustrate this, James handed round a roughly half centimetre square example of the ChipSat design. James discussed the huge diversity of length scales across the project, from the 100 nanometre scale of the sail surface's nanostructure, right up to the 4 x 10^{15} metre scale of the distance to Alpha Centauri – a variation of 22 orders of magnitude! He noted that one of the major challenges was stabilising the sail in the laser beam during the acceleration phase; this was something they were hoping to address using holograms on the sail surface. (A poster discussing this idea had been presented on Friday evening by C Bangs.) A key project requirement is scalability, both in terms of the hardware itself, and the cost of producing it. To meet their requirements, they need to reduce the cost of the laser (price per watt) by four orders of magnitude, and the cost of the optics by three orders of magnitude. For the optics, this may involve accepting slightly lower optical quality in manufacture, and correcting for this digitally in real time. If they can achieve a truly scalable solution, then creating genuine architectural megastructures could follow in future, in order to send heavier payloads and/or achieve higher probe velocities – but only once they've achieved their central goal.



James Schalkwyk of Breakthrough Initiatives explains problems of lightsail stability under photon pressure

Following coffee, **Remo Garattini** of Bergamo University, Italy, talked about *Casimir traversable wormholes*. He started with an introduction to the history of wormhole studies, which started in 1916 with a wormhole identified by Flamm as a solution to Einstein's Field Equations of General Relativity. Einstein and Rosen generalised this in 1935, coupling General Relativity and Electromagnetism, and creating what is now called the Einstein-Rosen bridge. John Wheeler did more work on this in 1962, showing that if such a wormhole were created, it would be non-traversable – ie its throat would close before anything could travel through, thus preserving causality. In 1988, Kip Thorne demonstrated that you could 'steal' a wormhole from the quantum foam using the Casimir effect, and make it stable. Remo demonstrated this mathematically, before concluding that a traversable wormhole is currently 'completely useless' as it's too small to use. However, there may perhaps be some way to amplify it in future.

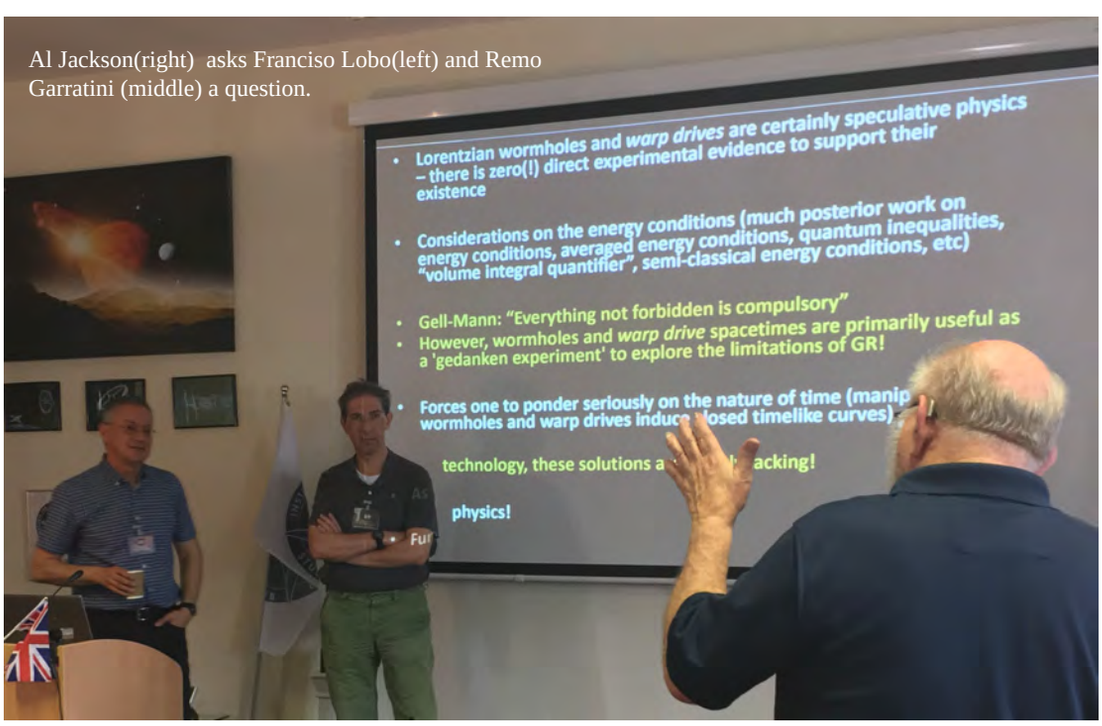
Remo Garattini shows a mathematical example of a traversable wormhole solution



Francisco Lobo of the University of Lisbon followed this up with *Wormholes, warp drives and interstellar travel*. Francisco's starting point was to ask not what is currently feasible, or what might be feasible in a few decades, but what the laws of physics allow to happen. Starting from Einstein's Field Equations of General Relativity, Francisco discussed the mathematics of wormholes, showing as he said that 'Physics is geometry'. He then noted how the physics of wormholes had been adopted in the 2014 Hollywood blockbuster 'Interstellar', which used Kip Thorne as a consultant and was thus pretty accurate. Francisco briefly moved on to the physics of warp drives, summarising Alcubierre's work, but noting Krasnikov's conclusion in 1998 that an Alcubierre warp bubble can neither be created nor controlled by a member of the starship's crew, making it of limited practical value. He concluded with a few words on the possibility of time travel along closed time-like curves.

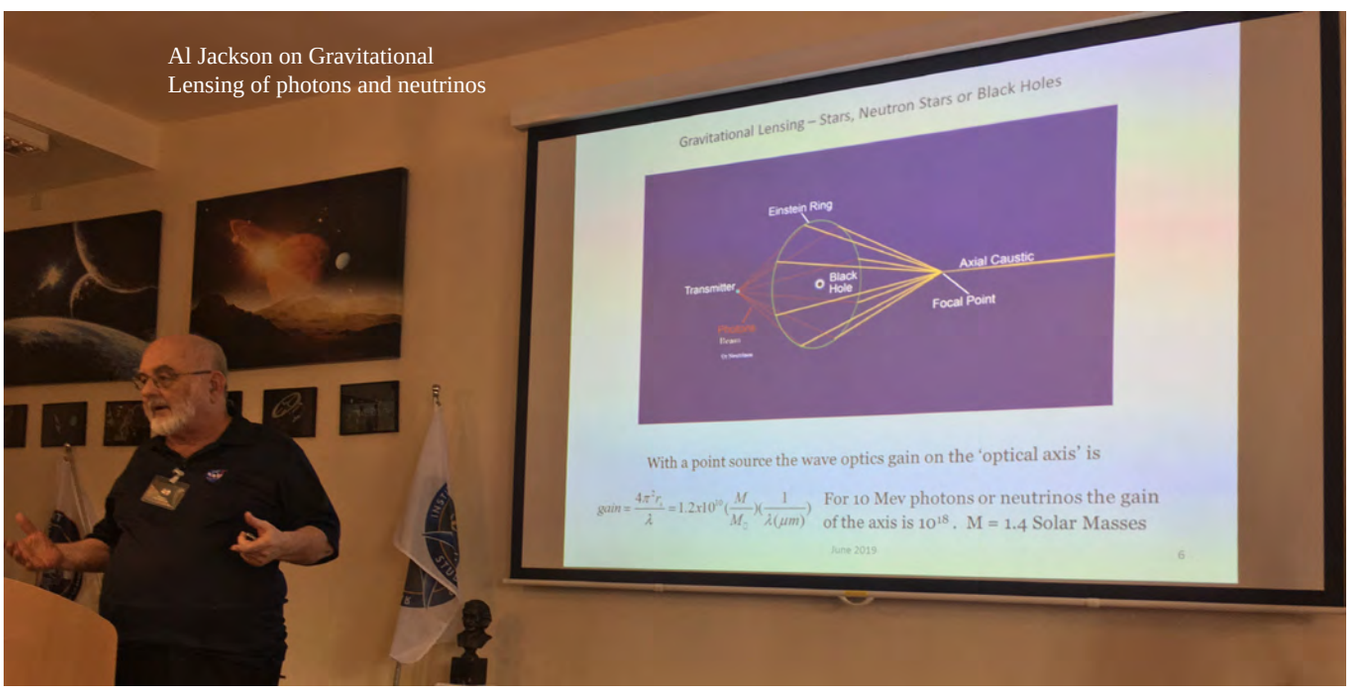
A question and answer session followed, featuring **Remo Garattini and Francisco Lobo**.

Al Jackson(right) asks Franciso Lobo(left) and Remo Garratini (middle) a question.

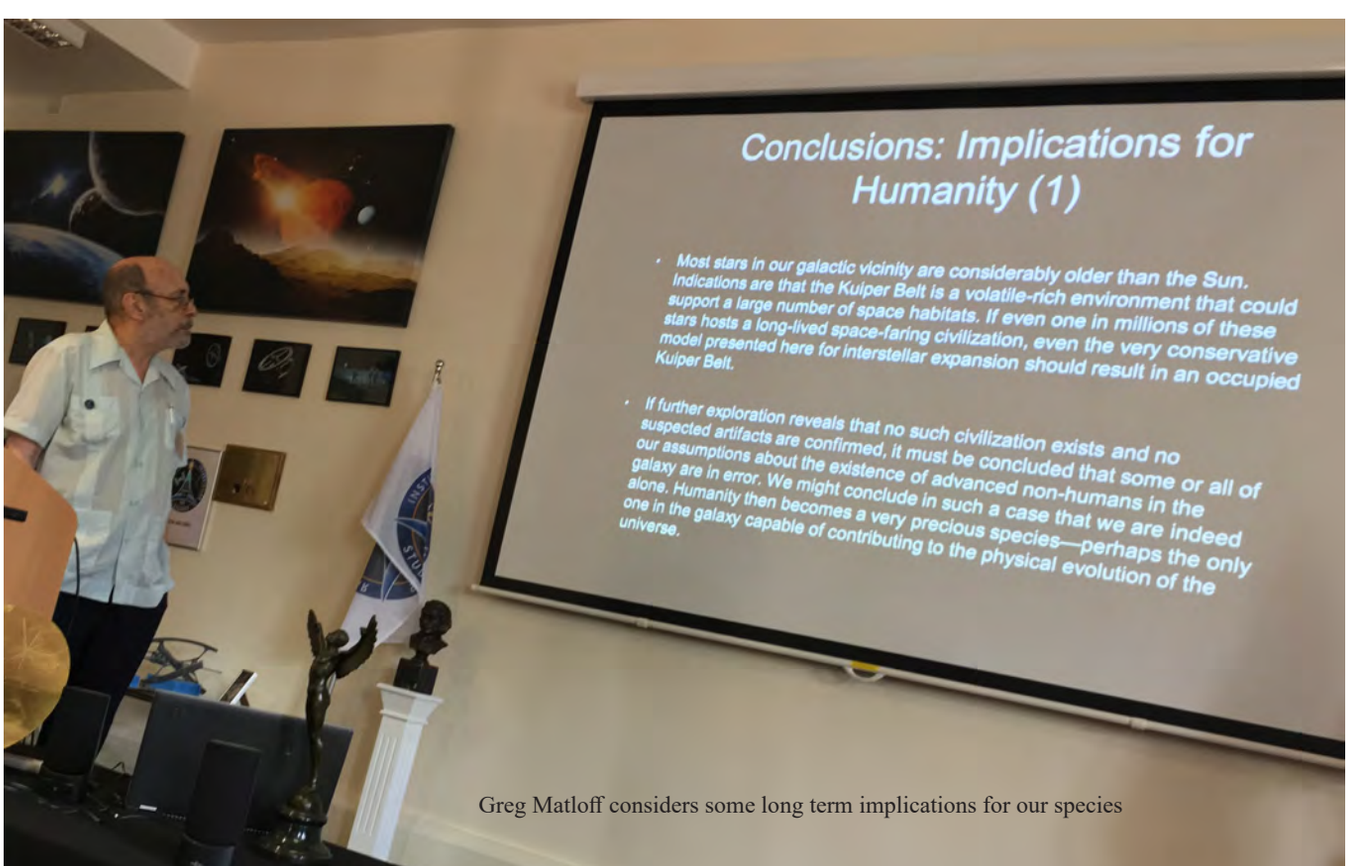


Al Jackson of Triton Systems presented on *Neutrino Beacons for Interstellar Communications*. Al proposed that an advanced civilisation might choose to use beamed neutrinos, focused by a gravitational lens, as their means of interstellar communication, the advantage being that neutrinos are not easily extinguished by contact with matter, so will be able to communicate over extremely long distances. The lens would be a black hole or neutron star, and this could amplify the signal significantly. Even so, the signal strength would be very weak, so it is likely that the civilisation would build a Dyson swarm of transmitters orbiting a neutron star, which would boost the signal significantly. This implies that such a mode of communications will only be available to a Kardashev Type II civilisation.

Professor Greg Matloff of the City University of New York asked, *Is the Kuiper Belt inhabited?* Greg reminded the audience of the Fermi Paradox, but then noted that if intelligent aliens had encountered our solar system, they would get to the Kuiper Belt before they got anywhere near the



Al Jackson on Gravitational Lensing of photons and neutrinos



Greg Matloff considers some long term implications for our species

planets. And the Kuiper Belt is resource rich, so might they have chosen to settle there, rather than come to visit Earth? Our biosphere might well be poisonous to them anyway, given that although there are around 230 amino acids in all, life on Earth only uses around 10 % of them, so the likelihood of a perfect overlap with alien biology is small. Greg also noted that recent observations by ESA's Gaia space observatory suggest that our solar system is approached to within around one light year by another Sun-like star roughly every million years. Given this, might a suitably advanced and long-lived race of extraterrestrials wait until the next close approach before 'hopping across' to the neighbouring star system? Greg pointed out that if such a civilisation did this, and thus doubled the number of star systems they had visited every million years, they would be in more than one billion star systems after thirty million years. In the light of this, Greg suggested that it would be worth surveying the Kuiper Belt in the infrared and visible wavelengths, looking for emissions from a functioning alien outpost, or for unusual Kuiper Belt Objects that might represent the remnant megastructures left behind by aliens. In this regard, Greg mentioned three anomalies we are already aware of: Saturn's moon Methone, which looks almost exactly like an egg; Ultima Thule, whose two lobes are strangely flat; and the interstellar asteroid Oumuamua, which is long and thin and has also, unexpectedly, been speeding up as it leaves the solar system. Greg concluded by noting that if we do explore the Kuiper Belt, but find no evidence of past or present extraterrestrial visitation, this would also be an important result, as it would strengthen the argument that we truly are alone.

There followed a discussion session on megastructures, SETI and interstellar communications, involving **Al Jackson, Greg Matloff** and **James Schalkwyk**.

Greg Matloff responds to Kelvin Long, Al Jackson and James Schalkwyk on the left

Kelvin F Long brought the workshop to a conclusion at one o'clock, with a round of thanks to all those who had organised the event or helped to run it. He wished all participants a safe journey home, and looked forward to further such workshops happening again in future.

FISW 2019

This was a convivial as well as an intellectually stimulating workshop. Before the lunch break on the Saturday, a group photograph was taken of all workshop participants, standing on the steps of the Bone Mill. After the formal programme on the same day concluded, workshop participants reassembled at The Swan Hotel in nearby Wotton-under-Edge for a three course dinner, concluding with an extremely entertaining after-dinner speech from **Greg Matloff**.

The BIS monthly Spaceflight has also reported on FISW 2019. Stephen Ashworth's report, *Above & Beyond*, was in SpaceFlight Vol 61 September 2019, already published!

The workshop on a sunny Saturday in June.
front row: Sonny White, John Davies (hat), Rob Swinney, Kelvin F Long, Richard J Soilleux, Greg Matloff, Samar AbdelFattah
Credit: Rob Swinney

Greg Matloff delivers the after dinner speech
Credit: Rob Swinney

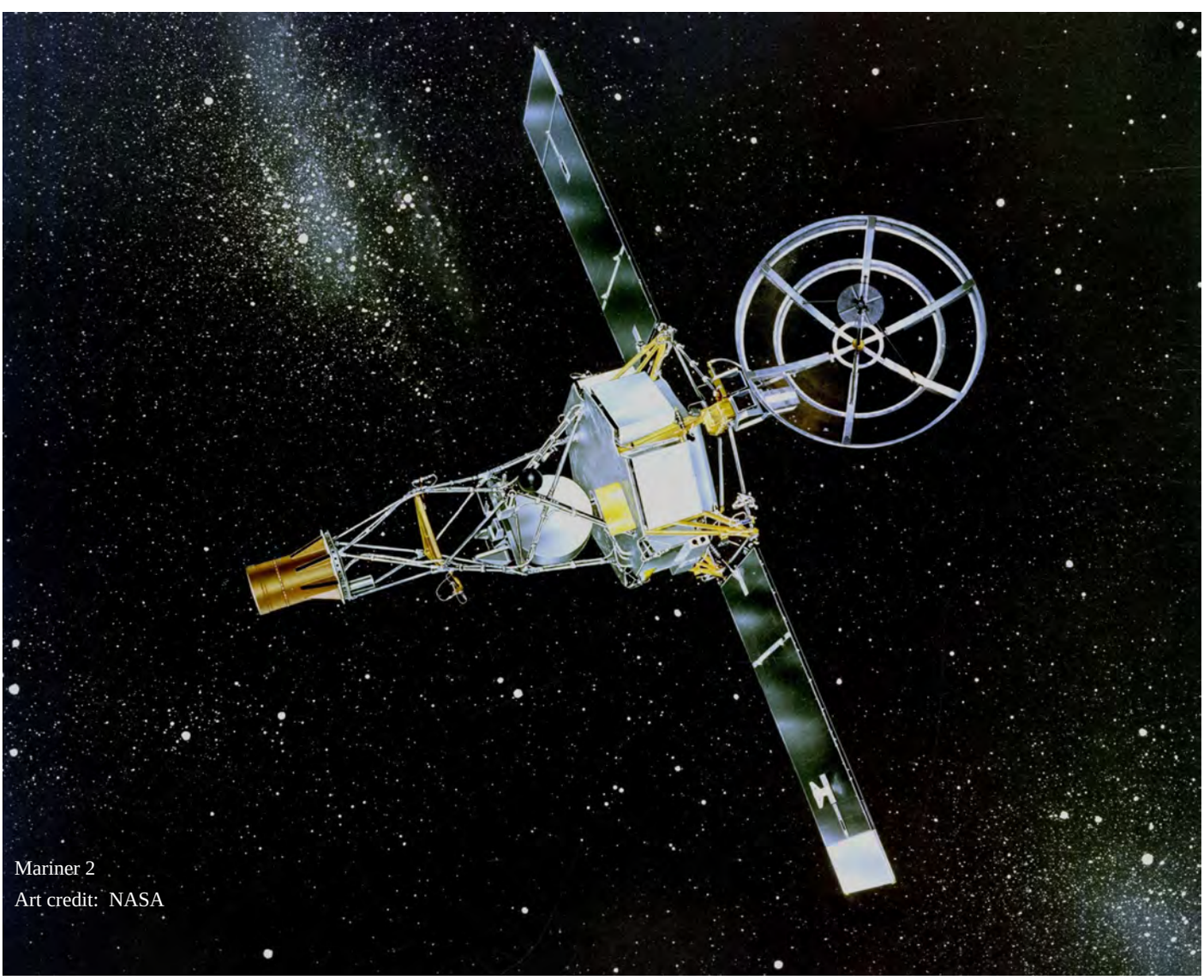
Mariner 2 spacecraft model - part 1: The research phase

Terry Regan

Terry Regan is the lead modelmaker in i4is. He has also designed and built the Daedalus model you will find at the British Interplanetary Society HQ in London and the 4 metre high 2001 monolith he built (with a little help from John Davies and rather more from Paul Campbell) which was our centrepiece at the last World SF Convention held in London in 2014. Here he reminisces about the vital research he does for all his projects – and in this case, for the Mariner 2 spacecraft which went to Venus in 1962.

