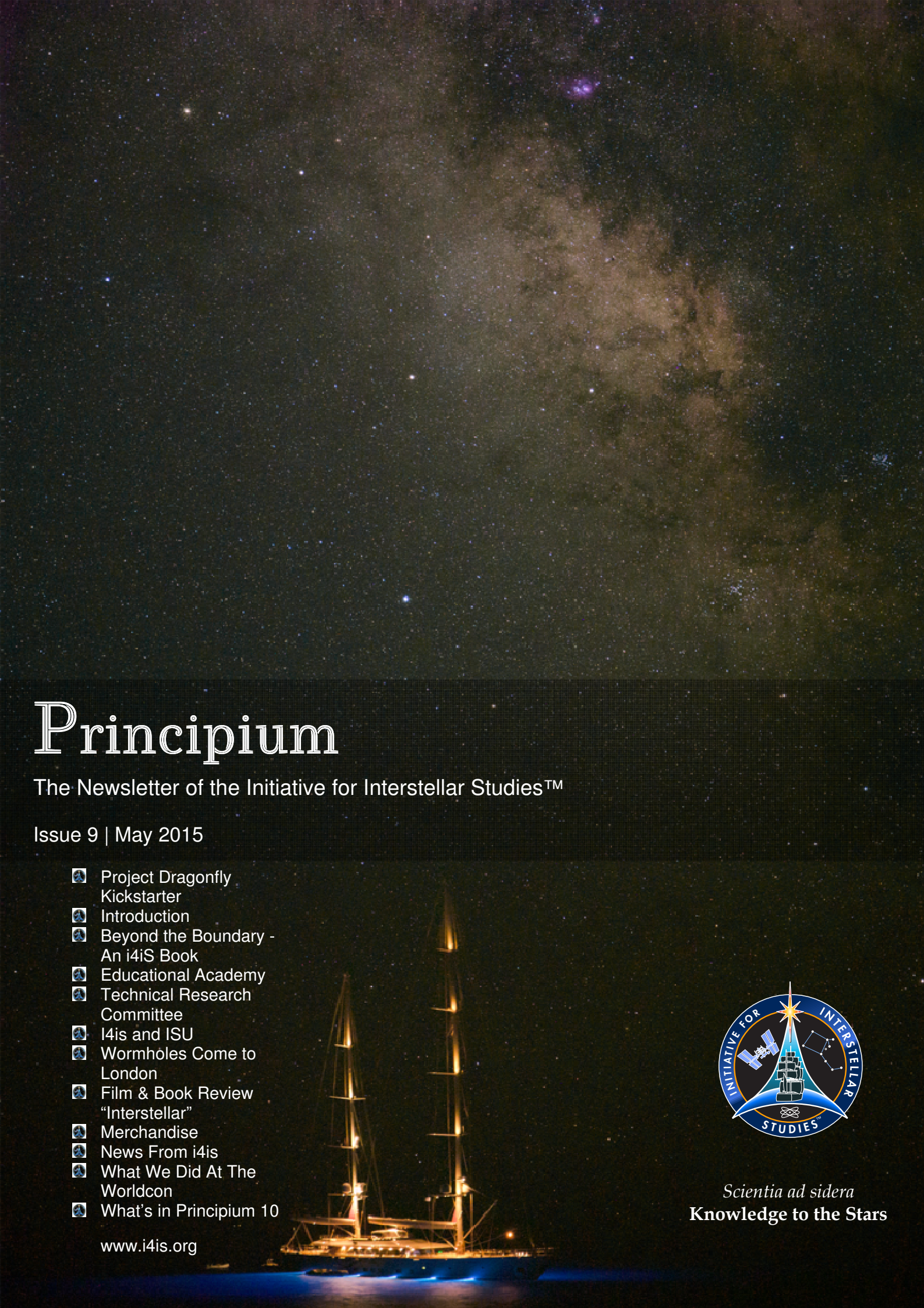


Principium

The Newsletter of the Initiative for Interstellar Studies™

Issue 9 | May 2015

www.i4is.org

Scientia ad sidera

Knowledge to the Stars

Notes from the Editor

This edition of Principium is the first since the June/July 2014 edition, Principium 8. We hope to reinstate a quarterly schedule for this, the principal publication of i4is. We have now adopted a single column layout, which we believe will be easier to read on a computer screen or tablet. For this edition our cover art is a photograph we love and we are most grateful to its author, Stavros Hios, for permission to use it. He joins the artists who have kindly provided their work to Principium, David Hardy, Alex Storer, Jon Lomberg and Adrian Mann. We will be featuring the best work from these and other visual authors in future editions of Principium.

John I Davies, Editor, Senior Researcher, i4is

STOP PRESS - Project Dragonfly Kickstarter

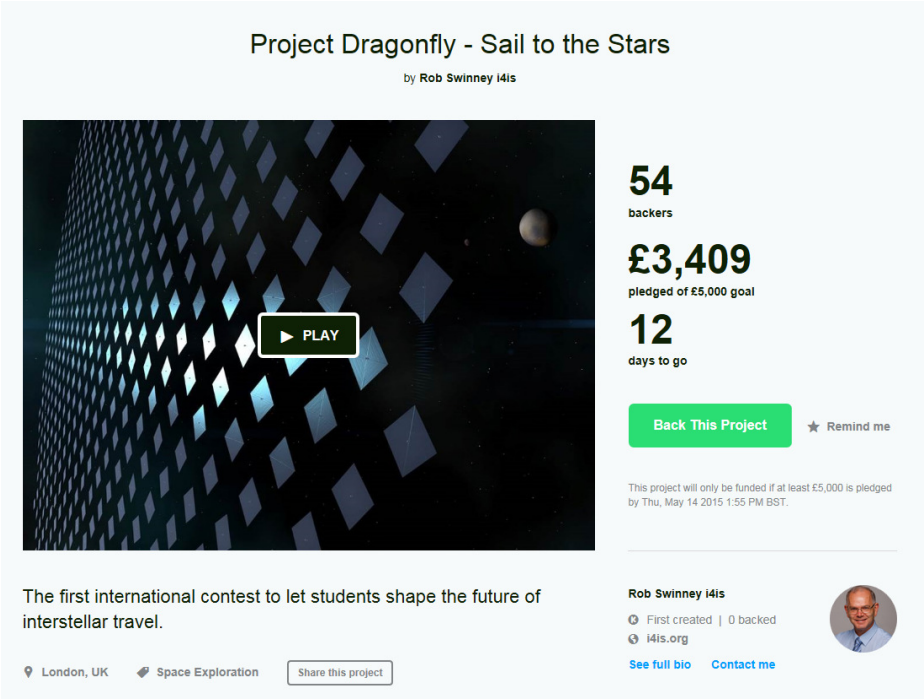
The first international contest for students to shape the future of interstellar travel.

We live in a unique time: we may soon have the technological capabilities to build and launch a spacecraft to the stars. Project Dragonfly is a feasibility study for an interstellar mission, conducted by small, distributed spacecraft, using laser sails, capable of reaching the target star system within a century and able to decelerate. To be conducted with technology available by 2024-2034 and space infrastructure available by 2050.

Four universities from all around the world are currently participating in the contest: ***Cairo University, Technical University of Munich, University of California Santa Barbara*** and ***Cranfield University*** partnering with both the ***Skolkovo Institute of Science and Technology*** in Moscow and the ***University Paul Sabatier*** in Paris.

Your contribution directly supports the international students working on this in their own time. It will be used to fund the teams' travel expenses to their final presentations in London and the organization of this event.