I have had an interest in this little robotic probe for quite a while now as it's the first man-made spacecraft to successfully visit another planet. The start of deep space exploration, leading the way for other spacecraft to visit the inner and the outer planets and to the Voyagers leaving the solar system and, hot on their heels, New Horizons. One day, i4is may even send our Andromeda probe out to the nearest stars! So I thought Mariner 2 would make a good subject for a scratch build model.

As with all my model projects I start by researching the subject and I also need plans of the spacecraft. So my first port-of-call was the internet and I came across a web site called Historic Spacecraft where



Mariner 2
Art credit: NASA

I found four clear photos of a full size replica of Mariner 2 so I downloaded the photos. Next step was to pop into the British Interplanetary Society library. They were very helpful, but I didn't find much of direct relevance, and above all I couldn't find any plans! But I was given some contact details at NASA, JPL, NASA archive department and the Smithsonian Museum and also a contact at the Science Museum London so emails were sent out.

I got replies from all the contacts from the US but they couldn't help me and in one email they said that the engineering drawings may have been lost or destroyed as it would be an old spacecraft and would be of limited interest now. I got a reply from the Science Museum and they informed me that they have a research department and it's free to use – "Fantastic!" I emailed them with the information I am after and got a reply a week later, saying yes we may have the information you require, however it's in a large hangar on an airfield in Swindon! But can be brought up to the research department so I made an appointment. I spent two days there sifting through loads of documents and did find some plans but they weren't of huge use to me.

I had now spent several months researching on Mariner 2 and one evening I was on the internet where

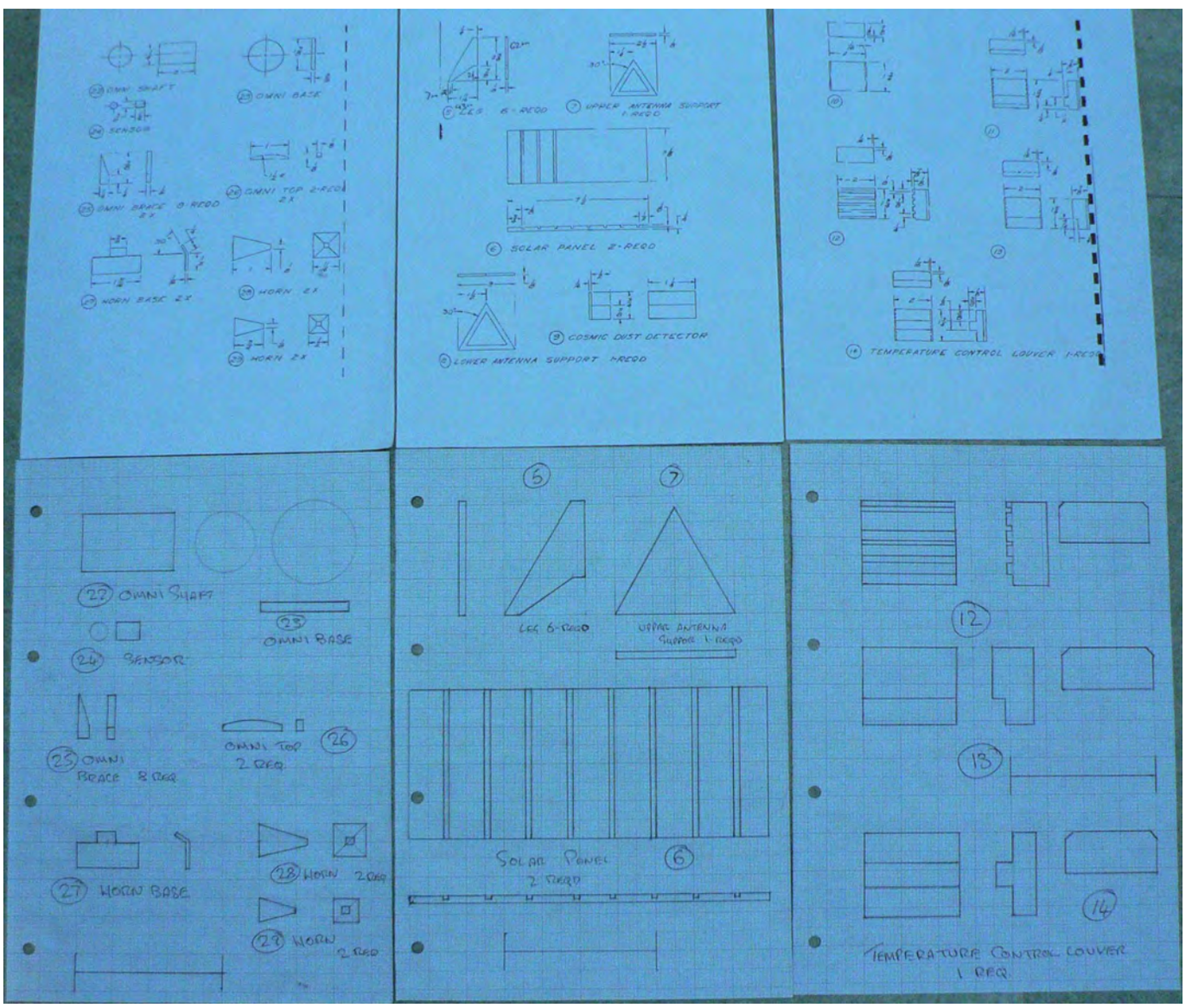


Figure 1: Terry came across 11 pages of hand-drawn plans of Mariner 2 on the web with all the components. Here are six of them. The top three are the original plans/drawings and the bottom three are his re-drawings on graph paper showing how the drawings scale up using the measurements in the originals.

Credit: Unknown - please get in touch with Terry <terry.regan@i4is.org> or the editor <principum@i4is.org> to identify or claim.

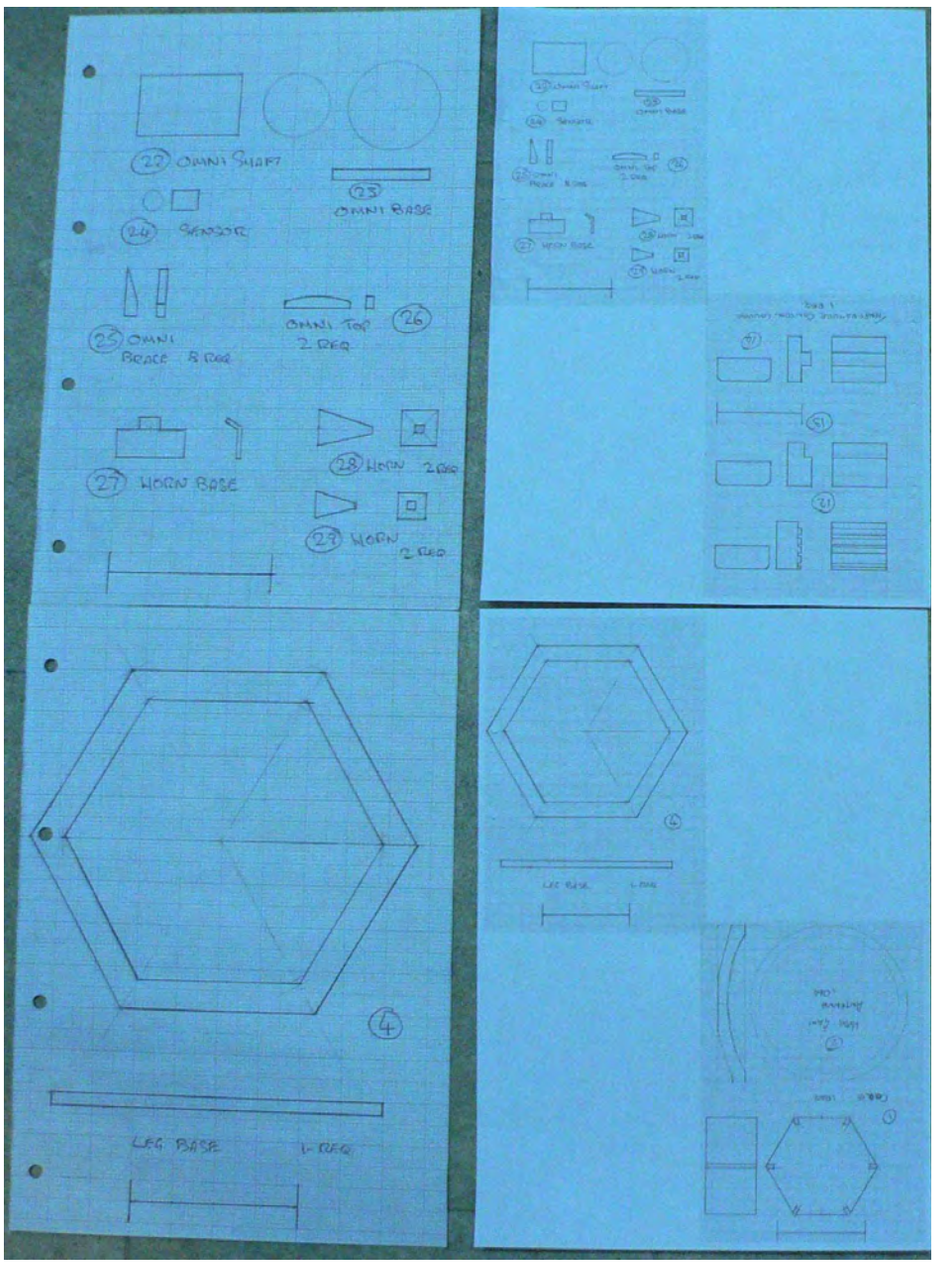


Figure 2: Here Terry shows how the two sheets on the right scale down from originals laid out on graph paper, as in the examples on the left and in Figure 1.

Credit: Unknown - please get in touch with Terry <terry.regan@i4is.org> or the editor <principum@i4is.org> to identify or claim.

I stumbled across 11 pages of hand-drawn plans of Mariner 2 with all the components, but all the measurements were in imperial rather than metric. I think these were drawn up to make a museum model and so it would be too big for my collection. As the drawings are not to scale I had to redraw all the parts on graph paper then reduce those 50 % to make a desktop model. I also came across a set of detailed photos of a broken model of Mariner 2 belonging to the Smithsonian Museum so downloaded the photos. This model didn't have much detail on it. A couple of months later I came across a set of highly detailed photos of a full size replica of Mariner 2 again. I think it belongs to the Smithsonian Museum. I forwarded all the photos to my cousin Paul, who is a professional engineering photographer.

I now had all the information required to build a detailed model of Mariner 2. In part two I will talk a little about the history of Mariner 2 and describe, step by step, the build of the model. On a last note, I have been contacted by the Scottish Dark Sky Observatory, asking me to make them a model of Mariner 2 – so now I have two to build!

JOIN I4IS ON A JOURNEY TO THE STARS!

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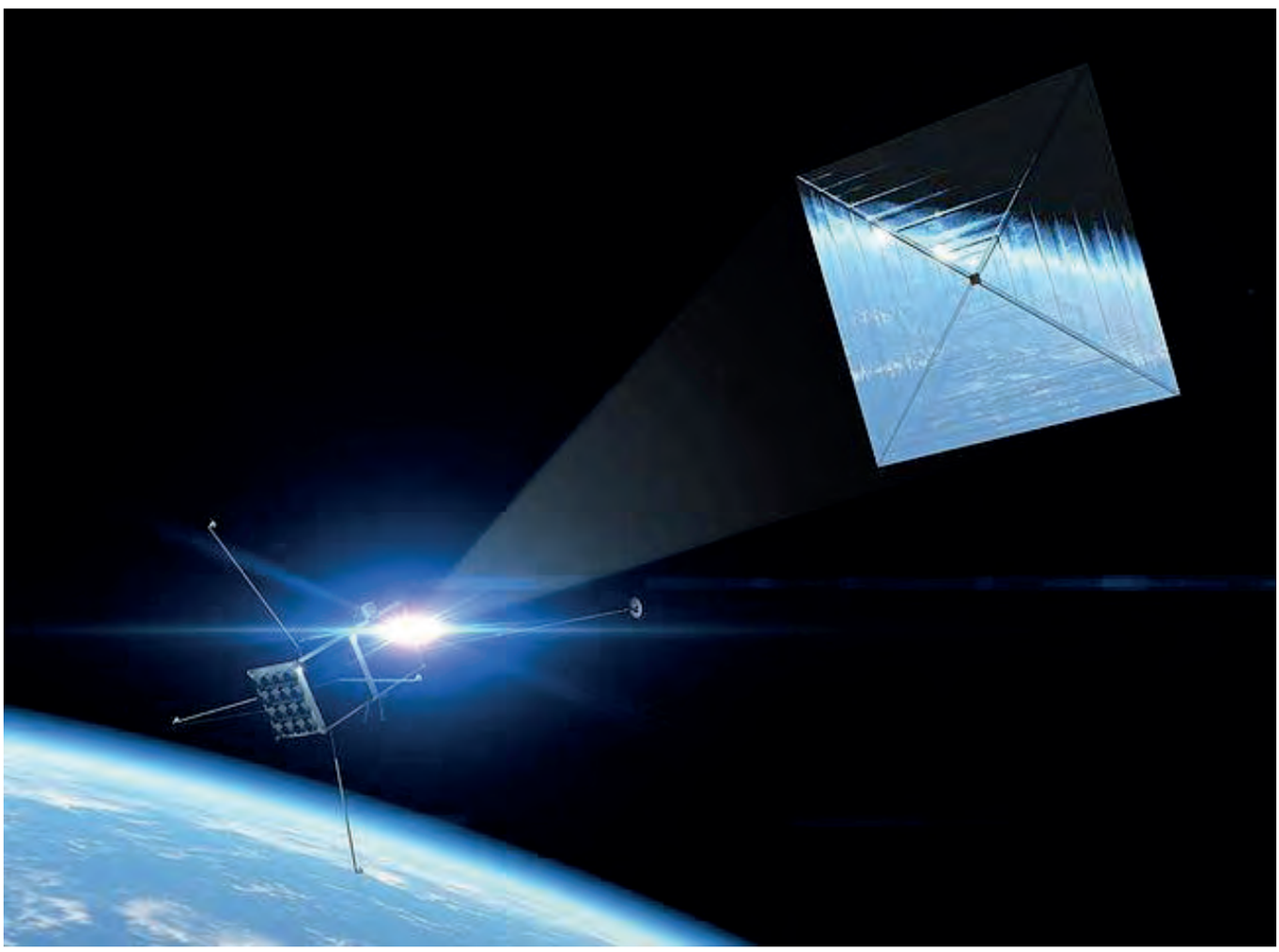
Would you like to help drive the research needed for an interstellar future...
... and get the interstellar message to all humanity?



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- conducts theoretical and experimental research and development projects; and
- supports interstellar education and research in schools and universities.

Join us and get:

- member exclusive posts, videos and advice;
- free or discounted publications, merchandise and events;
- advanced booking for special HQ events; and
- opportunities to contribute directly to our work.

To find out more, see www.i4is.org/membership

Interstellar News

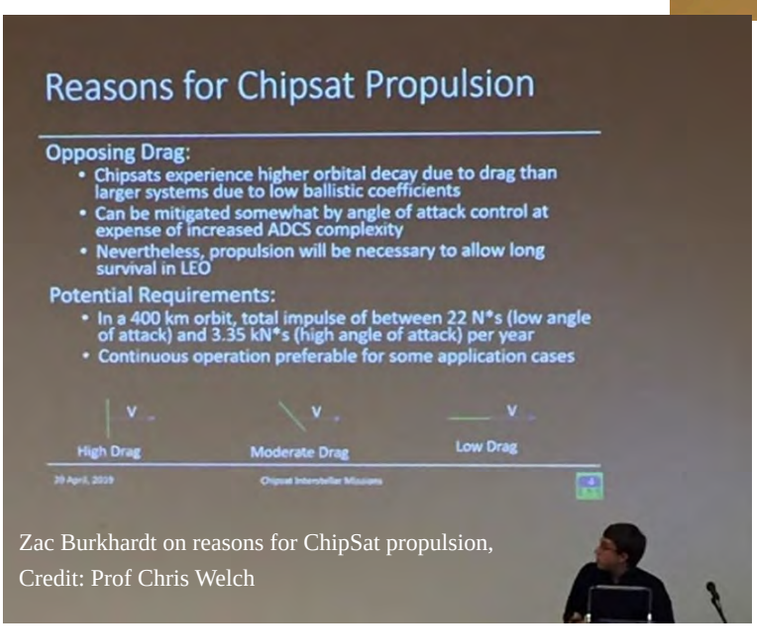
Patrick J Mahon and John I Davies report on recent developments in interstellar studies

ISU ChipSat elective

i4is has been delivering elective course items at the International Space University, Strasbourg, for many years. This year we delivered the ISU #MSS19 ChipSat Spacecraft and Mission Design elective. Lead by i4is Executive Director Andreas Hein this was in association with key ChipSat people including Mason Peck (Cornell University), Zac Manchester (Stanford University), Brett Streetman (Draper Labs). Former ISU student Zac Burkhardt demonstrated his exceptional analytical skills, looking into ChipSat applications and propulsion. And Breakthrough Starshot was also involved with the participation of James Schalkwyk of Breakthrough Initiatives.

Andreas Hein, i4is Exec Director, on a ChipSat mockup,

Credit: Prof Chris Welch



Zac Burkhardt on reasons for ChipSat propulsion,

Credit: Prof Chris Welch

Jodrell Bank becomes UNESCO World Heritage Site

On 7 July, the Jodrell Bank radio observatory in Cheshire, UK, part of the University of Manchester, was awarded World Heritage Site status by the United Nations Educational, Scientific and Cultural Organisation (UNESCO), in recognition of its tremendous scientific endeavours since its creation in 1945 and its role in achieving a transformational understanding of the Universe. The award places Jodrell Bank on an equal footing with such icons of world history as Stonehenge, the Great Wall of China and the Taj Mahal.

i4is editor John Davies recalls being

The Mark 1 Lovell telescope

Credit: Jodrell Bank

taken to see it as a child in the late 1950s. A recent visit showed the 250 foot dish is still an eye-popping piece of ironmongery. It's built partly out of old bits of battleship and was conceived by Bernard Lovell and his University of Manchester team. It first hit the headlines when Sputnik 1 bleeped past overhead. If you haven't yet visited the UK and you want to see some "serious iron" then the old Mark 1, as it used to be called, and the Forth Bridge are the things to see! Our i4is Deputy Director Rob Swinney did the first of his two Masters degrees there and remembers a retired Sir Bernard, as he had then become, dropping in occasionally.

at the Royal Institution a Tsiolkovsky balloon experiment - team timer and balloon wranglers

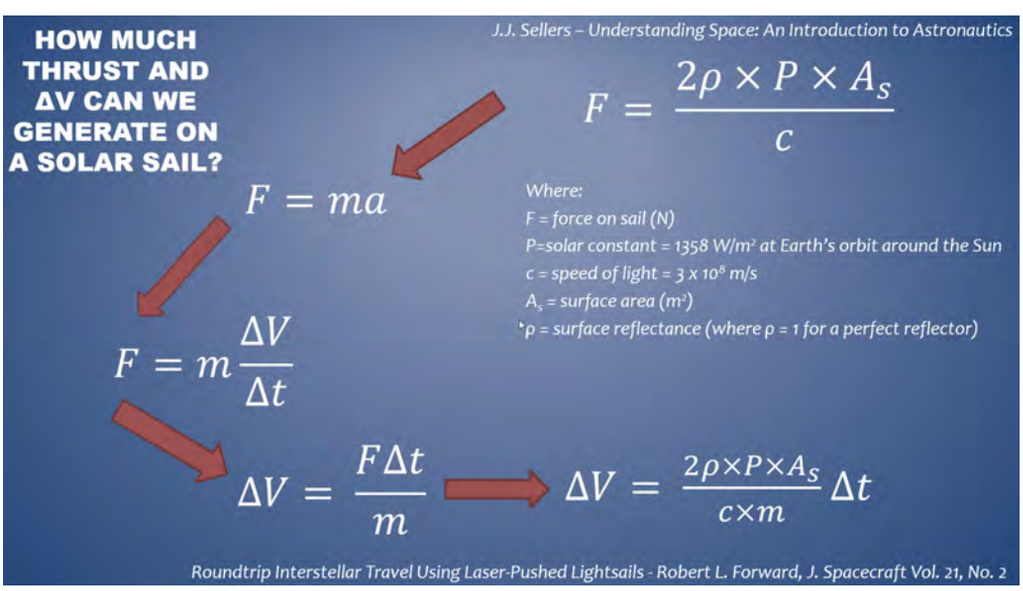
Credit: Rob Swinney

i4is at the Royal Institution - 2019

For the second successive year i4is was invited to take part at the Summer Schools of the Royal Institution of Great Britain. This time we delivered not only to a 13-15 age group as last year but also to a 16-18 group. Satinder Shergill and John Davies delivered Skateboards to Starships and we were again joined by Rob Matheson. We were also proud to have i4is Deputy Director and head of education Rob Swinney. Work commitments mean that Terry Regan could not join us. As before we had very engaged students and excellent support from the RI team.

Satinder explains a point to a very engaged student Credit: Rob Swinney

We would love to run these or similar events at schools and colleges in the UK or worldwide. Please contact John I Davies <john.davies@i4is.org> to discuss.



at the Royal Institution - the elementary photon sail challenge

at the Royal Institution - John explains Omega, the hydrogen bomb rocket idea from Freeman Dyson
Credit: Rob Swinney

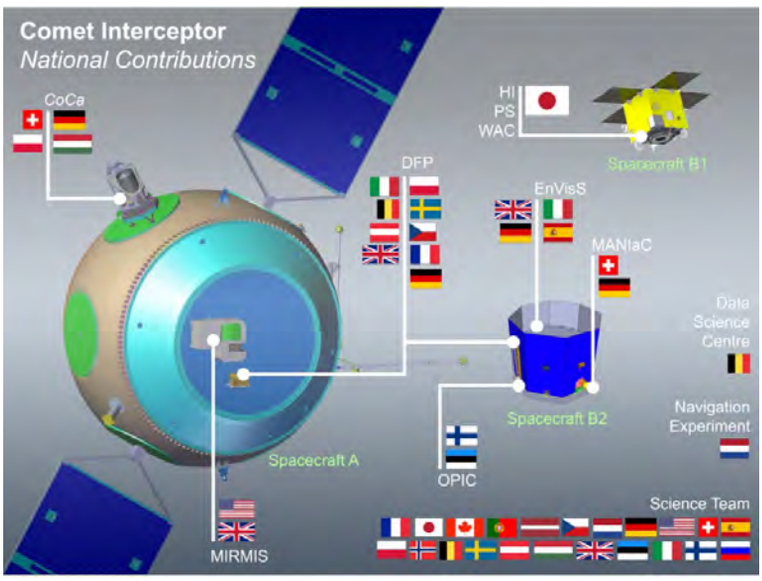
at the Royal Institution - The i4is team - Satinder Shergill, Rob Matheson, John Davies and Rob Swinney
Credit: Rob Swinney

LightSail 2 demonstrates propulsion method for cubesats

On 31 July, the Planetary Society announced that LightSail 2, launched on 25 June, had successfully raised its orbit using only the power of light. This is the first on-orbit demonstration of using a solar sail for propulsion, at a size and scale suitable for cubesats www.planetary.org/explore/projects/lightsail-solar-sailing/.

Solar sails use the tiny momentum carried by solar photons to propel a spacecraft. They have been studied for decades, but have a mixed history experimentally. In 2005, the Planetary Society launched Cosmos-1 on a Russian rocket. Unfortunately, the launch vehicle did not achieve orbit and the world's first solar sail was lost. In 2010, the Japanese Space Agency JAXA successfully launched IKAROS, a 200 square metre solar sail which performed a successful fly-by of Venus. Because the LightSail 2 solar sail is six times smaller in area (at 32 square metres), and the spacecraft is one-sixtieth the weight of Ikaros (at 5 kg), it is compact enough to be suitable for providing on-orbit propulsion for a cubesat.

LightSail 2 is currently in a 720 kilometre high orbit. It is expected to stay in orbit for around a year, before atmospheric drag pulls it down sufficiently to re-enter the atmosphere and burn up.



Comet Interceptor - National Contributions
Credit: ESA

ESA to develop a spacecraft to visit a pristine comet – or future interstellar visitor

On 19 June, the European Space Agency announced that it had selected, as the first of its new 'fast-development' class of missions, the 'Comet Interceptor'. Comprised of three spacecraft which will be launched to the Earth-Sun L2 Lagrange point, some 1.5 million kilometres away from the Earth in the direction opposite the Sun, the idea is that the probes will wait there until a suitable target is detected – a pristine comet, or an interstellar object like Oumuamua, entering the solar system for the first time. They will then travel to their target and the probes will observe the object from three different perspectives, enabling a 3D profile of the object to be obtained.

While NASA and ESA have both sent probes to comets before, the targets have previously always been short period comets which have visited the solar system on multiple previous occasions, their nature and composition being changed as a result. Comet Interceptor presents the first opportunity to investigate a pristine target. The €150 million, 1,000 kg spacecraft will be developed over the next eight years, ready for a launch opportunity in 2028. The engineering and science teams seem to represent most of the spacefaring nations.

Readers may recall our *News Feature: Oumuamua, Project Lyra and Interstellar Objects*, John Davies & Adam Hibberd, in Principium, Issue 24, February 2019 which described the mission. In the next issue there was a report of the Inaugural Lecture of Professor Geraint Jones, University College London, Mission Proposal Lead of the Comet Interceptor team in our *News Feature: All Comets Great and Small* in Principium, Issue 25, May 2019.

And our friends at Astronomy Now magazine have also featured the Comet Interceptor mission in the September issue (already out) *New mission to chase down a comet - The comet hunter* by editor Keith Cooper.

Recent interstellar papers in JBIS

The Journal of the British Interplanetary Society has been busy with matters interstellar since we last reported. Here are the papers we noticed.

BIS members can access JBIS both online and in old-fashioned print. And remember BIS members receive a 20 % discount on annual membership of i4is.

Three interstellar issues -

VOLUME 71 NO.12 DECEMBER 2018

General interstellar issue

SOLAR SYSTEM ESCAPE MISSION WITH SOLAR SAIL SPACECRAFT

within a framework of post-Newtonian Gravitational Theory

Olga L Starinova & Irina V Gorbunova

DO ALIEN CIVILISATIONS EXIST?

Derek Pugsley

HEAT TRANSFER IN FUSION STARSHIP

Radiation Shielding Systems

Michel Lamontagne

THE HALO DRIVE: FUEL-FREE RELATIVISTIC PROPULSION

of large masses via recycled boomerang photons

David Kipping

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VOLUME 72 NO.2 FEBRUARY 2019

General interstellar issue

DIRECT FUSION DRIVE

for Interstellar Exploration

S A Cohen et al.

INTERMEDIATE BEAMERS FOR STARSHOT:

Probes to the Sun’s Inner Gravity Focus

James Benford & Gregory Matloff

REALITY, THE BREAKTHROUGH INITIATIVES

and Prospects for Colonization of Space

Edd Wheeler

A GRAVITATIONAL WAVE TRANSMITTER

A.A. Jackson and Gregory Benford

CORRESPONDENCE

VOLUME 72 NO.4 APRIL 2019

General interstellar issue

POSITRON PROPULSION

for Interplanetary and Interstellar Travel

Ryan Weed et al.

SPACECRAFT WITH INTERSTELLAR MEDIUM MOMENTUM

EXCHANGE REACTIONS: the Potential and Limitations of

Propellantless Interstellar Travel

Drew Brisbin

ARTIFICIAL INTELLIGENCE

for Interstellar Travel

Andreas M Hein & Stephen Baxter

- and a drive proposal in a general issue -

VOLUME 72 NO.5 MAY 2019

General issue

A REACTION DRIVE

Powered by External Dynamic Pressure

Jeffrey K Greason

Kelvin F Long leaves i4is

i4is regret to announce that co-founder and former President and Executive Director, Kelvin F Long, resigned from the organisation in early August. He was Executive Director of i4is until October 2017. He served as President and board member until September 2018. The i4is Board regret Kelvin's decision but wish him well for the future with his new venture, the Interstellar Research Centre, looking at a broader range of questions about human existence in the Universe (interstellarresearchcentre.com). We are thankful to Kelvin for his many successful initiatives and founding support of i4is.

Closure of i4is Headquarters

The Initiative for Interstellar Studies (i4is) was delighted to host the second Foundations of Interstellar Studies Workshop (FISW II), between 27 and 30 June 2019 at The Bone Mill, its headquarters in Charfield, Gloucestershire, UK. The workshop was highly successful, with participants discussing many aspects of deep space and interstellar flight, from living in deep space through advanced propulsion concepts to the engineering of architectural megastructures.

FISW II will be the last event that i4is holds at The Bone Mill. While the wonderful nineteenth century building has served us well, we have encountered several challenges in making it into a viable headquarters for i4is. The most significant of these has been the high level of business rates levied by the local council, despite us being a not-for-profit organisation. Having been unsuccessful in our appeal against the council’s decision, we reluctantly came to the conclusion that we would have to close the HQ with effect from 1 July 2019.

The Mill in 2017
Credit: Kelvin Long

We have thoroughly enjoyed the nearly two years for which The Bone Mill has been i4is's headquarters, and we will take away many very positive memories of our time there. i4is will continue to operate exactly as it does now in all other respects.

News Feature:

Starship Congress 2019: "Bend Metal"

Andreas C Tziolas, co-founder and the President of Icarus Interstellar, introduces the imminent congress of Icarus Interstellar.

Icarus Interstellar will meet in San Diego Air and Space Museum on September 13-15th, 2019 to ask the question: "What is the Terrestrial Business Case for Interstellar-Grade Technologies?"

The meeting will bring together entrepreneurs, innovators, scientists and business groups to present ideas and create opportunities for how interstellar-class ideas can lead to marketable products and businesses today, on Earth, so we can develop those technologies we will need to BUILD A STARSHIP.

The focus of the workshop is to pair scientists with business developers and funders together to generate ideas and present paths for concept design, rapid prototype development, business incubation, marketing, sales, distribution, fundraising, automation, and industrialization - with a focus on the technologies that will create the interstellar industrial basis needed for sustained, long term human space exploration and inhabitation.

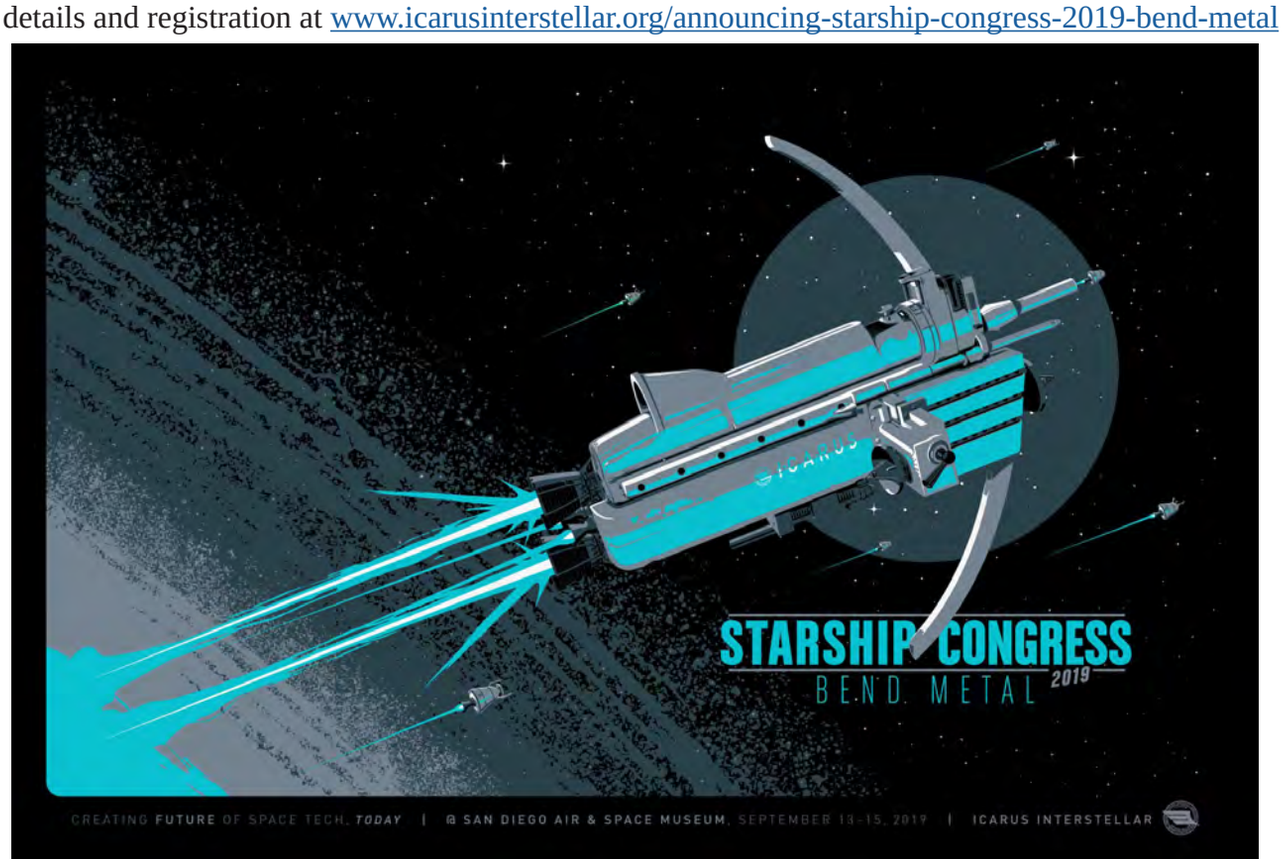
Interstellar-grade solutions for shielding, energy storage, interplanetary communications, food, sustainability, robotics, AI, and automation that have contemporary terrestrial applications, which can create quantum leaps in materials, technologies, processes, and services across Earth, which inevitably lead to a permanent "urban" human presence in space.

"Can we work backwards from technologies needed to BUILD A STARSHIP to fill current commercial market NEEDS, which will in turn sustain their growth into the future? "

Confirmed Keynote speakers of note for the event are:

- Planetary Society - discussing the incredible achievement with Lightsail 2
- Momentus: Space - discussing their orbit to orbit satellite delivery service solution
- US: Patent and Trademark Office - discussing the importance of IP protection and how it encourages investors and business growth.

Full details and registration at www.icarusinterstellar.org/announcing-starship-congress-2019-bend-metal

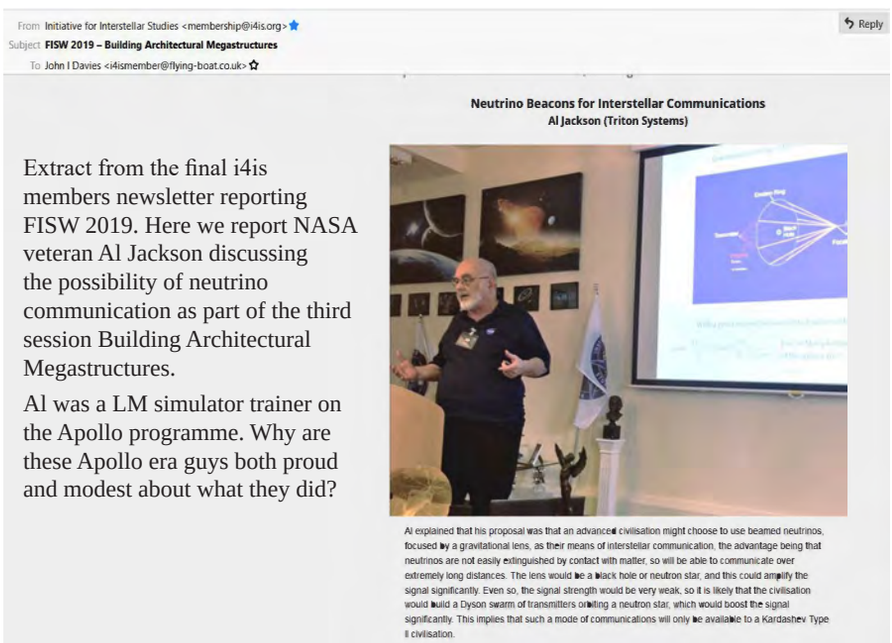


The i4is Members Page

The i4is membership scheme launched in December 2018 and we are now adding new members-only material to the website regularly. This page features currently available content and what is planned. Membership has always been about drawing together all who aspire to an interstellar future for humanity. Your contribution, together with the voluntary work of our team and their donation of their own expenses, helps us to take the vital early steps toward that goal.

Here's more of what we have. We'll keep you up to date as we add to this content in the next issue of Principium and in our members' email newsletter.

You need to login with your i4is identity to access members content. If you are not yet a member you can sign up via - i4is.org/membership - or simply find out more about membership.


From Initiative for Interstellar Studies <membership@i4is.org>
Subject FISW 2019 – Building Architectural Megastructures
To John I Davies <i4ismember@flying-boat.co.uk>
Reply

Neutrino Beacons for Interstellar Communications
Al Jackson (Triton Systems)

Al explained that his proposal was that an advanced civilisation might choose to use beamed neutrinos, focused by a gravitational lens, as their means of interstellar communication, the advantage being that neutrinos are not easily extinguished by contact with matter, so will be able to communicate over extremely long distances. The lens would be a black hole or neutron star, and this could amplify the signal significantly. Even so, the signal strength would be very weak, so it is likely that the civilisation would build a Dyson swarm of transmitters orbiting a neutron star, which would boost the signal significantly. This implies that such a mode of communications will only be available to a Kardashev Type II civilisation.

Extract from the final i4is members newsletter reporting FISW 2019. Here we report NASA veteran Al Jackson discussing the possibility of neutrino communication as part of the third session Building Architectural Megastructures.

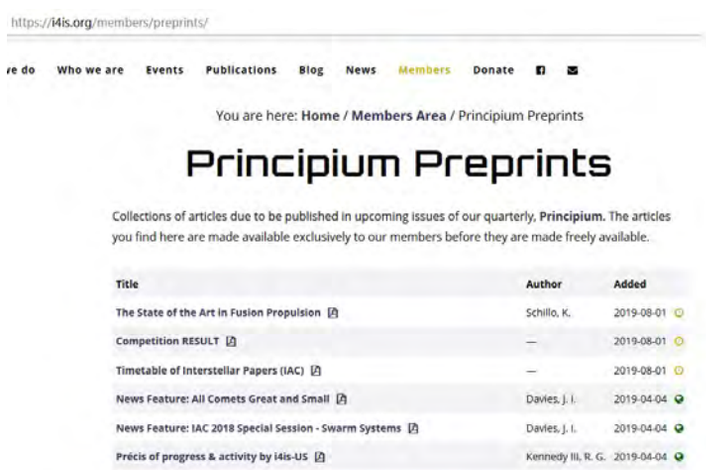
Al was a LM simulator trainer on the Apollo programme. Why are these Apollo era guys both proud and modest about what they did?

Members Newsletter

We have now sent out five exclusive email newsletters to members with the latest news of i4is and the whole interstellar endeavour. These arrive in your Inbox only when there is something really worth saying - we delivered three covering the FISW 2019 event at the end of June. Much more about it in the News Feature in this issue, page 4.