Remember a Kickstarter only works if the funding target is reached and the deadline is 13th May



But they need your support to achieve this - as of 30th April we have 66% funding including support from some very notable people such as Vinton G Cerf, one of "the fathers of the Internet". More recently he has been a leader of the Interplanetary Internet study at NASA's Jet Propulsion Laboratory. Join him and us by showing your support at –

www.kickstarter.com/projects/1465787600/project-dragonfly-sail-to-the-stars.

Imagine in a couple of decades that a real spacecraft is launched to the stars and that the design of the spacecraft stems from this competition. You will have helped to initiate it, reaching another star - a major event in human history. This competition is a part of the i4iS Alpha Centauri Prize awards.

Introduction

By Remo Garattini

Remo Garattini at the i4iS wormhole symposium, November 2014

Every time I see stars in the sky, I wonder if we will be able to reach them. It seems only a crazy dream. However every dream can be approached with a beginning and I think that a such a beginning was achieved when in 1987, in the American Journal of Physics, there appeared a paper written by Michael S. Morris and Kip S. Thorne, entitled "Wormholes in spacetime and their use for interstellar travel: a tool for teaching general relativity". This pioneering paper was the first serious attempt to put interstellar travel on a solid theoretical basis using a wormhole solution. Since then, the arguments have been explored very deeply and in more recent years, it has been a subject of major interest. But why?!

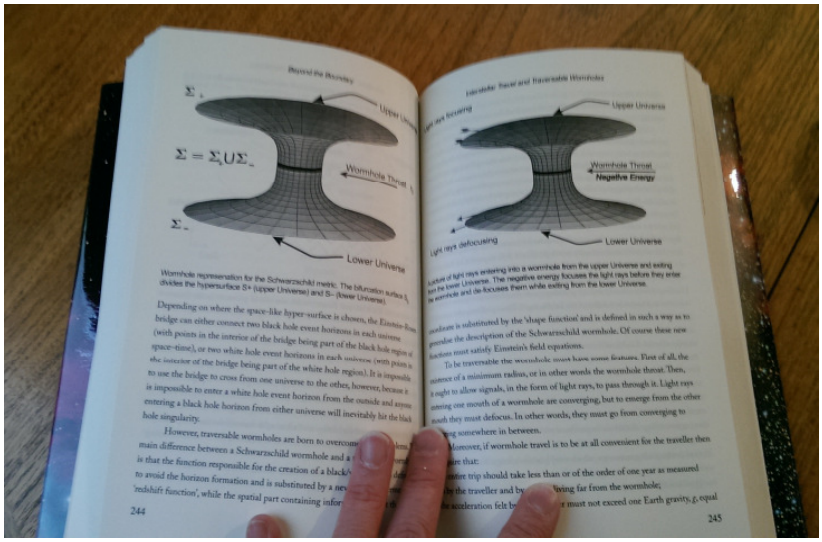
Let us stop for a moment and try to think what we can do with a spaceship. The best spaceship that humankind can build has to face the problem of the speed of light. Indeed, this represents a barrier that can neither be passed nor reached. It can only be approached by spending an amount of energy which tends to infinity. Therefore one needs to reconsider the adventure of interstellar travel with a different tool: a traversable wormhole. One could think that this method is the closest to a realisation of science-fiction. However is a nuclear propulsion spacecraft a less demanding challenge?

Alright, we have the technology to build a nuclear power plant on earth, but we need it on a spacecraft and it seems to me that such a technology is not ready now and for the immediate future and I have no prediction when. Some people consider ships that burn antimatter as fuel. In my opinion, this proposal is as close to science-fiction as the proposal for the traversable wormhole. Once again one could object that, in a particle collider, antimatter can be created… however antimatter creation is one thing but its usage for propulsion requires production in large quantities.

Thus a traversable wormhole is the best alternative to the usual space propulsion: note that I am not talking about a "warp drive" which has a different history. Of course, as for a nuclear spaceship or an antimatter fuelled spaceship, we need to discover natural wormholes before

thinking about the creation of an artificial one and from this point of view the winner is a nuclear/antimatter spacecraft.

But if we want to discourage any effort in the direction of traversable wormhole research, we need to be aware that a traversable wormhole requires “exotic matter”; namely matter whose mass-energy density is negative. This exotic matter is an “anti-gravity source” and today it is not possible to confirm the existence of such material. But why should a traversable wormhole deserve so much attention despite of these problems? Well, a traversable wormhole is a short cut in space allowing big distances to be crossed in a reasonable amount of time, one year for example. This “crossing the wormhole” can be realized without violating the speed of light barrier - and this sounds good. Notwithstanding these appealing features of a traversable wormhole, there remains the question of the exotic matter which cannot be avoided unless one discovers anti-gravity independently. Fortunately Quantum Electro Dynamics (Q.E.D.) supports the existence of exotic matter with an interesting effect termed Casimir Effect, due to Hendrik Brugt Gerhard Casimir [On the attraction between two perfectly conducting plates, Proc. Kon. Ned. Akad. 51, 7 (1948), 793-795].



Book chapter contribution to “Beyond the Boundary” on "Interstellar Travel and Traversable Wormholes" by Remo Garattini

The device producing the Casimir effect is the following: two parallel conducting surfaces, in a vacuum environment, attract one another by a very weak force that varies inversely as the fourth power of the distance between them. This kind of energy is a pure quantum effect; no real particles are involved, only virtual ones. Of course, this is not a material made up by exotic matter; it is only a device which behaves “like” exotic matter. This is good news, but the issue is that this effect works at nanoscales, while we need a factor of 10^9 to begin to think that a Casimir device can be used for interstellar travel. How to use a Casimir device to produce a traversable wormhole? In my opinion this is the real challenge of the future for interstellar travel. A challenge in which i4is is also involved.

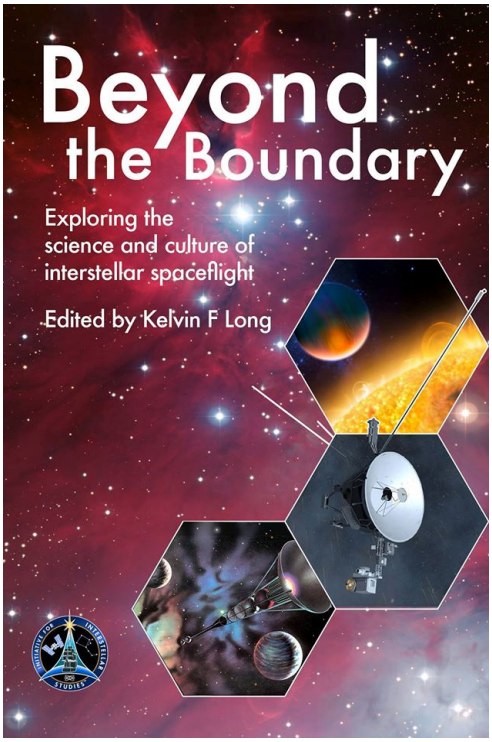
Indeed, I have to say with some satisfaction that, this issue of Principium can report the third meeting on warp drive and traversable wormholes. This took place in London at the British Interplanetary Society in November 2014. It is the first to be organised by i4is: a signal that things are going in the right direction.