Principium preprints

Collections of articles due to be published in upcoming issues of our quarterly, Principium. The articles you find here are made available exclusively to our members before they are made freely available when Principium is published. These are late drafts so may not be exactly what appears in Principium (i4is.org/members/preprints/).


https://i4is.org/members/preprints/

re do Who we are Events Publications Blog News Members Donate

You are here: Home / Members Area / Principium Preprints

Principium Preprints

Collections of articles due to be published in upcoming issues of our quarterly, **Principium**. The articles you find here are made available exclusively to our members before they are made freely available.

Title	Author	Added
The State of the Art in Fusion Propulsion	Schillo, K.	2019-08-01
Competition RESULT	—	2019-08-01
Timetable of Interstellar Papers (IAC)	—	2019-08-01
News Feature: All Comets Great and Small	Davies, J. I.	2019-04-04
News Feature: IAC 2018 Special Session - Swarm Systems	Davies, J. I.	2019-04-04
Précis of progress & activity by i4is-US	Kennedy III, R. G.	2019-04-04

Videos

Videos of events we have held and other original material including -

- *Starship Engineer*, 6 videos of the 2016 (i4is.org/videos/starship-engineer)
- Project Dragonfly, 5 videos of the 2015 event (i4is.org/videos/project-dragonfly/) including presentations by the 6 finalist teams.
- Foundations of Interstellar Studies 2019 (FISW 2019). Videos of all the presentations will be available soon in the members section of the website.

Help us to grow!

Print the poster on the following page, on page 21 (white background) and a student poster on page 2. Tell your friends and colleagues and - if you have time - think about joining our team.

We need all your talents - it isn't all rocket science but requires time and the unique talents of our members.

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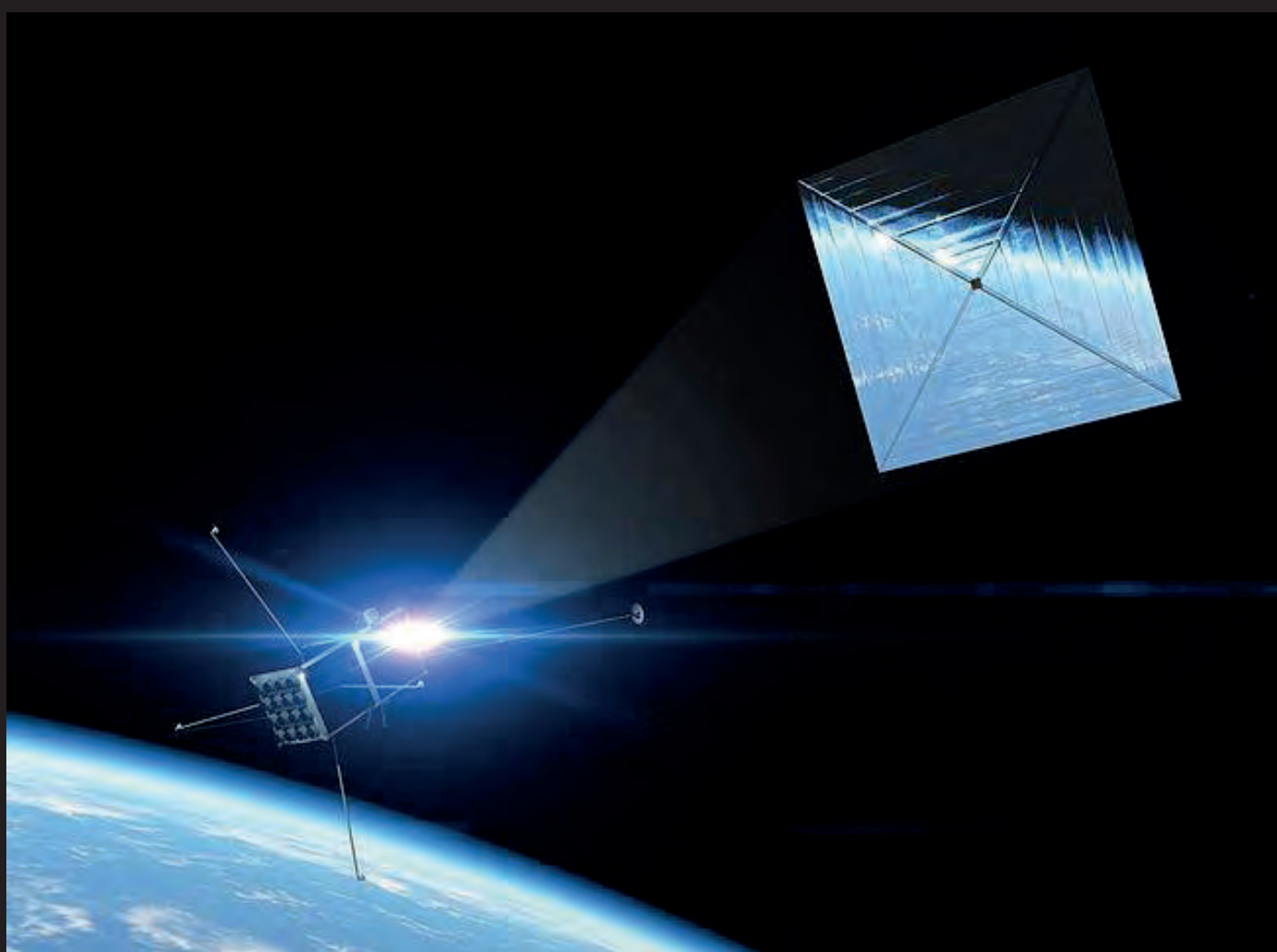

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- supports interstellar education and research in schools and universities.

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News Feature: Interstellar Workshop of the European Space Agency

Andreas M Hein reports from the European Space Research and Technology Centre (ESTEC) in Noordwijk, the Netherlands.

We know that NASA has funded research on interstellar travel for a long time. But how about the European Space Agency, ESA? Not much has been done to our knowledge. However, this has now changed.

The Advanced Concepts Team (ACT) of the European Space Agency (ESA) has organized a workshop on interstellar travel on the 20th-21st of June at its research and technology centre ESTEC in the Netherlands. It is the first time that ESA organized a dedicated workshop on this topic, which is accompanied by the upcoming publication of an interstellar issue of Acta Futura, the open journal of the Advanced Concepts Team.

Key members of the interstellar community gave presentations or were present, such as Phil Lubin (Project Starlight / Breakthrough Starshot), Pontus Brandt (1000 AU mission, Johns Hopkins Applied Physics Laboratory), i4is Deputy Director Rob Swinney (giving an update on Project Icarus), Angelo Vermeulen (on an evolving world ship), and Michael Hippke (on interstellar communication) to name a few. A notable presentation was given by Dario Izzo from the ACT, who presented the latest results of the Global Trajectory Optimization Competition, where the problem was to find a strategy to settle the galaxy most efficiently, using a set of starships. The mathematical problem behind this challenge seems to be not well known and further research seems to be promising, also using a more realistic scenario for colonization.

The workshop consisted of presentations and panel sessions and “unconference” sessions, in which interstellar-related topics were suggested by participants, then discussed in small working groups, and then presented. For example, I attended the workshop on architecture in space, developing a space infrastructure, and artificial intelligence and interstellar travel. The attendees seemed to be mostly ESA staff but also external attendees were present with various backgrounds, as the workshop was open to everybody.

The workshop provided excellent opportunities for exchanging ideas, discussions, and networking, not only during the unconference sessions but also during lunch coffee and lunch breaks. A workshop dinner took place at a nice Italian restaurant in Noordwijk right beside the beach with the workshop organizers and presenters.

Several i4is people attended the event (Rob Swinney, Angelo Genovese, Andreas Hein, Remo Garattini). I gave a review presentation on world ships on the first day of the workshop and also participated in two panels and Rob Swinney surveyed Fusion Propulsion Technology for Interstellar Missions. Rob Swinney and Kelvin Long also participated in panels. i4is people again played a key role in an interstellar workshop.

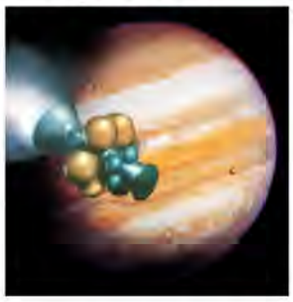
Stay tuned for the upcoming issue of the accompanying Acta Futura in which the world ship paper will be featured. Acta Futura is an open access on-line journal run by scientists connected with the Advanced Concepts Team.

The event website is at indico.esa.int/event/309/ which also includes links to the presentations.

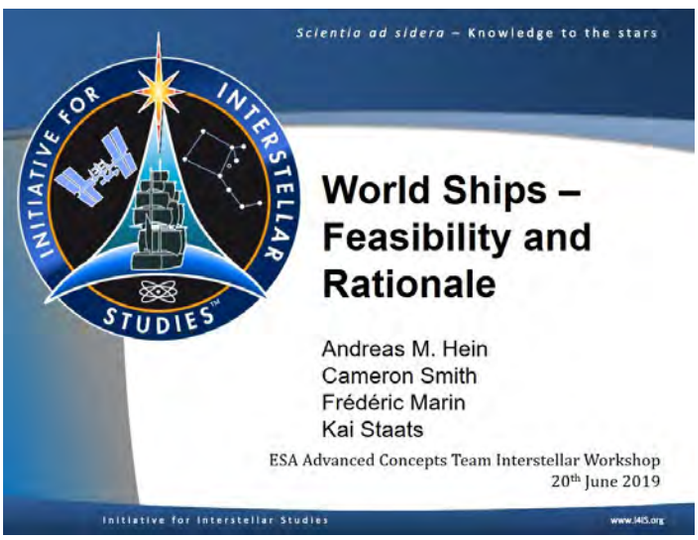
And the programme is at indico.esa.int/event/309/attachments/3485/4673/workshop_program.pdf

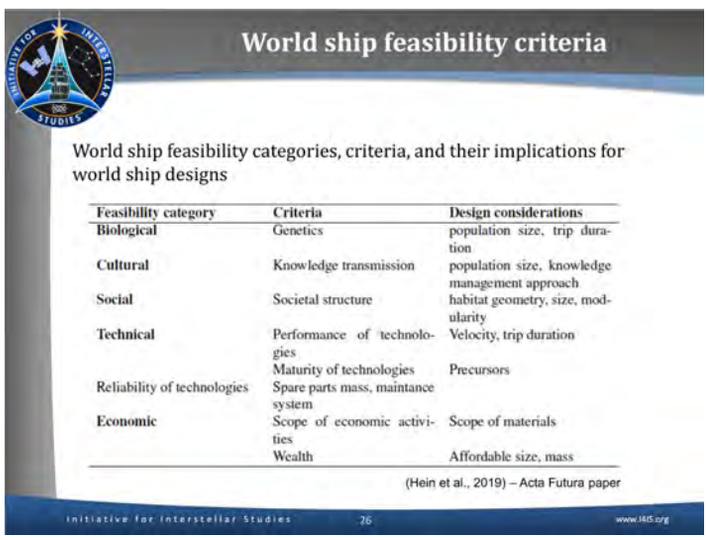
Case Study: Fuel Acquisition

- Daedalus mission to mine He3 from the atmosphere of Jupiter
- Alternatives include
  - Solar wind
  - Asteroids
  - Comets
  - Accelerator
  - The Moon
  - Other planets or moons

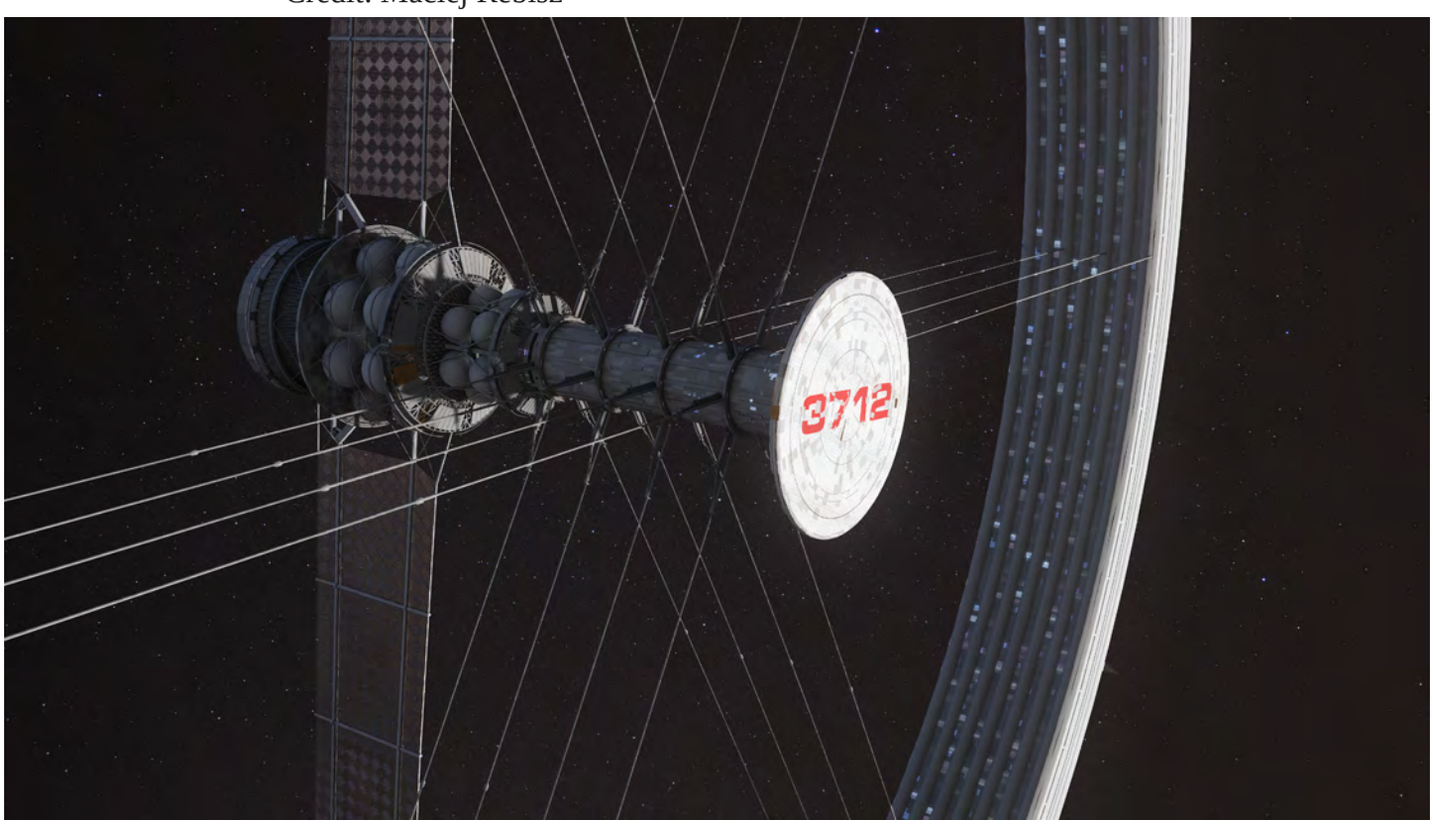


Planet	Jupiter	Saturn	Uranus	Neptune
Distance (AU)	5.2	9.5	19.2	30.1
V_{escape} (km/s)	59.5	35.5	21.3	23.5
Atmosphere *	89%H, 10%He	95%H, 3%He	83%H, 15%He	80%H, 19%He





ESA ACT workshop from Hein on Worldships Torus Worldship
Credit: Maciej Rebisz



Become an i4is member

Patrick J Mahon

How becoming a member of i4is helps our work and delivers exclusive benefits to you

We are a growing community of enthusiasts who are passionate about taking the first steps on the path toward interstellar travel - Now!

The best way to support the mission of i4is is to become a subscribing member. You will be directly supporting the interstellar programme. If you have time you can get actively involved with our projects but we appreciate that not everyone who shares our interstellar vision has the time or resources to do this.

In addition to supporting the programme, members have access to privileged content. This included exclusive reports in our Members Newsletter from the Second Foundations of Interstellar Studies Workshop in June. You also have access to videos of i4is events including the complete Starship Engineer course we delivered at the BIS in 2016, and 'The Interstellar Minimum' test paper to explore your knowledge of starship engineering. We will shortly also be publishing videos of all the presentations at the Second Foundations of Interstellar Studies Workshop.

Excerpt from i4is Members Newsletter 03/07/2019, James Schalkwyk of Breakthrough Initiatives discussing Breakthrough Starshot's plans for sending a gram-scale spacecraft to a habitable exoplanet within five parsecs of Earth, at 20 % of the speed of light, within thirty years.

Building Breakthrough Starshot
James Schalkwyk (Breakthrough Initiatives)

James discussed Breakthrough Starshot's plans for sending a gram-scale spacecraft to a habitable exoplanet within five parsecs of Earth, at 20% of the speed of light, within thirty years. They are focused on solutions involving solar or laser sails. James discussed the hug diversity of length scales across the project, from the 100 nanometre scale of the sail surfac nanostructure, right up to the 4 x 10^15 metre scale of the distance to Alpha Centauri – a variation of 22 orders of magnitude! If they can achieve a truly scalable solution, then creatir

Early drafts of Principium articles are also shared with members before general publication of each issue.

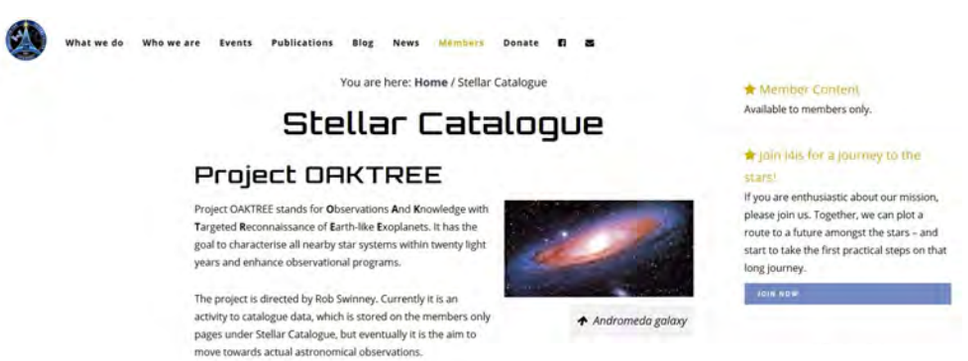
More details are on the i4is members' page, also in this issue of Principium. You will get access to all this content, and much more, if you choose to join.

Our Stellar Catalogue - Project OAKTREE - has the goal to characterise all nearby star systems within twenty light years and enhance observational programmes, beginning with an activity to catalogue data. It is on the members exclusive pages - i4is.org/stellar-catalogue

We send a regular news email exclusively to members, containing the latest news on interstellar developments and our own activities.

To see the other benefits of membership, or to join, please go to i4is.org/membership

Join i4is now and help us build our way to the Stars!



Project Oaktree - from our members exclusive pages

The State of the Art in Fusion Propulsion

Part Two of a two-part essay

Kevin Schillo, University of Alabama in Huntsville

In our last issue, Kevin Schillo began his survey of fusion-based propulsion systems. Here he concludes with Part Two of this essay, surveying the various fusion-based propulsion systems based on the Z-Pinch, and a number of concepts which use reaction chamber liners, before concluding with some observations about future research avenues. Kevin has based both parts of his essay on the extensive literature search he did for a dissertation in support of his PhD research.

Z-Pinch Fusion

Z-pinch fusion is a magneto-inertial fusion (MIF) concept that consists of running current in the million amp (MA) range through a plasma over microsecond timescales. The current generates a strong magnetic field due to the Lorentz force (en.wikipedia.org/wiki/Lorentz_force), which compresses the plasma until fusion reactions occur.

The Pulsed Fission-Fusion (PuFF) is a spacecraft propulsion system concept that utilizes a Z-pinch to compress a cylindrical target of lithium deuteride that is surrounded by a layer of fissionable material such as uranium, which is surrounded by another layer of lithium deuteride. This is illustrated in Figure 4.