Rob Swinney (Chair), Kelvin F Long, Remo Garattini , John I Davies, Silke Britzen at "Interstellar Wormholes: Physics and Practical Realisation" i4is Symposium at BIS, 24 November 2014

Beyond the Boundary

An i4is Book

The i4is team has published ***Beyond the Boundary*** and it is now on sale. The book has been edited by the i4is Executive Director, Kelvin F. Long. It contains chapters on technology, space art, space music, warp drives, wormholes, laser propulsion, electric propulsion and world ships. Several of its contributors are first time published authors while others are already widely published. The objective has been to give a voice to a wide range of writers with serious interests in the stars and how we will reach them. Contributors include academics, artists, astronomers, bloggers, computer scientists, engineers,



Hardcover, 458 pages Price: £30.00, €38.22, $45.03

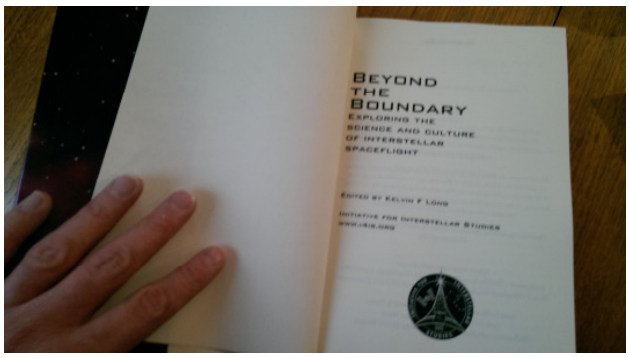
entrepreneurs, musicians, novelists, teachers and scientists.

To order your copy, go to www.lulu.com and search for *kelvin long*.

Endorsement

From the NASA physicist Les Johnson:

"***Beyond the Boundary*** *will be a valuable reference for those interested in the technical aspects of interstellar travel and for those interested in the less technical but equally important questions of "why go?" and "what do we do when we get there?" Given that travelling to the stars is perhaps the most important long-term endeavour facing humanity, it is a relief to know that some are thinking seriously today of how this might actually be accomplished*."



Les Johnson

http://www.lesjohnsonauthor.com/

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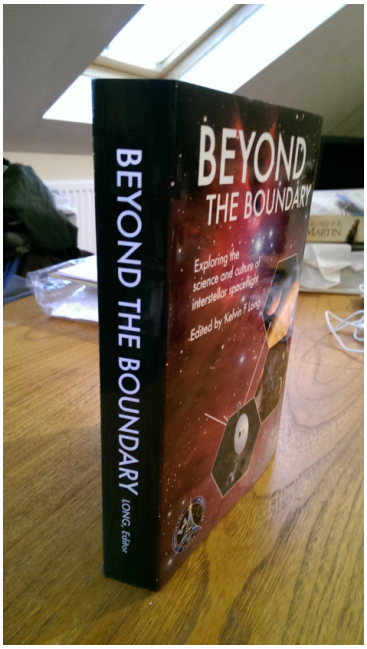

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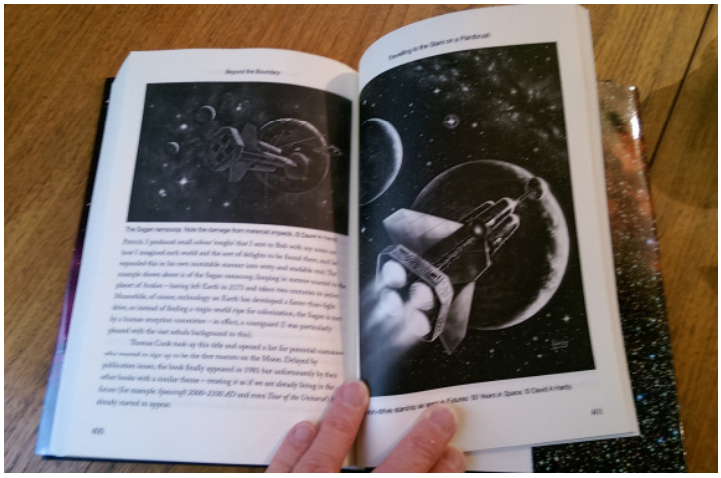
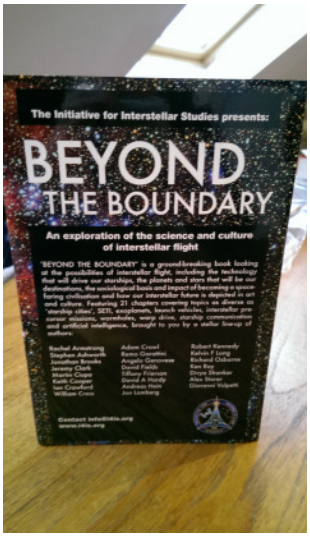




Educational Academy

By Rob Swinney, Chairman

Rob Swinney, Chair of i4iS Educational Academy Committee

The Academy is a vital component of the Initiative for Interstellar Studies. Its activities are essential to our achievement of Institute status.

It's been a busy year at the i4is Academy. The work is undertaken by many i4is members but it is the committee that organises these activities. New members on the committee this year include Gillian Norman, John Davies, Angelo Genovese, Terry Regan and Marc Casson. Their input and support is most welcome.

Although the work of the Academy has been ongoing for several years, since the incorporation of i4is in 2014 some things are being refined. If you are part of i4is in any way, or even if you are not, we would be interested to hear your thoughts on the Academy.

Angelo Genovese, i4is Educational Academy Committee

Terry Regan, i4is Educational Academy Committee

Over the last three years we have been technical supervisors of 10 Masters Projects undertaken by the students of the International Space University. The projects were created in collaboration with the ISU and all relate to, or promote, research into interstellar studies of

some description. With the ISU we have initiated an award for the 'Best Interstellar Themed Project', the first interstellar themed project award for a student project. The award includes a prize of €500. Last year it was won by Andrew Alexander for his report and work on project BAIR (a black hole augmented interstellar rocket). The new students for this year are Brian Ramos, Shambo Bhattacharjee and Melissa Guzman with projects ranging from orbital organic gardens and 'extreme long term storage in space' to characterising the local stellar environment.

And I'm now happy to introduce our newest volunteer project advisor, Professor Rachel Armstrong of Newcastle University, who will be working with Brian Ramos on the orbital organic gardens project and also helping with the team project.

Professor Rachel Armstrong, Chair of the Sustainability & Development Committee

Gill Norman, i4is Educational Academy Committee

In addition to the individual projects, this year, for the first time, i4is is supporting one of the team projects for the Masters students at ISU. This will entail working with some 22 students at the University looking at all aspects of interstellar world ships.

John Davies, i4is Educational Academy Committee

The ISU have been one of the leading supporters of our work and much of that is thanks to the efforts of Professor Chris Welch at the ISU who also sits on the Advisory Board of i4is. In addition to ISU we have worked with Southampton University in the last year and we also hope to further develop relationships with York University and Newcastle University.

If you were beginning to feel that we were focusing too much on the graduate and post-graduate aspect of studies, this was just our initial goal. We are developing our repertoire with earlier stage education with presentations to school students and developing material to support related academic courses such as GCSE Astronomy. We are also working on interactive educational material for primary school students and this area is being looked after by our new members, John Davies, Gill Norman and Terry Regan.

In the longer term, we are creating our own series of courses and qualifications and the first major one under development is the Starship Engineer course. Initially this will be a short course made up of five days of modular material that we will introduce in 2015. These

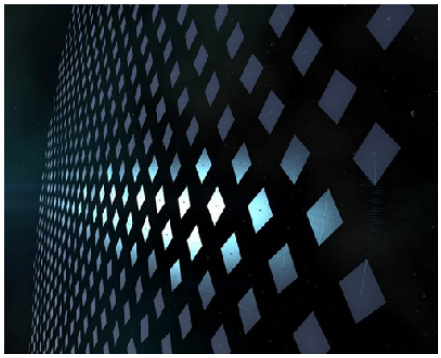
activities and the planned ***Starship Engineer*** course in particular, will support our case to become the Institute for Interstellar Studies as we have always planned.

Technical Research Committee

By Andreas Hein, Chairman

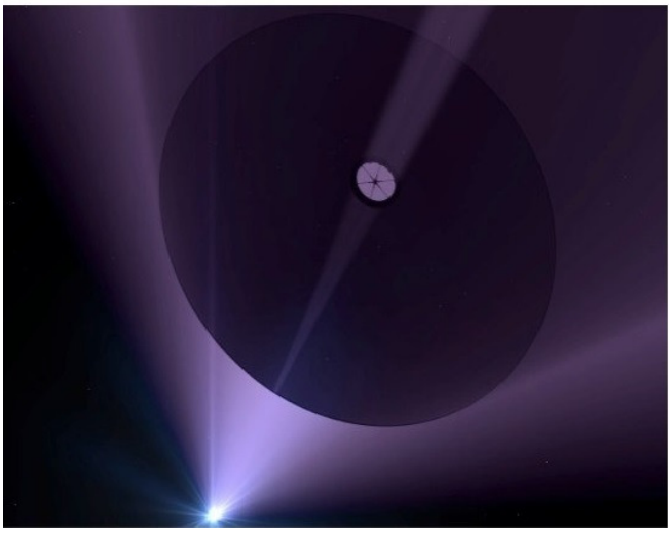
The technical research committee is i4is' research and development arm. Our mission is to work on the technologies and science to go to the stars. Our strategy is to concentrate on areas that we think are highly promising for conducting such a mission and that are feasible in the foreseeable future. We also look into high-risk / high-reward areas which have not yet been covered by existing research.

As we are still a very young organization, we started with one major project in 2014: the Project Dragonfly Design Competition. **Project Dragonfly** is a feasibility study for an interstellar mission, conducted by ***small, distributed spacecraft, propelled primarily by laser sails***. The spacecraft should be capable of reaching the target star system within a century and be able to decelerate at the target system. We believe that such a mission can be conducted with technology available by 2024-2034 and a space infrastructure available by 2050. The competition's main objective is to identify ***innovative mission architectures*** that are feasible in terms of both required technologies and required resources. The final design reports of the teams will cover all areas which are relevant to returning scientific data from such a mission: instruments, communication, laser sail design, power supply, secondary structure, deceleration propulsion, etc. The economic as well as the technological feasibility of the architecture will be assessed by the teams. The results from the competition will serve as a basis for future technology development - actually realising such a mission. For example, a crucial research area is to investigate materials for the sail. The material has to have a very low density to save mass, high temperature resistance to be able to tolerate intense radiation from the laser, and a high reflectivity to generate thrust. One attractive candidate material is graphene, which has an extremely low density and high temperature resistance. However graphene has low reflectivity. We are currently looking into ways to increase its reflectivity, while preserving its other characteristics.



Laser Sail Swarm

At the time of writing we have four international student teams from universities all over the world in the competition. We have also assembled a team of advisors, each a renowned expert in a field relevant for the competition.



In parallel with Project Dragonfly, we are working on the problem of crewed interstellar travel. The i4is World Ship Project, in cooperation with the International Space University (ISU), has a team of students working on the diverse problems of a crewed, cross-generational, mission to the stars.

In 2014 we also explored new manufacturing methods to create large structures in space such as world ships and space colonies. For example, working with an ISU postgraduate, we assessed the potential of 3D-printing for manufacturing these structures. The results of this study were presented by the ISU student at this year's International Astronautical Congress (IAC) in Toronto. And another of our researchers presented at the IAC on solar sail missions.

For 2015, we plan to expand our activities in manufacturing methods for large sail structures in space and the use of artificial intelligence to automatically design and manufacture space systems

We think that both areas of research are not only relevant for an interstellar mission but have disruptive potential - contributing to a space infrastructure in our Earth-Moon system.

I4is Continued Relationship with the ISU

The initiative for Interstellar Studies has just begun its 3rd year of collaboration with the International Space University (www.isunet.edu). This year three Master's projects have got under way. The first is titled ***Biological Life Support Systems for Future Spaceflight Missions*** by ISU student Brian Ramos and his project is externally advised by Professor Rachel Armstrong, University of Newcastle. The study looks at the design of self-sustaining ecologies for outer space.

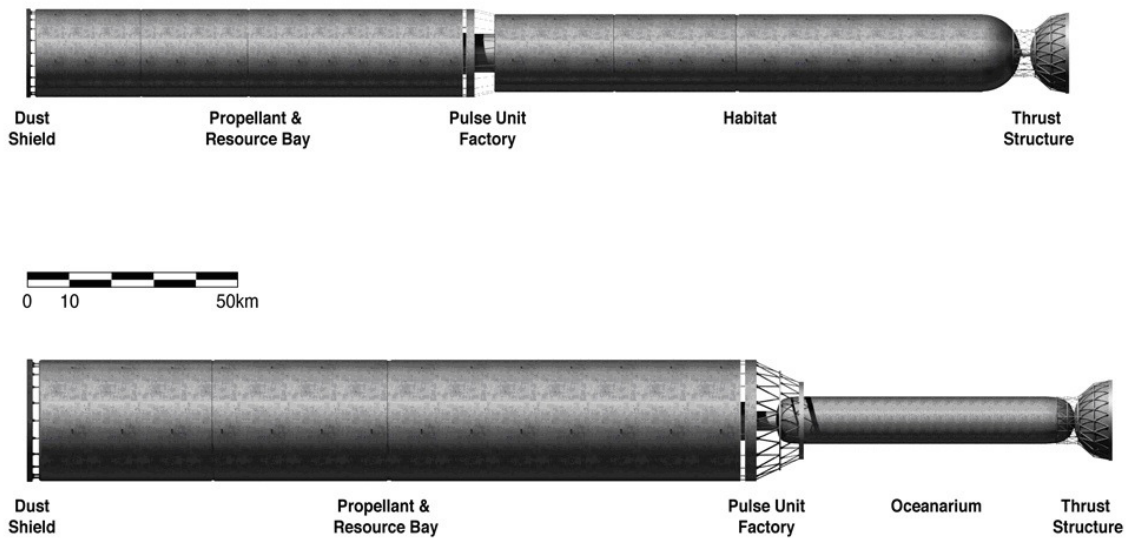
The second is titled ***Programme to Characterize the Local Stellar Environment*** by ISU student Shambo Bhattacharjee and his project, externally advised by Rob Swinney of i4is.

This is also a study that feeds into the i4is Project OAKTREE, an initiative to characterise all of the stars and objects of interest within 20 light years. The third project is titled ***External Memory*** by ISU student Melissa Guzman and externally advised by Andreas Hein of i4is. This project aims to assess the variety of long-lasting storage devices in space.

We also have an extra solar system exploration Team project, led by Professor Chris Welch and with the Director i4is Educational Academy, Rob Swinney, as the i4is lead advisor. The lead ISU students are Jean-Francois Rococo, the Project Coordinator, supported by Brian Ramos and Micah Klettke. The Project Editor will be Daphne De Jong. This project addresses the challenges facing the large-scale transport of humans to other star systems using slower-than-light spacecraft.