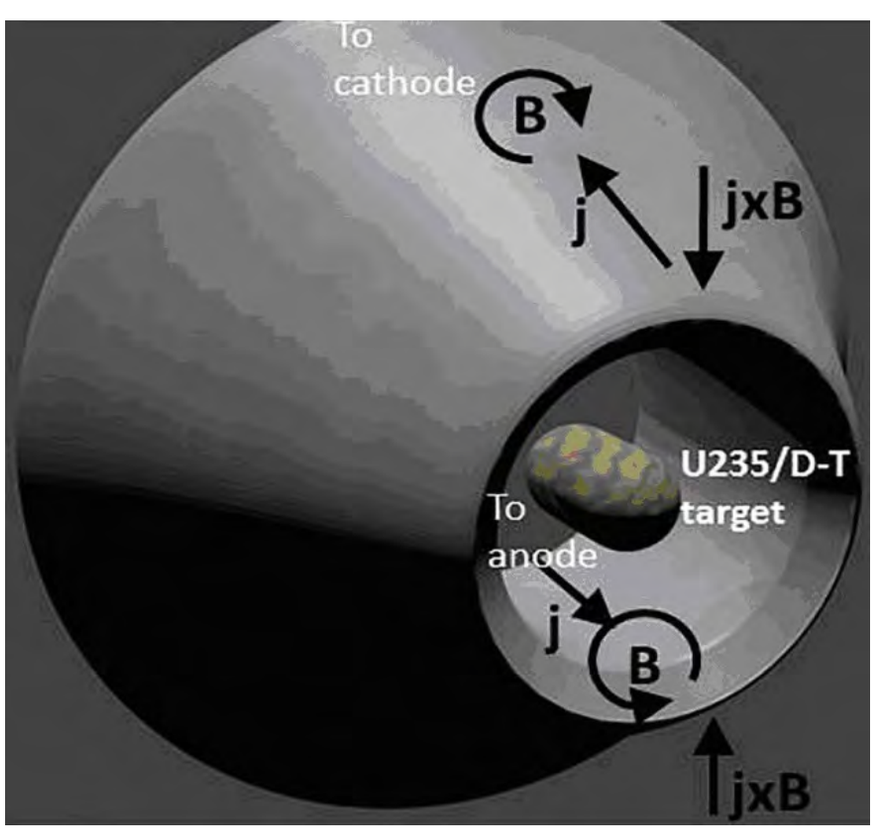


Figure 4. PUFF target compression [15].

As the target compresses, uranium atoms begin to fission. These neutrons transmute some of the lithium-6 atoms to tritium. As the target continues to compress, deuterium and tritium atoms begin to fuse together, increasing the temperature and pressure while generating more neutrons, which initiate more fission reactions. This sustains the energy release and further compresses the fusion fuel. This fortuitous cycle continues until a detonation wave propagates through the target, and allows for a more complete burnup of both the fissionable and fusion materials. The high power pulses will be delivered with linear transform drivers, inductive transformers with a primary inductor consisting of fast-switch, low inductance cavities to induce a current. A stack of cavities can produce extremely high voltages with pulse widths of less than 100 nanoseconds.

An illustration of a PuFF spacecraft propulsion system is shown in Figure 5 with a vehicle configuration shown in Figure 6. In Figure 6, a large capacitor bank can be seen at the rear of the vehicle, which is needed to produce and discharge the powerful current needed to compress the PuFF targets in a Z-pinch. Ongoing research in linear transform drivers seeks to significantly reduce the size and mass of the capacitor banks needed to compress the PuFF targets. Developing this technology is vital in order to reduce the overall mass of a spacecraft that uses a PuFF propulsion system.

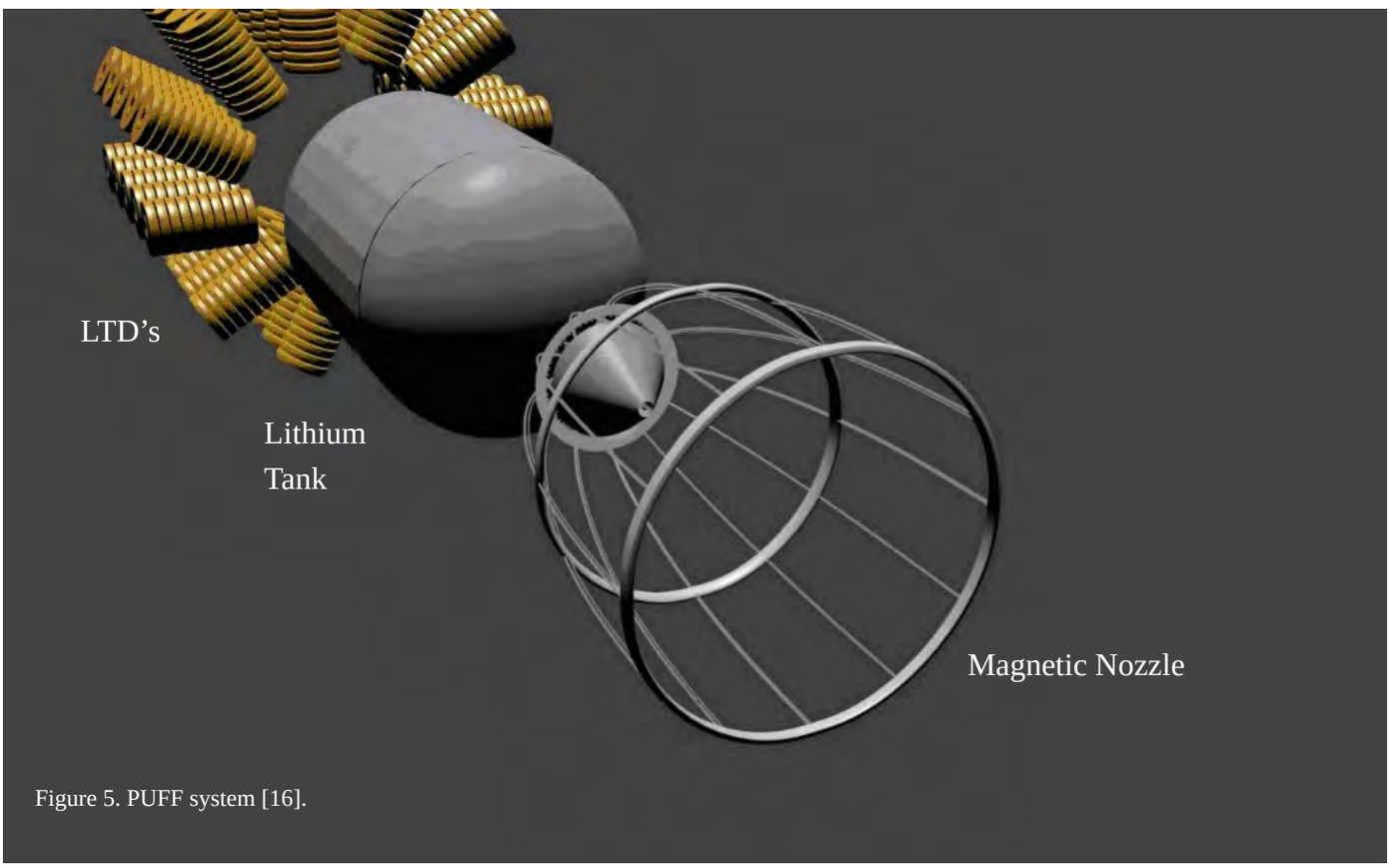


Figure 5. PUFF system [16].

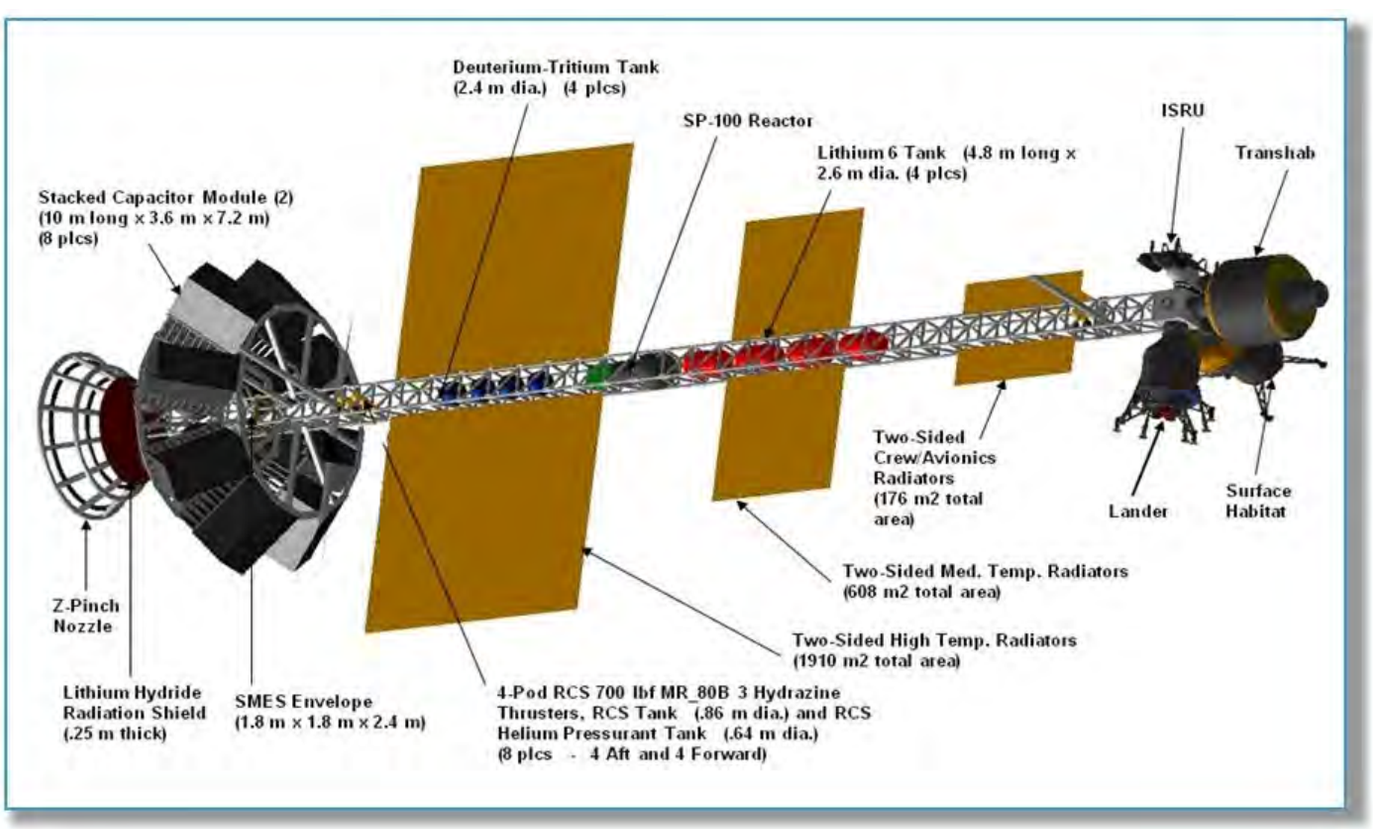


Figure 6. Z-pinch vehicle configuration [17].

One of the most crucial pieces of hardware for the PuFF project is the Charger-1, which is shown in Figure 7.

Figure 7. Charger-1 pulsed power machine [18].

The Charger-1 is a 550 kJ, 3 TW pulsed power machine located at the Aerophysics Research Center on Redstone Arsenal in Huntsville, Alabama. Once operational, the Charger-1 will discharge a powerful electrical current to compress PuFF targets in a Z-pinch [18].

Miernik et al investigated a Z-pinch fusion propulsion system. In this concept, a Z-pinch is formed using an annular nozzle. Deuterium-tritium is injected through the inner nozzle and lithium-6 is injected through the outer nozzle. The Li^6 is focused in a conical manner so that it will mix with the D-T at a point, with this point acting as a cathode. The Li^6 acts as the current return path. The Li^6 also reacts with neutrons generated by D-T fusion reactions. This results in more tritium being produced, thus creating high-energy products that boost the engine's energy output, allowing for very high exhaust velocities. This is shown in Figure 8.

Freeland and Lamontagne investigated an unmanned starship design called Firefly, which uses deuterium-

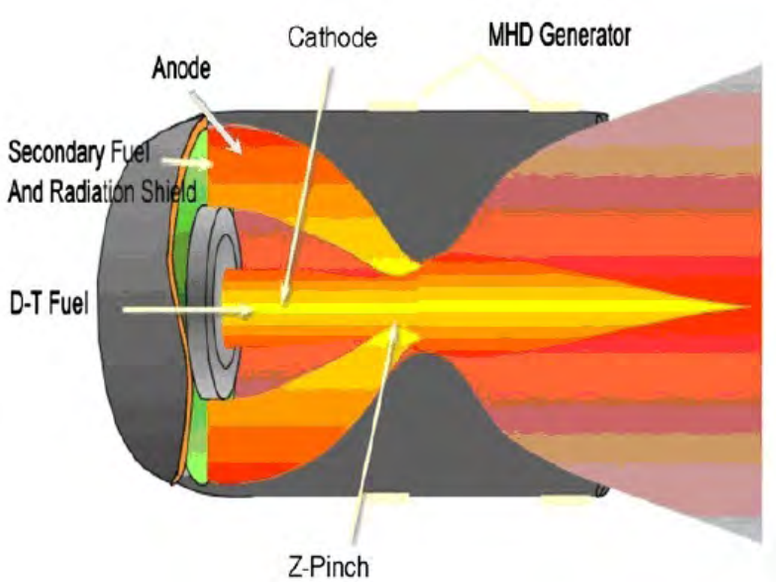


Figure 8.
Z-pinch fusion propulsion concept [2].

deuterium fusion in a Z-pinch reactor. The spacecraft is designed to have a long, thin core that allows for the high energy neutrons and Bremsstrahlung radiation produced in the D-D reaction to escape, eliminating the need for much shielding that would otherwise make the vehicle extremely massive. The Firefly is intended to reach Alpha Centauri within 100 years of its launch [19]. [Editor's note: The Firefly spacecraft design was explored in detail in issue 22 of Principium, in August 2018.]

A magnetic nozzle is needed to convert the resulting fusion energy into a propulsive impulse. This magnetic nozzle consists of current-carrying rings arranged in a parabola focused on the location where fusion reactions occur. Once the Z-pinch initiates fusion reactions, the resulting hot plasma expands rapidly and compresses the magnetic flux. As this occurs, the magnetic field strength and magnetic pressure increase until the magnetic pressure is equivalent to the dynamic pressure of the plasma. The magnetic field lines then rebound to their original configuration, ejecting the plasma and imparting propulsive momentum onto the space vehicle [2]. An illustration of this process is shown in Figure 9.

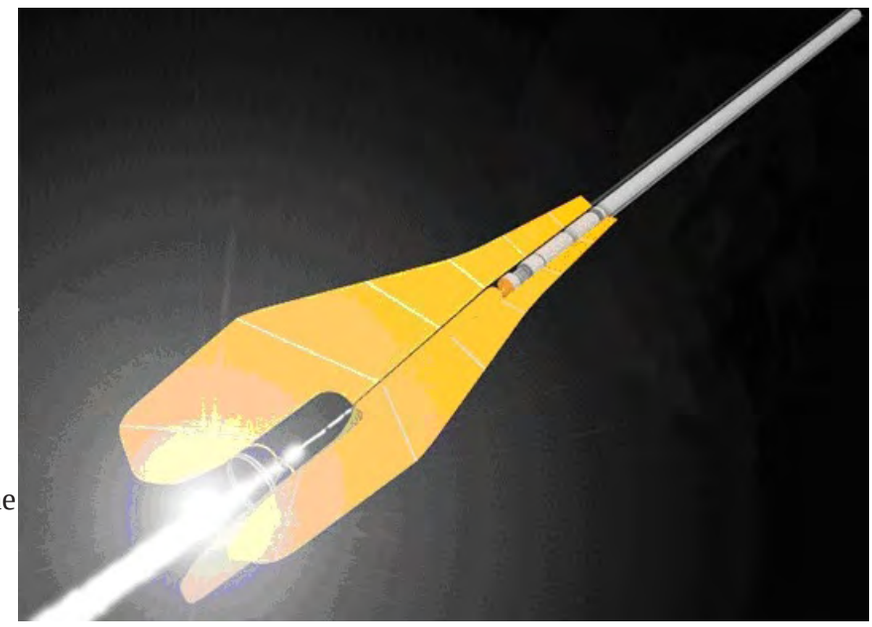


Figure 9. Icarus Firefly starship.

Currents are also induced in the coils during the plasma's expansion phase. This electrical power can then be used to recharge the system and repeat the cycle [20].

Concepts using Reaction Chamber Liners

Much research on magneto-inertial fusion has focused on using solid liners. A major disadvantage of solid liners is that they are not reusable, with a new liner having to be manufactured and then injected into the reaction chamber for each shot that is made. Debris may also be deposited on the interior wall of the reaction chamber when solid liners are used, damaging the system. In order for the fusion system to be reusable, the hardware that injects the liner and the reactor chamber wall must be located far enough away from the fusion target in order for the system to be reusable.

To address these issues, Francis Thio developed the concept of plasma jet magnetoinertial fusion (PJMIF). In the PJMIF concept, a series of plasma jets is used to form a cylindrical or spherical liner, which then implodes on a magnetized fusion fuel target and brings it to fusion conditions [21]. This is illustrated in Figure 10.

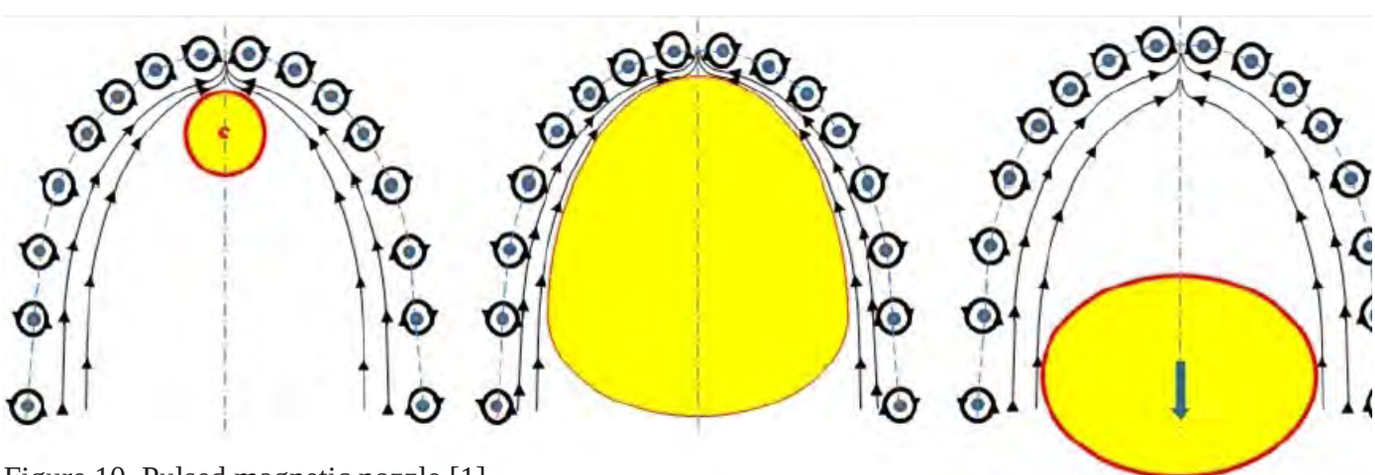


Figure 10. Pulsed magnetic nozzle [1].