A project such as a world ship will almost certainly require international co-operation. While identifying and addressing all the scientific and technical challenges concerned it will need to maintain the global political will and focus over the many years necessary to resource, build and launch a worldship. It will also require innovation and new approaches in non-technical areas. Some of the topics that will need to be addressed by the project, categorized under the different ISU disciplines, include:

- Space Engineering: Worldship system requirements, approximate size, mass and cost, construction techniques.
- Space Physical Sciences: Interstellar environment, extraterrestrial resources and on board science capabilities.
- Space Applications: Worldship requirements for communications, navigation, and remote sensing.
- Human Performance in Space: Worldship life support/ecosystem, food/agriculture, and psychosocial issues.
- Space Policy, Economics and Law: Extraterrestrial law, international cooperation, worldship resourcing and financing.
- Space Management and Business: Worldship project infrastructure needs, assembly plan and schedule.
- Space Humanities: Ethical issues of worldship missions, cultural implications, societal/governance issues.



The Alan Bond/Tony Martin JBIS worldships from the 1984 study (credit: Adrian Mann)

While explicitly referencing any underlying assumptions and boundary conditions during this project, the ISU team will, as a minimum:

1. Define, document and critically assess relevant previous research into slower-than-light interstellar travel with an emphasis on relevance to multigenerational worldships.
2. Evaluate the current level of understanding of interstellar flight in the context of worldships and the knowledge gaps that need to be filled, both through future research and by practical demonstrations.
3. Define the technical and non-technical solutions that would be needed, including short- to mid-term pilot programs, to explore the validity of the interstellar worldship concept as well as longer term commitment to a preferred large-scale approach within the next one hundred years.
4. Identify preferred concept designs, system architectures and technology developments needed for the development of an interstellar worldship.
5. Examine the policy, legal, societal and ethical aspects of an interstellar worldship and its development program.

6. Evaluate and assess the political, programmatic and financial potential and the related constraints for interstellar worldships and identify potential and preferred development scenarios.
7. Develop a roadmap for the 2015-2115 timeframe to further the state of knowledge and/or implement pilot and larger-scale space-based solutions leading to a worldship mission launch in 2115.

Typical worldship designs (credit: Adrian Mann)

Feature: Wormholes Come to London

By Kelvin F. Long

On Monday 24th November 2014 there was a rip in the fabric of space-time, centred on the British Interplanetary Society, in Vauxhall, London. This was a one day symposium organised by i4is in collaboration with the BIS, to discuss ***Interstellar Wormholes: Physics and Practical Realisation***.

Our topics were -

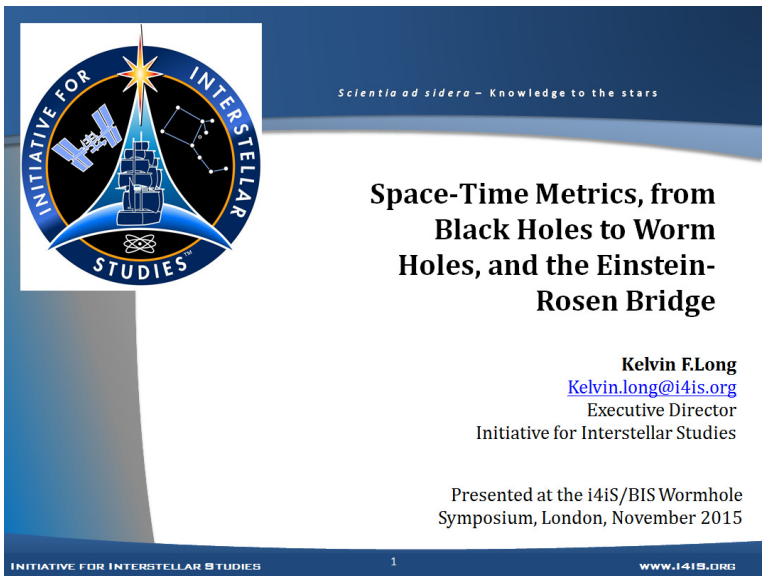
- Space-Time Metrics from Black Holes to Worm Holes and the Einstein-Rosen Bridge, Kelvin F. Long
- Observations of Black Holes – Towards the Event Horizon, Silke Britzen

- Traversable Wormholes and the Casimir Energy in Modified Gravity, Remo Garattini
- Using Micro-Wormholes in Interstellar Communications, Tiffany Frierson
- Wormholes in Science Fiction, John Davies

This is the first of our reports from the Symposium. The others will follow in the next issue of Principium.

Chairing the meeting was i4is Deputy Director Rob Swinney, who welcomed everyone warmly to this exciting and unusual gathering.

Kelvin F. Long, Executive Director of i4is, opened the meeting with a discussion on "**Space-Time Metrics from Black Holes to Worm Holes and the Einstein-Rosen Bridge**". He started with a discussion on the General Theory of Relativity, published by Albert Einstein in 1915. General Relativity (GR) is a theory of gravitation. Isaac Newton saw that "gravity is the force of attraction between two bodies at rest or in motion", but Einstein saw more clearly that "gravity is a manifestation of space-time curvature". The American physicist John Wheeler said that "Space tells matter how to move, and matter tells space how to curve". General Relativity is a continuous field theory in contrast to the particle theory of matter.



Kelvin explained some of the key concepts from the special and general relativity theories. The combined speed of the motion of any object through the four dimensions of space and time (space-time) is always precisely equal to the speed of light. This does not contradict the constant light speed law, for that refers to motion only in the space directions.

He explained how Einstein had showed that events were observer dependent, and that two distant observers measuring the same event may disagree on space and time measurements. But the quantity that they would agree on is known as the Space-Time Interval. And this key concept is the foundation of all metric equations. The numerical value of this interval is the same for all observers, no matter how fast they are moving relative to one another. Kelvin explained the concepts of proper time and proper distance between events (co-ordinates), which are invariant for all observers and can be written as a line element or metric - space-like ($S^2=x^2-t^2$), time-like ($\tau^2=t^2-x^2$) and null-like ($x=t=0$).

General Relativity has fundamental principles explained by Einstein. They include the principle of equivalence, which states that all locally freely falling and non-rotating "laboratories" are completely equivalent for the performance of all physics experiments. The second fundamental principle is inherited from Einstein's earlier Special Theory and is simply the invariance of light speed. The third principle is known as 'Mach's principle', which states that all inertial frames are those in which the fixed stars are not rotating. In other words, there are no inertial masses in a void universe. This is the same as saying that a body will experience no inertial forces when it is at rest or in uniform motion with respect to the centre of mass of the entire universe. The fourth principle of General Relativity is the principle of covariance, which states that the laws of physics should be invariant under co-ordinate transformation, and this is why tensors are often used as convenient mathematical tools. The fifth fundamental principle is the correspondence principle, which states that old physical laws should still apply at the appropriate limits. In particular, special relativity when gravity is absent and Newtonian gravity in the case of weak gravitational fields.

Kelvin introduced the Einstein field equation, which is a relationship that equates the geometry of space-time with the so called mass-energy of the source which generates the gravitational field. He developed a standard metric solution, and showed how the Einstein field equation was solved for some standard problems from a 16 component matrix, which was reduced to a symmetric 4 component signature (-1, +1, +1, +1), in the case of flat (no gravity) space-time, known as a Minkowski metric.

Kelvin moved on to discuss the history of black holes and how, at the start of their theoretical examination, they were not taken seriously. He quoted the astronomer Arthur Eddington in 1935 "*the star has to go on radiating and radiating and contracting and contracting, until I suppose it gets down to a few km radius when gravity becomes strong enough to hold in the radiation and the star can at last find peace. Various accidents may intervene to save the star, but I want more protection than that. I think there should be a law of nature to prevent the star from behaving in this absurd way*".

A paper by Robert Oppenheimer published in 1939 first demonstrated the theoretical collapse of a star to a black hole. The model was for an idealized imploding star, which was assumed to be perfectly spherical, no rotation, uniform density, zero pressure, no shock waves, no ejected matter and no outpouring of radiation. The conclusions of the paper were "*an external observer sees the star asymptotically shrinking to its gravitational radius…we expect that this behaviour will be realised by all collapsing stars which cannot end in a stable stationary state…. of course, actual stars would collapse more slowly than the example that we studied analytically because of the effect of the pressure of matter, or radiation and of rotation*".

Kelvin went on to explain the physics of black holes and the calculation of the smallest dimension, known as the Schwarzschild radius; for the Sun this would be around 3 km. The Schwarzschild solution shows how, once the star has fallen within this gravitational radius, and from the perspective of an external observer, time would come to a halt and the radius would sink to infinitesimal size. And it is necessary to have some grasp of black hole physics to understand wormhole theories.

A paper by Albert Einstein and Nathan Rosen in 1935 demonstrated one of the first mathematical descriptions of a wormhole by performing a co-ordinate transformation on the Schwarzschild equation removing the region containing the curvature singularity. The solution is a mathematical representation of physical space by a space of two asymptotically flat sheets (-infinity, +infinity) connected by a bridge or Schwarzschild wormhole with a throat. The purpose of the paper had actually been to produce a field theory for particles such as electrons and Einstein and Rosen were not intending to produce a wormhole solution. But this is essentially what their solution is and the phenomenon is known colloquially as an 'Einstein-Rosen bridge'. However this is not a traversable wormhole.

The next major developments of a theoretical wormhole were by Kip Thorne and Michael Morris in the 1980s. They constructed a metric to describe a spherically symmetric and static wormhole, with the radii decreasing from negative infinity to a minimum value where the throat was located, and then increasing from this minimum value to positive infinity. This has a solution with the distinctive feature of being horizon-less. However, the physicists calculated that such metrics for wormholes would need enormous amounts of negative energy to hold open the throat, now referred as exotic energy.

Appendix: Wormhole Knowledge

If we start with the equation that describes events that pass through a spherically symmetric (non-spinning) centre of gravitational attraction one defines the Schwarzschild metric, which could be the equation to describe a black hole in polar co-ordinate form.

$$ds^2 = -\left(1-\frac{r_g}{r}\right)dt^2 + \left(1-\frac{r_g}{r}\right)^{-1} dr^2 + r^2(d\theta^2 + \sin^2\theta d\phi^2)$$

To an observer external to the black hole any particle approaching the black hole will appear to freeze at the event horizon, where r=rg, and this will define the event horizon of a black hole as the time term goes to zero:

$$-\left(1-\frac{r_g}{r}\right)dt^2 \equiv -\left(1-\frac{r_g}{r_g}\right)dt^2 \equiv -(1-1)dt^2 \equiv 0\times dt^2 = 0$$

To an observer external to the black hole any particle approaching the black hole will rush towards a singularity and be crushed by tidal gravitational forces. This will define the singularity of a black hole as the radii go to infinity:

$$+\left(1-\frac{r_g}{r}\right)^{-1} dr^2 \equiv +\left(1-\frac{r_g}{r_g}\right)^{-1} dr^2 \equiv +(1-1)^{-1}dr^2 \equiv \frac{1}{0}\times dr^2 \to \infty$$

We can also produce the first wormhole solution, the Einstein-Rosen bridge, by performing a co-ordinate transformation on the Schwarzschild equation, and simply substituting $r=u^2+2m$. This will then produce the following metric equation which describes a (non-traversable) wormhole solution:

$$ds^2 = -\frac{u^2}{u^2+2m}dt^2 + 4(u^2+2m)du^2 + (u^2+2m)^2 d\Omega^2$$

More advanced and realistic (traversable) wormhole solutions were later advanced by Kip Thorne, where f(r) and b(r) describes the shape of the wormhole and are known as the redshift function and shape function respectively.

$$ds^2 = -e^{2\phi(r)}dt^2 + \frac{dr^2}{1-b(r)/r} + r^2 d\Omega^2$$

Film Review: "Interstellar"

By Keith Cooper

Director: Christopher Nolan

Script: Christopher Nolan, based on a story by Jonathan Nolan and Kip Thorne

Starring: Matthew McConaughey, Anne Hathaway, Jessica Chastain, Michael Caine

Running time: 166 minutes

From the release of the first teaser trailer in November 2013, I was sceptical about ***Interstellar***. Here was Hollywood, muscling in on the territory of the interstellar community and bringing all Hollywood's clichés along with it for the ride. The interstellar community is about building an optimistic future for humanity, and that the only way we'll be able to successfully explore the stars is by working together, improving things on Earth, and forging

an adventurous spirit that embraces science and technology. On the other hand in the trailers the film ***Interstellar*** depicted a dying Earth and a last gambit to go into space.

So when I walked into the BFI's IMAX cinema at Waterloo in London for a preview screening of the film, my expectations were not particularly high. Nearly three hours later, I walked out of the cinema, my mind blown.

Yes, the Earth was dying. Yes, we'd made a mess of our future. What I didn't expect was that, despite all this, ***Interstellar*** would tell a tale where scientists are the main, heroic characters, where science is the key to saving humanity, and where eventually there is an optimistic future for humanity that is being driven by the pursuit of science. These are all things held dear by the ethos of our community, and things that our civilisation could do well to learn from.

Despite the name, ***Interstellar*** is not about interstellar travel per se. There's no discussion of world-ships or Bussard ramscoops, of specific impulses or fusion efficiency. Our team of astronauts, led by Matthew McConaughey's character Cooper, travel to another galaxy by cheating in a way; a mysterious intelligence out in the Universe has opened up a wormhole close to Saturn (cue one of the film's many magnificent visuals, with the astronauts' ship, Endurance, passing in front of the ringed planet) that leads to a supermassive black hole in a distant galaxy. Three planets orbit the black hole, and it is the mission of the crew of Endurance to find out whether any of these worlds could become a new home for humanity. No one suspects that it isn't the planets that they have been brought there for…

The real star of the film is Gargantua, a hundred-million solar mass supermassive black hole, and visual effects company Double Negative have outdone themselves by creating a black hole simulation that is even more accurate than the simulations that astrophysicists use, with 23 million pixels per image in IMAX quality footage! Of course, you can't make such a big deal about a black hole in a science fiction film if you don't send your characters into it – and beyond that, you'll need to see the film to find out what happens.

I am avoiding spoilers where I can because the film will have the biggest impact on the viewer if you go into it without too much prior knowledge about the plot. Let me just say that it is the only film I have ever seen where the key to saving the human race is to unify General Relativity with quantum mechanics to produce a theory of quantum gravity. That's how unique ***Interstellar*** is.