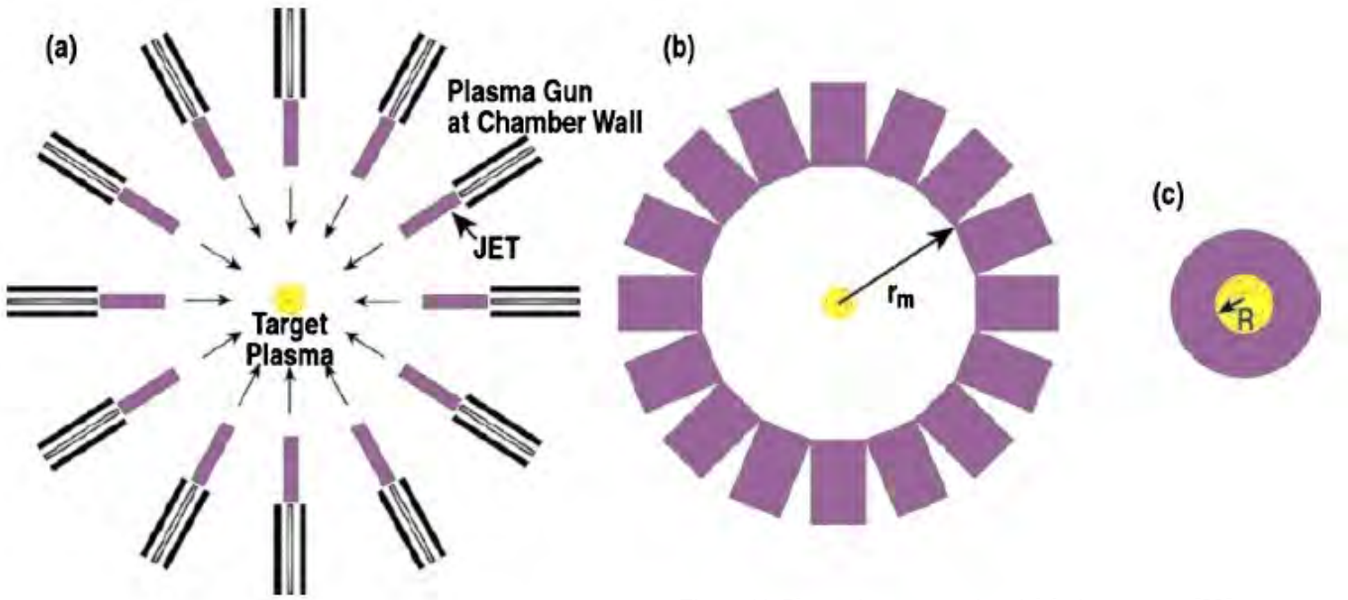


Figure 11. Plasma jet magneto inertial fusion concept [22].

Once the plasma liner has been formed and has reached the boundary of the target, the target and shock boundaries go through five stages. In the first stage, the plasma liner forms and begins to implode to the target. Then a radially inward shock is launched at the interface of the target and liner. In order for this to be done, the liner velocity exceeds the local target sound speed. A layer of shocked target material forms behind the shock and begins to move inward. The liner compression continues and is a primarily isentropic process.

The shock then reaches the origin, at which point the target has been entirely heated by the compressing shock. Immediately after shock collapse, a reflected shock begins to propagate radially outward. The material in the target that is behind the reflected shock will reach its peak temperature and pressure during this process. Once the reflected shock reaches the boundary of the target and liner, it will either continue propagating outward or be reflected inward. The reflected shocks become progressively weaker until the pressure of the inner target is equivalent to the dynamic pressure of the liner, at which point a stagnation shock will begin to propagate outward through the liner. The existence and number of secondary converging or reflected shocks that may occur at this point will depend on the strength of the mismatch between the dynamic pressure of the liner and the static pressure of the target.

After this point, the liner has completely stagnated. A rarefaction wave will then travel radially inward, disassembling the stagnated system of the liner and target, with the target no longer being confined once the wave reaches the origin. The dwell time can be approximated as the time it takes for the outgoing shock to propagate through the target and liner plus the time of the rarefaction wave.

During confinement, there are four characteristic velocities of interest. These are the expansion speed of the target, the rate of propagation of the outgoing shock wave through the liner, the incoming liner velocity, and the rarefaction velocity. Because the expansion speed of the target is relatively small, the compressed target does not expand significantly until after the rarefaction wave reaches the target.

The PJMIF concept avoids many of the problems associated with solid liners. The driver hardware can be far away from the fusion target so that it is not damaged or destroyed with each shot. This would avoid the high cost associated with destroying the materials in solid liners and transmission lines. The standoff driver of a plasma driver would also have higher repetition rates than the driver for a solid liner. The standoff distance and reusability offered by plasma liners may be opening a path that could lead to a viable reactor concept.

Several studies have researched using PJMIF as a spacecraft propulsion system [25]. Among these is the HOPE study, which was a conceptual design for a crewed vehicle to the outer solar system investigated by Adams et al and Cassibry [3, 24], and illustrated in Figure 12.

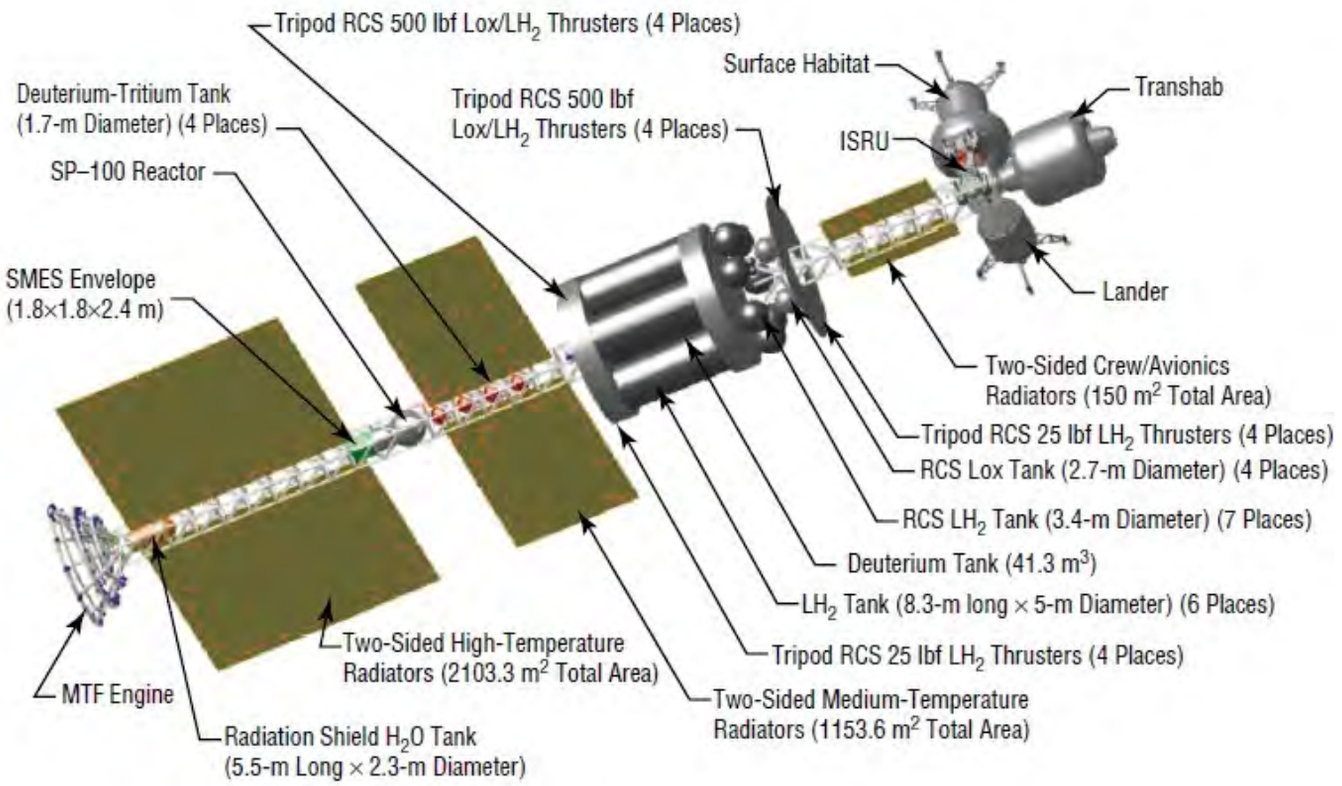


Figure 12. HOPE conceptual vehicle design [3].

The propulsion system for the HOPE vehicle has the target plasma located at the focus of the magnetic nozzle. A pair of conical theta pinches (which consist of an axial magnetic field and an azimuthal current) are positioned at diametrically opposite positions on each side of the nozzle's focus. These theta pinches launch a pair of spheromak plasmoids at the focus of the nozzle. The toroidal magnetic fields of the spheromak plasmoids are oriented in opposite directions, which allows the two spheromaks to merge with each other upon collision, forming a field reverse configuration (FRC) plasmoid. Once the FRC plasmoid has been formed, the plasma guns are fired, and the liner compresses the plasmoid.

The plasma gun used in this system consists of two concentric electrodes connected to a capacitor. Plasma enters through the gap between the electrodes, after which a switch is closed, which allows for the formation of a high potential gradient between the inner and outer electrodes. This causes the gas to ionize, completing the circuit and discharging the capacitor. The plasma gun has a converging two-barrel arrangement with internal contouring so that the plasma jet can be focused.

Conclusion

The plethora of fusion reactor concepts and vast parameter space in which magneto-inertial fusion can operate leaves no shortage of research for scientists and engineers to conduct. Many of these concepts hold great potential for use in both terrestrial energy production and spacecraft propulsion, but it is too soon to state which concept will ultimately lead to a breakeven fusion reactor. The technology readiness level (TRL) is low for many of these concepts, and years or decades of continued research will be needed in order to raise their TRLs and determine which one, if any, of them will lead to a viable fusion reactor.

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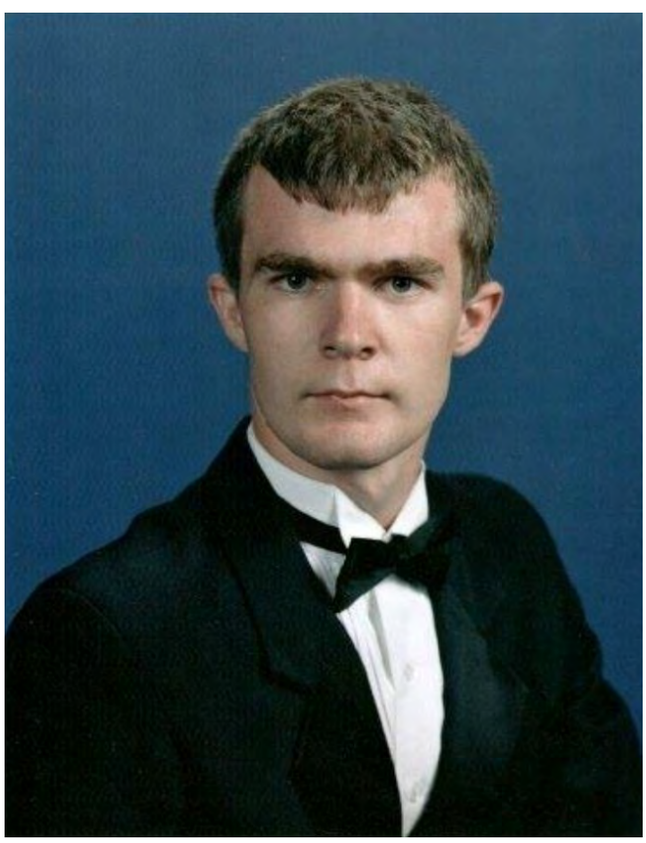
About the Author

Kevin Schillo obtained a Bachelor of Science degree in aerospace engineering from the University of Central Florida and a Master of Science in aerospace systems engineering from the University of Alabama in Huntsville. Throughout his career Kevin has worked for NASA, the Center for Space Nuclear Research, and HyperV Technologies researching and designing rockets, satellites, nuclear reactors, and nuclear fusion concepts. He is currently pursuing a PhD in aerospace systems engineering at the University of Alabama in Huntsville researching plasma jet driven magneto-inertial fusion. Kevin is also an aspiring science fiction author with a collection of short stories. The Tabernacle of Legion is his first novel. He is currently writing the sequel to The Tabernacle of Legion and another novel.



70th International Astronautical Congress 2019

Papers by the i4is Team

John I Davies

The Initiative for Interstellar Studies brings together an all-volunteer team committed to the achievement of interstellar travel and communication. Several of us have papers being presented at the 70th International Astronautical Congress to be held in Washington DC, USA, 21 - 25 October, 2019. We present here abstracts of papers by -

Dr Andreas Hein, Executive Director, Initiative for Interstellar Studies and Researcher / System Architect, CentraleSupelec, Paris

Satinder Shergill, PhD student, Cranfield University, UK / Physics & Robotics teacher at Space Studio West London

Robert Matheson, Initiative for Interstellar Studies, London, UK

Dan Fries, Initiative for Interstellar Studies, USA

T Marshall Eubanks, Space Initiatives Inc, USA

Kelvin F Long, Initiative for Interstellar Studies, UK

Principium editor John Davies will be reporting from the Congress. Find us via twitter.com/i4interstellar, john.davies@i4is.org and at the British Interplanetary Society stand.

70th International Astronautical Congress 2019

17th IAA SYMPOSIUM ON VISIONS AND STRATEGIES FOR THE FUTURE (D4)
Space Resources: Technologies, Systems, Missions and Policies (5)

Author: Mr. Satinder Shergill
Cranfield University, United Kingdom, s.s.shergill@cranfield.ac.uk
Dr. Jenny Kingston, Cranfield University, United Kingdom, j.kingston@cranfield.ac.uk

ISRU COMMINUTION AND BENEFICIATION FOR PARTICLE SIZE AND SHAPE MODIFICATION

Abstract

The benefits of comminution and beneficiation for ISRU processing has often been overlooked on the assumption that extra-terrestrial regolith particles have already been comminuted by micro-meteoroid impacts over millennia. Hence it is important to recognise that although there will certainly be particle sizes present that could be further processed without size reduction, there is still a wide particle size distribution expected on planetary surfaces even in small sample areas. As uniformity in particle size cannot be expected, it is thus better to frame the purpose of ISRU comminution as particle size control and not just reduction. Understanding particle size requirements and the properties of these particles and grains at different stages of the ISRU chain would greatly enhance the separation, handling and transport of ISRU material across subsystem interfaces. Comminution could also enable the smoothing of rough regolith particles (shape modification), to minimise the abrasive nature of highly angular regolith particles and grains. It is generally acknowledged that comminution can result in modification of particle shapes and so can be useful for terrestrial mining uses, but this feature of comminution is yet to be fully explored for ISRU. Certain comminution processes can result in more angular particles, which is useful for a potential increase in surface area for chemical reactions. While other comminution processes will result in the smoothing of highly angular particles, which would be useful for reducing abrasive contact, and in turn could extend the lifetime of all operational machinery, seals and hardware that the regolith encounters. This paper explores and presents some of the methods, and benefits of comminution and beneficiation for ISRU, being investigated at the Cranfield Space Research Centre.

70th International Astronautical Congress 2019

17th IAA SYMPOSIUM ON VISIONS AND STRATEGIES FOR THE FUTURE (D4)
Space Resources: Technologies, Systems, Missions and Policies (5)

Author: Dr. Andreas Makoto Hein
Ecole Centrale de Paris, France, andreas-makoto.hein@centralesupelec.fr
Dr. Islam Fouad Abdin
Ecole Centrale de Paris, France, islam.abdin@centralesupelec.fr

ASTEROID MINING ARCHITECTURES: A ROBUST OPTIMIZATION APPROACH

Abstract

Asteroid mining is considered as an enabler of an in-space economy by supplying resources such as volatiles and metals to customers in space and to Earth. For analyzing the viability of asteroid mining, several parametric models have been proposed, taking various technical and economic factors into consideration. However, these techno-economic analyses face two challenges: the technological alternatives are limited to point designs and the large uncertainties associated with the parameters is not appreciated. In this paper, we apply a robust optimization approach to asteroid mining parametric models, taking uncertainties into account and exploring a larger number of technological alternatives. We apply this approach to two prominent use cases for asteroid mining: water delivery to cis-lunar space and returning platinum to Earth. We demonstrate that given the uncertainties in the parameters, developing technologies such as fast propellantless propulsion systems and rapid in-situ bootstrapping of mining capacities at the asteroid could significantly improve the feasibility of asteroid mining ventures.

70th International Astronautical Congress 2019

17th IAA SYMPOSIUM ON VISIONS AND STRATEGIES FOR THE FUTURE (D4)
Strategies for Rapid Implementation of Interstellar Missions: Precursors and Beyond (4)

Author: Mr T Marshall Eubanks
Space Initiatives Inc., United States, tme@space-initiatives.com
Dr. Andreas Makoto Hein
Ecole Centrale de Paris, France, andreas-makoto.hein@centralesupelec.fr

NEAR TERM INTERSTELLAR MISSIONS : FINDING AND REACHING INTERSTELLAR OBJECTS

Abstract

1I/'Oumuamua (or 1I) is the first InterStellar Object (ISO) known to pass through the Solar System.1I was unfortunately found in October 2017, after its perihelion, and is now on its way out of the Solar System. On the opening day of the 2019 IAC, it will be 14 Astronomical Units (AU) distant, well beyond the orbit of Saturn, and proceeding away from the Sun at 28.6 km / second. Despite this, 1I is without question closest and easiest to reach Interstellar target for spacecraft exploration, by several orders of magnitude. Even in the 2060s it will still be 1000 times closer, and that much easier to reach, than the nearest stars.

1I remains mysterious, exhibiting characteristics that have never before been observed in a celestial body, providing ample motivation for in situ spacecraft exploration. In Project Lyra, we and our colleagues have explored possible mission scenarios, both in the near term, leaving Earth in the early 2020s [1], and in subsequent decades [2].

Of course, if there is one ISO passing through the Solar System, there should be others. 1I kinematically appears to be part of the Pleiades Dynamical Stream (or Moving Group); the dynamical streams being a major part of the organization of stellar (and presumably also ISO) trajectories in the Galaxy. If ISOs, like stars, are predominantly entrained in a dynamical stream, their incoming velocities (magnitude and radiants) can be predicted, which will enable deep surveys looking for ISOs well before perihelion. This will assist in the execution of rapid-response missions to future ISOs transiting the Solar System.

Whether a mission is send to 1I, or a mission is sent to a subsequent ISO (or both), it seems clear that the first interstellar mission will be to one of these objects.

[1] Hein, A. M., Perakis, N., Long, K. F., et al. 2017, ArXiv e-prints. https://arxiv.org/abs/1711.03155[2] Hibberd, A., Hein, A. M., Eubanks, T. M. 2019, arXiv e-prints, arXiv:1902.04935. https://arxiv.org/abs/1902.04935[3] Eubanks, T. M. 2019, in Lunar and Planetary Science Conference, Vol. 50, 3262

70th International Astronautical Congress 2019

17th IAA SYMPOSIUM ON VISIONS AND STRATEGIES FOR THE FUTURE (D4)
Space Resources: Technologies, Systems, Missions and Policies (5)
Author: Mr. Robert Matheson
Initiative for Interstellar Studies, France, robmatheson95@gmail.com
Mr. Dan Fries, Initiative for Interstellar Studies, United States, danfries@web.de

A TECHNO-ECONOMIC ANALYSIS OF THE SPACE SOURCED VOLATILES MARKET WITHIN THE EARTH-MOON SPHERE OF INFLUENCE

Abstract

Asteroids constitute a wealth of metals and volatile resources. As humanity continues to grow on Earth and to expand into space, asteroid resources and the extraction thereof will play an important role in satisfying the demands of the resulting economy. Past studies have analysed humanity's near-term colonisation and utilization of near-Earth space in terms of technical parameters and resource requirements. A different set of studies has concentrated on technical and cost parameters for the near-term extraction of space resources from asteroids and planetary bodies. Bringing these two viewpoints together, we model the future market for volatiles in space, considering parameters around a base scenario in which there are humans on Earth, on the moon and on stations orbiting the moon and Earth, as well as private sector asteroid miners and government funded lunar surface operations both supplying volatiles. The model is based on a competitive market situation and the results are used to determine possible equilibria in the quantities of volatiles provided by these two sources, the number of asteroid miners that will compete in this market, the profitability of these asteroid miners and a price range for volatiles in the chosen scenario.