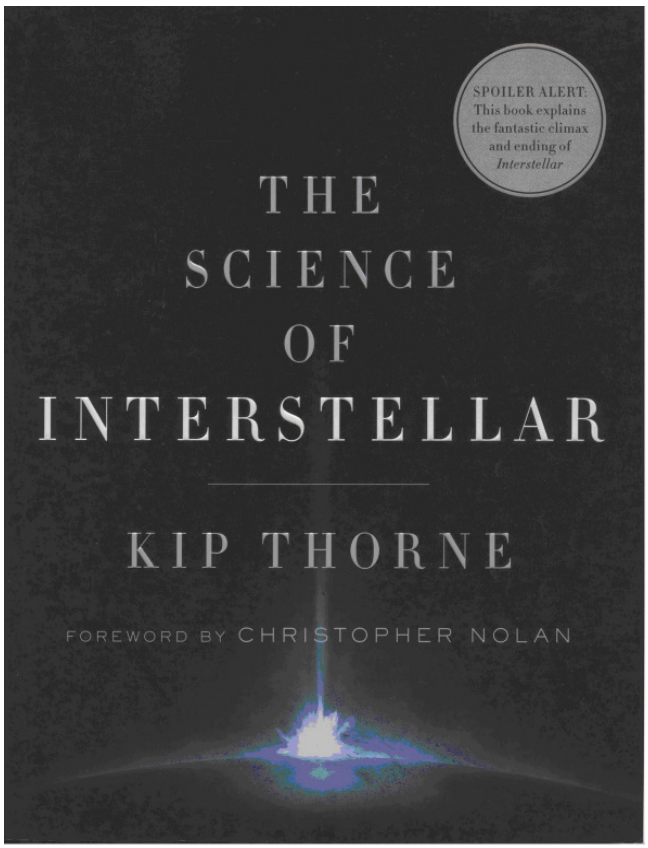
This certainly is not ***Star Trek***. ***Interstellar*** depicts space exploration as being very dangerous, while for much of the film the tone is one of despair, as things go wrong, the odds are stacked against our characters and hope seems to be in short supply. Yet hope there is and, at the last, it comes to the fore, heralding a fantastic future for humanity.

Once you have seen the film, you will really want to go back and see it again, to spot all the things you missed the first time around. ***Interstellar*** really is a film that rewards multiple viewings, especially once you have read Kip Thorne's book, ***The Science of Interstellar*** and are able to look at the film with a new scientific appreciation. Ignore critics who claim the science of the black hole or the time dilation on the planet closest to it are wrong – it's they who have got it wrong, and in Thorne's book, you will find out why.

Interstellar portrays science, and the exploration of space, in the most positive light. Yes, the film is a little too long, and yes, the stuff about 'love' being a force that transcends dimensions is eye-rolling and seems to have been included because Nolan either didn't want a purely scientific answer, or didn't trust the audience to accept one. But these are small quibbles when confronted with this near masterpiece of science fiction where the science is just as important as the fiction. It is a film about interstellar travel without being about interstellar travel, but the interstellar community could do far worse than to latch onto this film that epitomises the qualities that we will need to venture to the stars. Now if only Hollywood could couple the scientific ethos of ***Interstellar*** with the derring-do adventure of ***Star Trek***!

Book Review: "The Science of Interstellar"

By Keith Cooper



The Science of Interstellar

Author: Kip Thorne

Publisher: W M Norton

ISBN: 978-0-393-35137-8

Price: £14.99 (Pb) 324pp

Few people will come away from ***Interstellar*** truly understanding the science of the story they have just watched. Others may suspect the science to be wrong – especially the chances of surviving a black hole – but there are clues dotted around the narrative that flesh out the science for the careful viewer, and these clues are firmly expanded upon in Kip Thorne's book, ***The Science of Interstellar***.

Thorne is one of the world's leading scientists when it comes to General Relativity, wormholes, black holes and their ilk. Indeed, it would not be unfair to put him up on a pedestal alongside the likes of Roger Penrose and Stephen Hawking. Professor Emeritus in Theoretical Physics at Caltech, Thorne was friends with Carl Sagan and, when Sagan needed a method of travelling faster than the speed of light for his novel ***Contact***, it was Thorne who suggested wormholes and did the calculations. Wormholes once again feature in ***Interstellar*** and Thorne's accompanying book explains the science behind them as well as concepts of warped space, gravity, String Theory and quantum gravity that are also presented in the film.

This is no cheap cash-in on the film. Rather, Thorne was the genesis for ***Interstellar*** back in 2005, when he and his friend Lynda Obst, a successful Hollywood producer, developed the basics of its story. When Christopher Nolan came onboard and rewrote the script, Thorne remained as Executive Producer and Scientific Advisor. As Nolan says in his own words in the book's foreword, he would frequently quiz Thorne on the science, asking Thorne to get him out of scientific corners that he had written himself into.

For his part, Thorne had two rules. One was that nothing should violate the known laws of physics. The second was that any speculative science must spring from real theories, which have been peer reviewed and published in academic journals. And, for the most part, according to Thorne, the film works according to these two rules. On the odd occasions it deviates, which are generally for minor points, careful consideration was always taken. For instance, to navigate around a black hole, says Thorne, a spacecraft will need to utilise gravitational slingshots, but only other, smaller black holes have the requisite gravitational fields to slingshot a spacecraft around in the even stronger gravitational field of a supermassive black hole. The presence of smaller black holes around a bigger one would not be surprising – black holes grow through mergers – but in the film, Nolan was concerned that having more than one black hole would confuse viewers, so he changed it to a slingshot around a neutron star instead, which ultimately is never seen on screen anyway. The principle therefore remains correct, but the change renders the science just ever so slightly wrong. Did it have to be? I think they could have shown more than one black hole without confusing anyone, but I understand the choice. The fact that they included the slingshot in the first place is enough to impress me!

Like the film, there is not too much in the book about the science of interstellar travel beyond the discussion of wormholes. In the film, the spacecraft Endurance appears to be powered by chemical rockets (albeit highly efficient, reaching Saturn in two years, and then having plenty of fuel left over to fly around the black hole system) while the spaceplanes they use, called Rangers, are single-stage-to-orbit vehicles, presumably using some variation of air-breathing technology like Skylon's SABRE engine. Thorne does make an underestimation, as pointed out by i4is' John Davies and Kelvin Long, when he cites fusion-powered spacecraft as reaching velocities of only 300 kilometres per second by the end of this century, which would seem too small compared to Daedalus' designs that indicate it is possible to reach 100 times that velocity using fusion engines. To be fair, Thorne does not state it is the absolute limit that fusion rockets will reach, only that it will be the fastest we will reach by the end of the century as technology progresses. It is certainly not a fait accompli that we'll have Daedalus-style vehicles zipping around space by 2100, nor is it certain that we will crack the technology needed for highly efficient nuclear fusion as soon as we might like to, so Thorne may yet be proven correct. Whether you consider this a mistake, an underestimation, or an accurate

figure probably depends on how optimistic you are! However, the 300 kilometres per second that Thorne quotes seems to be derived from the Wikipedia page on interstellar travel, which Thorne references in the book. If this were any other book I would be concerned that the author's research on the topic was limited to just looking at the Wikipedia page, but since fusion power does not play a role in the film, and the majority of the book is about topics that Thorne is an expert in, I would put it down as a minor oversight.

We see Thorne's expertise come to the fore with the controversial science of the time dilation effect experienced on the world in the film called Miller's Planet. Christopher Nolan wanted an hour on Miller's Planet to be the equivalent of seven years on Earth. After seeing the film, many scientists publicly decried this plot point and when first confronted with it, Thorne was disbelieving of it too. However, after running calculations, he showed that a black hole spinning just a trillionth less than the speed of light could drag a planet around with it at half the speed of light – sufficient to create the time dilation effect.