70th International Astronautical Congress 2019

17th IAA SYMPOSIUM ON VISIONS AND STRATEGIES FOR THE FUTURE (D4)
Innovative Concepts and Technologies
Author: Dr. Andreas Makoto Hein
Ecole Centrale de Paris, France, andreas-makoto.hein@centralesupelec.fr

NEAR TERM INTERSTELLAR MISSIONS : FINDING AND REACHING INTERSTELLAR OBJECTS

Abstract

Miniaturization of electronic and mechanical components have allowed for an unprecedented down-scaling of spacecraft size and mass. Spacecraft with a mass between 1 to 10 grams are called AttoSats. An example for an AttoSat is the ChipSat, a credit-card sized spacecraft. Due to their small size, they introduce a new paradigm in spacecraft design, relying on agile development, rapid iterations, and massive redundancy. However, no systematic survey of the potential advantages and unique mission concepts based on AttoSats exists. This paper presents an integrated approach for assessing the potential of AttoSats for future space missions. First, we present the state of the art of AttoSat projects, their underlying technologies, and current technology trends. Next, we map out unique AttoSat characteristics and map them on future mission capabilities. We then derive a number of potential mission architectures for LEO and deep space missions. Finally, we go beyond AttoSats and explore how smart dust and nano-scale spacecraft could allow for even smaller spacecraft in the milligram and microgram scale.

70th International Astronautical Congress 2019

17th IAA SYMPOSIUM ON VISIONS AND STRATEGIES FOR THE FUTURE (D4)
Innovative Concepts and Technologies
Author: Dr. Andreas Makoto Hein
Ecole Centrale de Paris, France, andreas-makoto.hein@centralesupelec.fr
Mr. T. Marshall EubanksSpace Initiatives Inc., United States, tme@space-initiatives.com
ATTOSATS: CHIPSATS, OTHER GRAM-SCALE SPACECRAFT, AND BEYOND

Abstract
Miniaturization of electronic and mechanical components have allowed for an unprecedented down-scaling of spacecraft size and mass. Spacecraft with a mass between 1 to 10 grams are called AttoSats. An example for an AttoSat is the ChipSat, a credit-card sized spacecraft. Due to their small size, they introduce a new paradigm in spacecraft design, relying on agile development, rapid iterations, and massive. However, no systematic survey of the potential advantages and unique mission concepts based on AttoSats exists. This paper presents an integrated approach for assessing the potential of AttoSats for future space missions. First, we present the state of the art of AttoSat projects, their underlying technologies, and current technology trends. Next, we map out unique AttoSat characteristics and map them on future mission capabilities. We then derive a number of potential mission architectures for LEO and deep space missions. Finally, we go beyond AttoSats and explore how smart dust and nano-scale spacecraft could allow for even smaller spacecraft in the milligram and microgram scale.

70th International Astronautical Congress 2019

IAF SPACE SYSTEMS SYMPOSIUM (D1)
Innovative and Visionary Space Systems (1)
Author: Dr. Angelo C. J. Vermeulen
Delft University of Technology (TU Delft), The Netherlands, a.c.j.vermeulen@tudelft.nl
Mr. Mikhail Sirenko, TU Delft, The Netherlands, M.Sirenko@student.tudelft.nl
Mr. Brennan Lutkewitte, Technische Universität Berlin, Germany, Btlutkewitte@gmail.com
Mr. F Goldoust, TU Delft, The Netherlands, F.Goldoust@student.tudelft.nl,
Ms. Daniela Hallak, TU Delft, The Netherlands, daniela.hallak@gmail.com
Mr. Kelvin Long, Initiative for Interstellar Studies, United Kingdom, kelvin.long@i4is.org
Prof. Frances Brazier, Delft University of Technology TU Delft, The Netherlands, f.m.brazier@tudelft.nl

SIMULATING THE CONSTRUCTION OF CONCEPTUAL SPACE STRUCTURES TO EXPLORE THE POTENTIAL OF COMBINED ASTEROID MINING AND SPACE-BASED 3D MANUFACTURING

Abstract
Space-based manufacturing is considered a crucial next step for the further development of human settlement in space. There are vast quantities of building resources distributed throughout space, with asteroids among the most apparent candidates for large-scale mining and resource provision. In this presentation, we present a hybrid simulation model in which building materials extracted from asteroids are used in a differential 3D manufacturing process to create expanding modular space architecture. This work is part of the larger research programme EAS (Evolving Asteroid Starships) in which concepts for self-developing and evolvable interstellar spacecraft are being investigated by the DSTART team at Delft University of Technology. A high-level 'factory model' has been created that simulates the different steps of an entire production chain. The functions of the core disjunct components of the model range from mining, processing, storage, and 3D printing to biological life support and habitation. The model's backbone consists of a heuristic based on a decision tree that handles multiple incoming production requests. Production of architectural modules is needed to cope with (1) population growth of the inhabitants, and (2) the need for module replacement due to space weathering caused by particle bombardment and structural fatigue caused by high-energy cosmic radiation. The simulation model combines DEVS (discrete event system specification) and DESS (differential equation system specification) approaches and includes an abstract animated visualization. The model allows the user to keep track of material flows, bottlenecks and production efficiencies. In a series of simulation experiments three parameters are varied: (1) system properties (including e.g. processing speed and storage capacity), (2) resource availability (by varying the chemical composition of the asteroids), and (3) production demand (which depends on population dynamics and the need for module replacement). These experiments are designed to increase understanding of the performance of the envisioned system under different conditions. In this paper, the results of these different simulation experiments will be compared. The relevance for the larger project goals of EAS will be discussed, and conclusions will be drawn for future research on evolvable space architecture concepts.

70th International Astronautical Congress 2019
Timetable of Interstellar Papers

Following up abstracts of papers by the Initiative for Interstellar Studies team - here is a timetable of papers by the Initiative for Interstellar Studies team and others of interstellar interest. Details, including titles and authors, are as given on the IAC website.
Register for the Congress via - www.iac2019.org/registration2019.

IAC presentations are grouped into themed sessions and delivered in a predetermined order within each session. The list below is ordered first by day of the week and session time and then by order within each session. Watch out for sessions overlapping! Some sessions are not fully detailed at time of this publication. We will keep i4is members up to date via Members Newsletters - and, as always, keep an eye on our FB (InterstellarInstitute), Twitter (@i4interstellar) and LinkedIn (www.linkedin.com/groups/4640147)

MONDAY

day	date	room	session time	session id	**SESSION TITLE**	web address
Mon	21	145B	15:00	D1.1	**Innovative and Visionary Space Systems**	iafastro.directory/iac/browse/IAC-19/D1/1/

Order	Time	**Paper title**	Speaker	Affiliation	Country
2	15:20	**The Development of Dynamic Guidance and Navigation Algorithms for Autonomous On-Orbit Multi-Satellite Aggregation**	Mr Ryan Duong	Viterbi School of Engineering, USC	USA
3	15:40	**Human Agency And Autonomy In Long Duration Human Exploration**	Dr Stéphane Grès		France

day	date	room	session time	session id	**SESSION TITLE**	web address
Mon	21	144B	15.00	D4.1	**Innovative Concepts and Technologies**	iafastro.directory/iac/browse/IAC-19/D4/1/

Order	**Time**	**Paper title**	**Speaker**	**Affiliation**	**Country**
1	15:00	**Hive: A New Architecture for Space**	Dr. Henry Helvajian	The Aerospace Corporation	USA
2	15:12	**Master Planning and Space Architecture for a Moon Village**	Mr. Daniel Inocente	Skidmore, Owings and Merrill LLP	USA
3	15:24	**An Oasis on the Moon**	Mr. Phil Smith	Bryce Space and Technology	USA
4	15:36	**Steps toward self-assembly of lunar structures from modules of 3D-printed in-situ resources**	Prof. Alex Ellery	Space Exploration and Engineering Group, Carleton Univeristy	Canada
5	15:48	**Automated Multidisciplinary Design and Control of Hopping Robot Swarms for Exploration of Extreme Environments on the Moon and Mars**	Mr. Himangshu Kalita	University of Arizona	USA
6	16:00	**Mixed Reality Architecture in Space Habitats**	Dr. Jorge D Camba	Purdue University	USA

Order	Time	Paper title	Speaker	Affiliation	Country
7	16:12	**Technology Roadmap: a multi-attribute approach applied to reusable space transportation vehicles**	Mr. Giuseppe Governale	Politecnico di Torino	Italy
8	16:24	**The Selection of an Electric Propulsion Subsystem Architecture for High-Power Space Missions**	Mr. Christopher Andrea Paissoni	Politecnico di Torino	Italy
9	16:36	**General Research on Applications of Artificial Intelligence Technologies in Space Exploration Activities**	Prof. Feng QI	China Academy of Launch Vehicle Technology (CALT)	China
10	16:48	**Space Exploration Mission for Colonization: Spacecraft Requirements for Journey and In-Situ Expedition on Saturn's Moon-Titan**	Ms. Kirti Vishwakarma	University of Petroleum and Energy Studies	India
11	17:00	**AttoSats: ChipSats, other gram-scale spacecraft, and beyond**	Dr. Andreas Makoto Hein	Ecole Centrale de Paris	France
12	17:12	**Single-Person Spacecraft Transforms Weightless Operations**	Mr. Brand Griffin		USA
13	17:24	**Urban Planning at Planetary Scale: Architecting Low Earth Orbit**	Ms. Ariel Ekblaw	Massachusetts Institute of Technology (MIT)	USA
14	17:36	**Case Study of An Interstellar Mission To Luhman 16: Unmanned Interstellar Probe powered by Gas Core Nuclear Reactors**	Mr. Anand Kumar Singh	University of Petroleum and Energy Studies	India

day	date	room	session time	session id	SESSION TITLE	web address
Mon	21	146A	15:00-16:30	Special Panel Session	**Get Ready to Protect Earth from Asteroids – Planetary Defense in Your Hands**	www.iafastro.org/events/iac/iac-2019/technical-programme/special-sessions/

TUESDAY

day	date	room	session time	session id	SESSION TITLE	web address
Tue	22	146A	12:30-13:30	Special Panel Session	**Life's Journey Through the Universe**	www.iafastro.org/events/iac/iac-2019/technical-programme/special-sessions/

day	date	room	session time	session id	SESSION TITLE	web address
Tue	22	146A	16:30-18:00	Special Group Discussion	**Artificial Intelligent in Space: Are Intelligent Space Objects the Promise of the Future?**	www.iafastro.org/events/iac/iac-2019/technical-programme/special-sessions/

WEDNESDAY

day	date	room	session time	session id	SESSION TITLE	web address
Wed	23	143A	14.45	C4.6	**New Missions Enabled by New Propulsion Technology and Systems**	iafastro.directory/iac/browse/IAC-19/C4/6/

Order	Time	Paper title	Speaker	Affiliation	Country
1	14:45	**Air, carbon dioxide and water as oxidizers for metal-based fuels for aerospace propulsion and future space missions**	Mr. Ilyes Ghedjatti	Beijing University of Aeronautics and Astronautics (BUAA)	China
2	15:00	**Fitting a high total impulse electric propulsion system in a student CubeSat to compensate the atmospheric drag in low-earth orbit**	Mr. Victor François	Ecole Polytechnique	France
3	15:15	**Inductive Plasma Thruster (IPT) design for an Atmosphere-Breathing Electric Propulsion System (ABEP)**	Mr. Francesco Romano	Institute of Space Systems, Universität Stuttgart	Germany
4	15:30	**Impact of propulsion system characteristics on the potential for cost reduction of earth observation missions at very low altitudes**	Prof. Daniele Pavarin	CISAS – "G. Colombo" Center of Studies and Activities for Space, University of Padova	Italy
5	15:45	**GEO telecommunication satellite: new opportunities enabled by a 20kW class Hall thruster**	Mr. Christopher Andrea Paissoni	Politecnico di Torino	Italy
6	16:00	**3U Nanosatellite with Electric Propulsion as a Moon Probe for a Flyby Mission**	Mr. Derik Bhardwaj	University of Petroleum and Energy Studies	India
7	16:15	**Rotary solar sail for nanosatellite constellation formation**	Dr. Vera Mayorova	Bauman Moscow State Technical University	Russian Federation
8	16:30	**The Value Proposition of Multi-Megawatt Electric Power/Propulsion for the Human Exploration of Mars**	Mr. John Scott	National Aeronautics and Space Administration (NASA)	USA
9	16:45	**Manned mission to Europa using Advanced positron drive**	Mr. Mridul Jain	University of Petroleum and Energy Studies	India
10	17:00	**Prospects for the use of helicon thrusters for space exploration**	Mrs. Iana Kharlan		Russian Federation

Order	Time	Paper title	Speaker	Affiliation	Country
11	17:15	**The Kon-Tiki Mission – Demonstrating Large Solar Sails for Deep Space Missions**	Mr. Les Johnson	National Aeronautics and Space Administration (NASA), Marshall Space Flight Center	USA
12	17:30	**Launch System Solutions for Interstellar Travel**	Mr. Steven Vernon	Johns Hopkins University Applied Physics Laboraory	USA

THURSDAY

day	date	room	session time	session id	SESSION TITLE	web address
Thu	24	144B	09:45	D4.4	**Strategies for Rapid Implementation of Interstellar Missions: Precursors and Beyond**	iafastro.directory/iac/browse/IAC-19/D4/4/

Order	Time	Paper title	Speaker	Affiliation	Country
1	09:45	**An Interstellar Probe for the next Heliophysics Decadal Survey**	Dr. Ralph L McNutt, Jr.	Johns Hopkins University	USA
2	09:55	**Interstellar Probe: Cross-Divisional Science Enabled by the First Deliberate Step in to the Galaxy**	Dr. Pontus Brandt	Johns Hopkins University Applied Physics Laboraory	USA
3	10:05	**Dual Jupiter Swing-by Trajectory for Interstellar Probe**	Dr. Peter Gath	Airbus Defence and Space - Space Systems	Germany
4	10:15	**The Physics of Heat Shielding During an Oberth Maneuver**	Dr. Jason Benkoski	Johns Hopkins University Applied Physics Laboratory	USA
5	10:25	**Near Term Interstellar Missions : Finding and Reaching Interstellar Objects**	Mr T Marshall Eubanks	Space Initiatives Inc.	USA
6	10:35	**Sustainable Design for Extended Space Travel, Apprised**	Mr. Antoine Faddoul	Tony Sky Designs Group	USA
7	10:45	**Effect of ISM Impacts on Relativistic Spacecraft**	Mr. Jon Drobny	University of Illinois at Urbana-Champaign	USA
8	10:55	**The Breakthrough Starshot Initiative: Program Update and Next Steps**	Prof. Avi Loeb	Harvard University	USA

Order	Time	Paper title	Speaker	Affiliation	Country
9	11:05	**Experimental Study of Dynamics of a Lightsail Under Simulated Acceleration**	Mr. Hansen Liu	McGill University	Canada
10	11:15	**The Starshot Communication Downlink**	Dr. Kevin Parkin	Breakthrough Initiatives	USA
11	11:25	**Design of a strategy based on AI to boost interstellar travel: the case of Breakthrough Starshot Project**	Mr. Diego Jimenez	Private	Colombia
12	11:35	**Directed Energy - The Path to Radical Propulsion Advancement- Enabling Long Range Power Beaming for Rapid Interplanetary and the First Interstellar Missions**	Prof. Philip Lubin	University of California Santa Barbara	USA

day	date	room	session time	session id	SESSION TITLE	web address
Thu	24	IP Area	13:15	D4.IP	**Interactive Presentations - 17th IAA SYMPOSIUM ON VISIONS AND STRATEGIES FOR THE FUTURE**	iafastro.directory/iac/browse/IAC-19/D4/IP/

Interactive Presentations will be displayed on a screen in this dedicated location and available to view by all Congress attendees for the entire Congress week. In this afternoon session Congress each author is assigned a specific ten minute slot to personally present the topic and interact with the attendees present.

Order	Time	Paper title	Speaker	Affiliation	Country
1	13:15	**Contrasting the human value of lunar science versus lunar commerce**	Dr. Tony Milligan	King's College London	United Kingdom
2	13:15	**Ring Rockets**	Mr. Oleg Aleksandrov	Private individual www.oleg.space	United States
3	13:15	**Kobot Era: Robot modularity for optimized manned supervision.**	Mr. Philippe Martin	Telespazio Deutschland GmbH	Germany
4	13:15	**To Boldly Go: A Strategy for the Future of Engineering at NASA**	Mr. James MacKinnon	NASA Goddard Space Flight Center Greenbelt MD 20771	United States
5	13:15	**NIAC: The NASA Innovative Advanced Concepts Program**	Dr. Michael LaPointe	National Aeronautics and Space Administration (NASA)	United States

Order	Time	Paper title	Speaker	Affiliation	Country
6	13:15	**New supply chain methods using blockchain, 'Next Generation of Traceability' for aerospace industry.**	Mr. Pavlo Tanasyuk	University of Cambridge	United Kingdom
7	13:15	**Phobos and Mars Orbit as a Base for Main Belt Asteroid Mining**	Dr. Martin Elvis	Harvard-Smithsonian Center for Astrophysics (CfA)	United States
8	13:15	**Optical-RF Dual Relay Communication System for 1000-AU Interstellar Mission**	Mrs. Katelyn Kufahl	The John Hopkins University Applied Physics Laboratory	United States
9	13:15	**Project HELIOS Phase I: The Extraction of Helium-3 in Lunar Regolith for Aneutronic Nuclear Fusion**	Mr. Benjamin Wong	University of British Columbia	Canada
10	13:15	**Capacity Building in Space Science And Technology: The Space Generation Advisory Council Participation to The African Leadership Conference Youth Forum 2018**	Mr. Abraham Akinwale	Space Generation Advisory Council (SGAC)	Nigeria
11	13:15	**Prospect commercial routes in the Earth-Moon System's Service Volume**	Mr. Gabriele Impresario	Agenzia Spaziale Italiana (ASI)	Italy
12	13:15	**A Framework for Evaluating Challenges and Ways Forward in On-Orbit Servicing, Assembly, and Manufacturing**	Dr. Benjamin Corbin	IDA Science and Technology Policy Institute	United States

Exbitors at IAC 2019 (as of 29/7/2019)

3D PLUS USA, Inc., a.i. solutions, Inc., AAC Clyde Space, Aerojet Rocketdyne, Aerospace Corporation, The, Aerospace in Hawaii (Maui Economic Development Board), Aerothreads, AGI, AIAA, Air Liquide, Airbus SAS, Amphinicy Technologies, ARI Industries, Inc., Div Of Okazaki Mfg Co., ArianeGroup, Astroscale, ATG Europe B.V., Australian Space Agency, Azercosmos OJSC, Azista BST Aerospace, Belgian Space, Breakthrough Initiatives, BWX Technologies, Canadian Space Society, China HEAD Aerospace Technology Co., CNES - Centre National D'Etudes Spatiales (French Space Agency), CONFERS, COSPAR 2020 Sydney, Department of Science and Technology, South Africa, D-Orbit SPA, Dunmore Aerospace, Dynetics, ENPULSION, ESTECO, European Commission, Firefly Aerospace, Force Measurement Systems Inc., Forgital Dembiermont SAS, German Aerospace Center - DLR, German Pavilion, GK Launch Services, GKN Aerospace, Heinlein Prize Trust, Higher Orbits, Honeywell, Huntsville: The Rocket City, IAC 2019 Media Booth, IAC 2021 in Paris, ICEX, Spain Trade & Investment, ILC Dover, L.P., Indian Space Research Organization - ISRO, Infinite Composites Technologies, International Space University, ISL - Innovative Space Logistics, Israel Aerospace Industries (IAI), Israel Space Agency - ISA, ISS National Laboratory, Italian Space Agency, Italian Trade Agency, Jacobs, Japan Aerospace Exploration Agency - JAXA, JHU Applied Physics Lab, JUSTEK, KBR, Korea Aerospace Research Institute (KARI), L3Harris Technologies, Leaf Space Srl, Lockheed Martin Corporation, Luxembourg Space Agency, Made in Space Inc, Marotta Controls, METASENSING, Mohammed Bin Rashid Space Centre - MBRSC, Momentus, Moog Inc., Space and Defense Group, Morehead State University Space Science Center, NanoRacks, NASA, National Space Society & Space Development Foundation, New Zealand Space Agency - NZSA, NL - Space/SpaceNed, NOAA, NOAA Office of Space Commerce, Northrop Grumman, OffWorld, OPTEC SPA, Overleaf, Polish Space Agency - POLSA, Rocket Lab, Romanian Space Agency - ROSA, RS&H, INC, Safran Aircraft Engines, Scot Forge, SETI Institute, Shout About London (Space Junkies), Sierra Nevada Corporation, Singapore Space and Technology Association, SITAEL S.p.A., Skidmore, Owings & Merrill LLP, Skolkovo Institute of Science and Technology, Space Applications Services – ICE Cubes, Space Flight Laboratory (SFL), Space Generation Advisory Council (SGAC), Space Pioneers, Space Tango, SpaceCom, Spaceport America, Spacety, Spire, SPIRENT, Springer Nature, Surrey Satellite Technology Ltd, Swedish Space Corporation - SSC, Taksha Institute, Teledyne Brown Engineering, Telespazio, Telespazio, Thales Alenia Space, Tesat-Spacecom GmbH, The Launch Site, The MITRE Corporation, The Ohio State University, The Society of Japanese Aerospace Companies (SJAC), ThrustMe, TiSPACE Incorporated, UAE Space Agency, UK Pavilion, United Launch Alliance (ULA), United Nations Office for Outer Space Affairs - UNOOSA, University of Colorado, University of North Dakota, Department of Space Studies, University of Southern California Viterbi School of Engineering, University of Surrey, UK, VACCO Industries Inc, Valispace,

day	date	room	session time	session id	SESSION TITLE	web address
Thu	24	144B	14:45	D4.5	**Space Resources: Technologies, Systems, Missions and Policies**	iafastro.directory/iac/browse/IAC-19/D4/5/

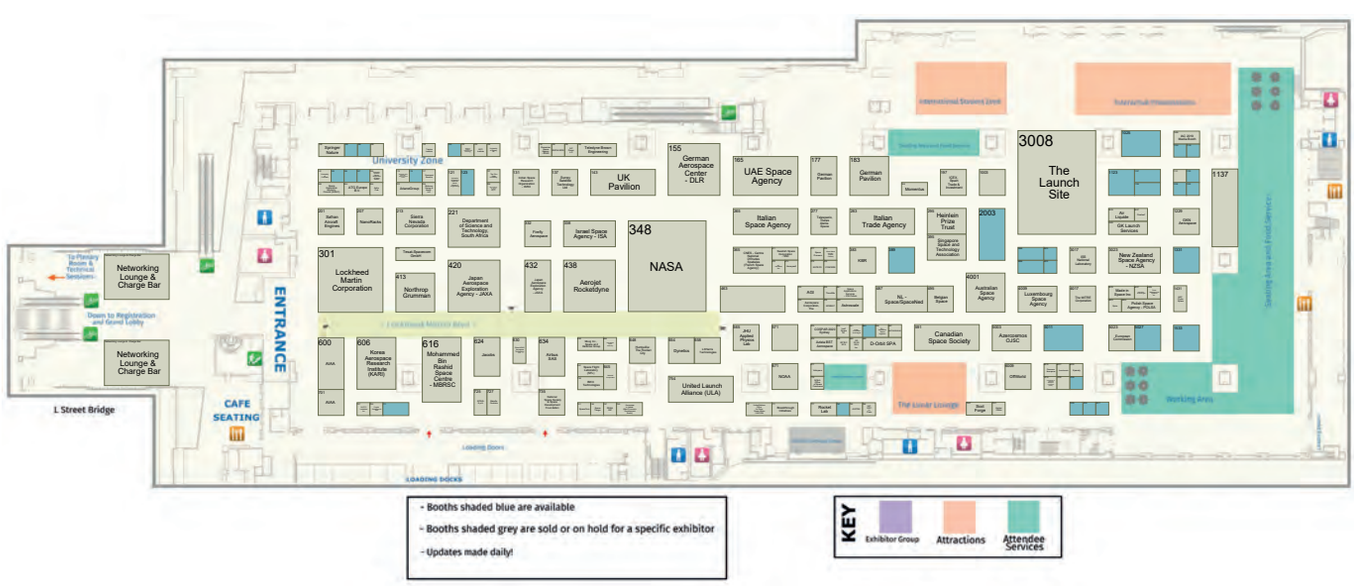
Order	Time	Paper title	Speaker	Affiliation	Country
4	15:12	**Asteroid Mining Architectures: A Robust Optimization Approach**	Dr Andreas Makoto Hein	Ecole Centrale de Paris	France
13	16:33	**A techno-economic analysis of the space sourced volatiles market within the earth-moon sphere of influence**	Mr Robert Matheson	Initiative for Interstellar Studies	France
14	16:42	**ISRU Comminution and beneficiation for particle size and shape modification**	Mr Satinder Shergill	Cranfield University	United Kingdom

FRIDAY

day	date	room	session time	session id	SESSION TITLE	web address
Fri	25	146A	14:00-15:00	Special Session	**Interstellar Probe: Humanity's First Deliberate Step into the Galaxy by 2030**	www.iafastro.org/events/iac/iac-2019/technical-programme/special-sessions/

Exbition Space at IAC 2019 (as of 29/7/2019) courtesy IAF

Exhibit Hall



Competition RESULT

The inspiration of space exploration – from Apollo to the stars!

In issue 25 of Principium, published in May, we challenged i4is members and supporters, and space fans more generally, to mark the 50th anniversary of the first manned Moon landing on 20 July 1969 by writing a poem to show how interstellar exploration can inspire us just as much today as the epic achievement of Neil Armstrong, Buzz Aldrin and Michael Collins did half a century ago, during the Apollo 11 mission.

We were delighted by the diversity of the entries we received, and are proud to publish below, fifty years to the day after Neil's 'one giant leap', the winning entry: *when your face became the moon*, by Dr Ina Roy-Faderman who will receive a year's free membership of the Initiative for Interstellar Studies, along with a copy of Principium 26.

Thank you to all the competition entrants.

when your face became the moon
Dr Ina Roy-Faderman

when your face became
the moon,
a blue drop
adorned your eye

hollow with flight
on earth,
a falcon feather drops
to this new home,

like apollo
god of the sun
and sometimes,
fire.

orion,
sight restored,
pulses

faceless, the arrow
hunts the hunter,
through the net of stars

you ride the years,
interstellar.
until your visor glimmers
blue again.

News Feature - The Principium Team

Patrick Mahon

As regular readers will know, Principium is the quarterly magazine of the Initiative for Interstellar Studies. The first issue was published in December 2012, shortly after i4is was launched, and since May 2015 we have kept to a regular schedule of four issues a year. Doing so requires a lot of work from many contributors, who provide us with articles, news items, project updates and wonderful images – all without payment. We are deeply grateful to them all. That content then needs to be transformed into the magazine you're reading now. The small team of people who make that happen every quarter are described below.

Carol Wright, Proofreader

Carol started reading Isaac Asimov at an early age, both fiction and non-fiction, which generated a keen interest in anything to do with space, along with a love of Star Trek, which continues to this day. It must be a family thing, as her brother Rob Swinney (i4is's Deputy Director) got started in a similar way!

Carol's rather varied working life started with secretarial work; later this was combined with undertaking Open University degree courses while stationed with her RAF husband in Cyprus. On returning to the UK, she did a BSc then an MSc in Computer Science at the University of Bristol. After University, she started working in a small computer science research company and grew into the systems management role, which continued when it was bought out by an American group. Having taken a break from her Open University degree, she finally completed it with a 2.1 in General Science.

Now that she is no longer working full-time, she keeps in touch with the computer world via technical services to friends and family, and gets enormous satisfaction working with Project Gutenberg on the proofing side – something which she is happy to do also for Principium.

Andreas M Hein, Deputy Editor

Andreas is the Executive Director of i4is. He has been Deputy Editor of Principium since issue 18 (August 2017), and his primary role is to check each issue for technical accuracy.

Andreas received his Master's degree in aerospace engineering at the Technical University of Munich. He obtained a PhD at the same university in the area of space systems engineering, focusing on the application of heritage technologies to space systems, doing part of his research at the Massachusetts Institute of Technology (MIT) System Architecture Lab. He also worked at the European Space Agency Strategy and Architecture Office on stakeholder analysis for future manned space exploration. Andreas has published over 30 articles on interstellar travel in peer-reviewed international journals and conferences. He is a member of the International Honor Society for Systems Engineering – Omega Alpha Association, a Fellow of the British Interplanetary Society, and a member of INCOSE.

Lindsay A Wakeman, Proofreader

Lindsay was fifteen when she joined the Royal Observatory, Edinburgh, and worked there for eight years, operating what was then the GALAXY machine, and later their computer systems. She remained in computing and became a UNIX system administrator (and, much later, Linux), working mostly in the university/public sector. She worked in the London software development team at the British Library for 11 years in the St Pancras building. Lindsay retired ten years ago and her current passion is learning English change ringing on church tower bells. She also enjoys the cinema, reading science fiction, and a good real ale. Lindsay's partner of 40+ years is John Davies – see below – and she helps out occasionally by late proofing Principium, mainly for minor cosmetic issues.

John I Davies, Editor

John joined i4is a couple of months after its formation in 2012. He found a natural role in the education programme given prior work as a STEM Ambassador to UK schools. He organised the i4is presence at the 2014 SF Worldcon in London (with Gill Norman, now Executive Secretary, BIS) including the 4 metre high monolith from 2001: A Space Odyssey (built by Terry Regan & Paul Campbell). He has been the editor of Principium since issue 9, published in May 2015. John is responsible for commissioning articles, writing content, securing artwork, laying out the magazine and project managing each issue of Principium. From this issue he shares that responsibility with Patrick.

John graduated in Electronics from Liverpool University, joining Hawker Siddeley Dynamics Space Projects Division, on the Bluestreak launcher and other projects, including an astronomical telescope study for ESRO and NASA, which became the Hubble. He spent most of his career in systems software development for communications and later consultancy in mobile data, retiring in 2008. When not doing his full-time volunteer job with i4is, he likes to see films of all genres and drink real ale with friends and his wife and partner of many years, Lindsay. He was founding convenor of the Philosophy group of the Islington University of the Third Age and sometime convenor of its Science group.

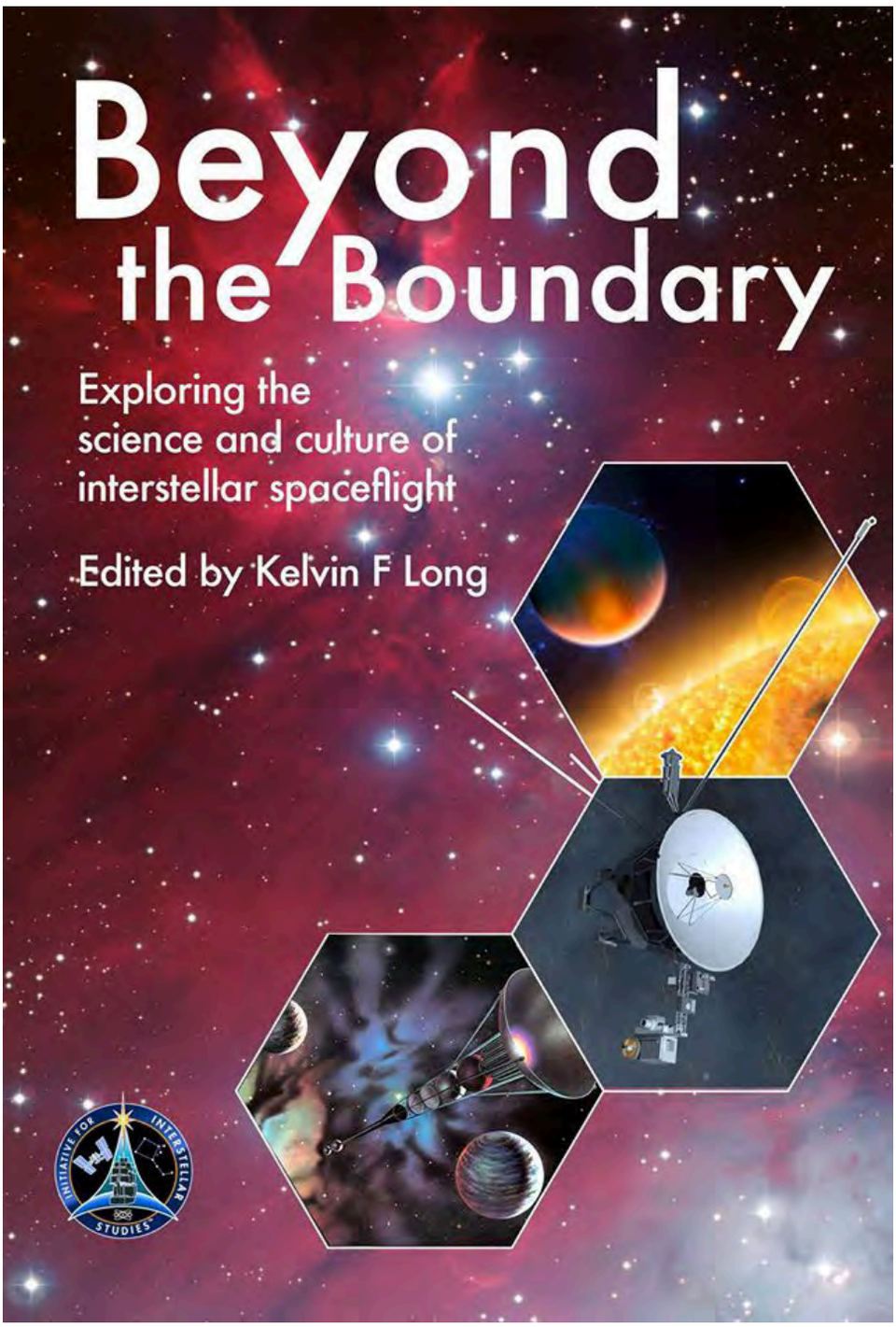
Patrick J Mahon, Editor

Patrick has been with i4is since attending one of our Starship Engineer courses in November 2015. After helping to proofread a revised version of the course notes the following year, he started to submit book and film reviews to Principium, and became Deputy Editor from issue 16 in February 2017 and co-Editor with John starting with this issue. Patrick's role is to write content, copyedit contributions and support his co-editor during the production process.

Patrick has a first degree in Maths and Physics from Warwick University and a Master's in Environmental Decision Making from the Open University. He has previously worked as a civil servant and for a trade association, and he now works for a national environmental charity, where he is responsible for policy development and political engagement. In his spare time, Patrick runs a local writers' group and both reads and writes science fiction.

with the editor. We're always looking for new ideas and new authors!

We hope this gives you a small insight into the team that puts Principium together every three months. If you're interested in contributing to a future issue of the magazine, please do get in touch.



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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.

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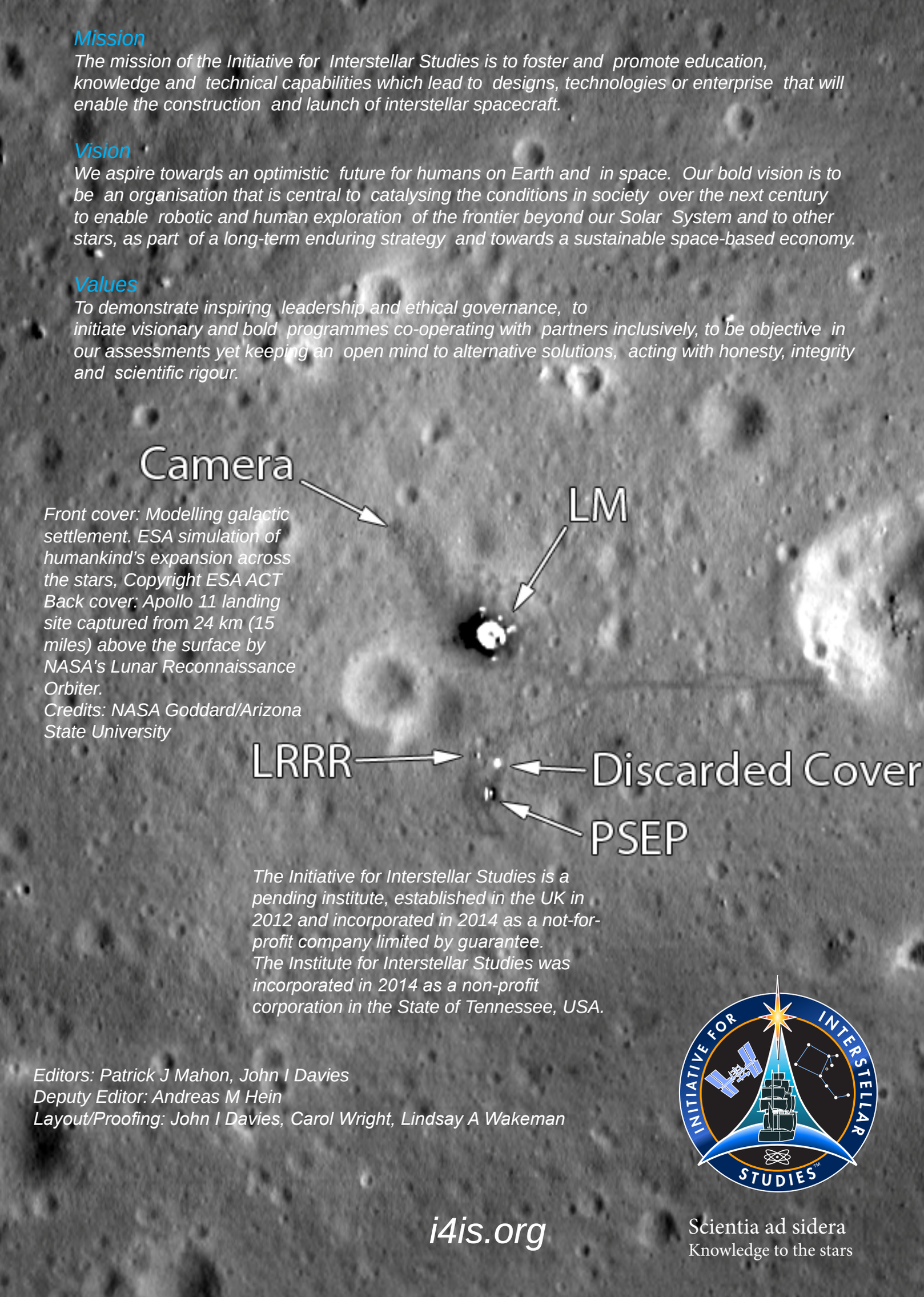
To demonstrate inspiring leadership and ethical governance, to initiate visionary and bold programmes co-operating with partners inclusively, to be objective in our assessments yet keeping an open mind to alternative solutions, acting with honesty, integrity and scientific rigour.



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Editors: Patrick J Mahon, John I Davies
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