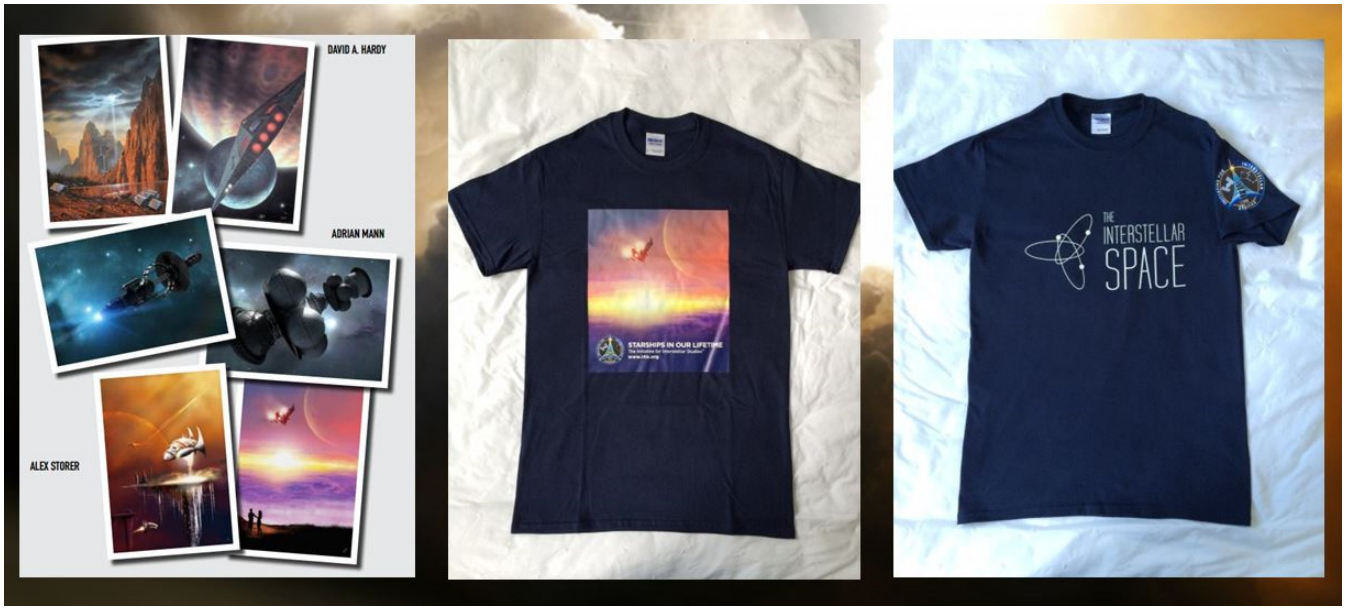
I don't want to get into too much detail about the rest of the topics covered in Thorne's book, as they give away the ending of the film. Suffice to say there is plenty on extreme physics, higher dimensions, string theory, the nature of black holes and event horizons, why it is theoretically possible to survive a supermassive black hole, what the mysterious space beyond our four familiar dimensions called 'the Bulk' is (which plays a large role in the film) and the secrets of the mysterious tesseract. Interestingly, Thorne says these are his 'interpretations' of the film. This does not mean they are different to what the film intended. For one, Thorne has been central to the film's production, but two, the best fiction always leaves itself open to different interpretations. ***Interstellar*** does likewise, and that's what helps drive subsequent debates about it.

Thorne explains all the scientific concepts without resorting to maths and using lots of diagrams, making it accessible to readers with little or no prior knowledge of theoretical physics. For those of us who do have a little knowledge, we may yearn for at least slightly more technical explanations, but we also know where else to find them. Their place is not in this book.

If you are looking for discussion on concepts of spacecraft propulsion, or issues that will affect interstellar travellers heading to Alpha Centauri, you won't find them in this book (try i4is' ***Beyond the Boundary*** book instead!). However, if watching the film has intrigued you, or you wish to learn about wormhole physics or the science of black holes, Thorne's book is an excellent introduction that, in conjunction with the film, will hopefully help inspire a new generation of scientists, including some among them who could one day make interstellar travel a reality.

Merchandise

We are pleased to bring you several merchandise items which feature artwork from some of our amazing artists, David Hardy, Adrian Mann, Alex Storer and Frank DaSilva. This includes post cards and i4is T-shirts. You can purchase a T-shirt for £15 and a pack of post-cards for £5, plus shipping. Just contact us at info@i4is.org



Pack of 6 postcards, i4is T-shirt (Alex Storer), i4is Loncon3 T-shirt (Frank DaSilva)

News From i4is

The last year has been a highly successful one for the Initiative for Interstellar Studies (i4is). We participated in the Tennessee Valley Interstellar Workshop (TVIW) with our own science fiction design workshop (more in our next issue) and we also set up our own symposium on the physics of wormholes held at the HQ of the British Interplanetary Society. In addition, we contributed to the World Science Fiction convention (Loncon3), held in London. This included our own hosted exhibition stand, presenting at the BIS session and hosting our own session to a packed out audience of over 200 people (more about this elsewhere in this issue). And last month we were at the 2015 UK National SF Convention, Eastercon, with a smaller but very prominent show (more about that in the next issue)

We have also held many physical and virtual meetings, bought merchandise to market, launched a new web site, and published our book “Beyond the Boundary”. Meanwhile, our

committee activities continue to ramp up and we have projects and initiatives going on across the globe. 2014 was an important year for us, and 2015 is looking even better.

One of the things we are pleased to announce is the launch of our very own supporting membership program. You can join for only £10/€12/$15 per year. If you would like to make a pledge to us, please get in touch and we would be most grateful for your support in our ambitious undertakings. All our directors and members are voluntary so every pound, euro and dollar really does make a difference to us. Contact us at info@i4is.org

Feature: i4is At the World Science Fiction Convention 2014, London

By John Davies

The 2014 World Science Fiction Convention, Loncon3, in August 2014, was the first really big event for The Initiative for Interstellar Studies. Here's how it happened as told by one of our project managers, John Davies.

The Team

John (organiser and your humble scribe), Terry Regan (builder of intricate models and mighty monoliths, practical brain), Gill Norman (our other main organiser, chivvier, charmer, Stakhanovite), Paul Campbell (organiser of AV and our other builder of mighty monoliths), Rob (video operator, charm and gravitas by the cubic yard!), Vidyasagar (brains, enthusiasm and can-do), Chris (adding ISU credibility and his own charm) and Kelvin (the indispensible) - and "on the day" Lindsay, Ian, Keith, Richard, Irianwen and Frank. And thanks to all for patience when nerves got frayed - mounting our projector on its side, packing the rope barriers and the tight squeeze of the monolith into that lousy van on the last day - we were there!

Flying the flag!

And we are extremely grateful to the Loncon3 team who granted us that large exhibition space, slotted half a day into the conference schedule, guided our first appearance at a big SF conference and sorted lots of things out as they happened.

The i4is Conference

Starting at the end! The i4is conference was a sell-out, thanks to -

- guerrilla marketing around the Con especially by Richard & Irianwen
- our star line up including writers Greg Benford, Alistair Reynolds and Stephen Baxter, world experts Kelvin Long and Rachel Armstrong
- and our message - we can go to the stars!

Rob Swinney, our Deputy Director, chaired the first half of the conference. Kelvin, our Executive Director, kicked off with ***Interstellar: realities and imagination*** discussing SF as an inspiration of future technologies sometimes leading to their realisation as a self-fulfilling prophecy. In particular, Arthur C Clarke's spacecraft and interstellar propulsion ideas may one day take us to the stars.


Greg Benford

Gregory Benford looked at ***Starships in Perspective***- starships are a huge step, but have striking historical parallels including US expansion across America in the 19th century and development of steam railways in just a few decades. And in less than 70 years we have moved from low earth orbit, about 120 kilometres, to Pluto, about 600 gigametres - i.e. 10^4 to almost 10^{12} metres - and one light year is "only" 10^{16} metres! Greg is a physicist, educator and author, a professor of physics at the University of California, Irvine, and his SF novels have won two Nebulas and many other awards.


Keith Cooper

Keith Cooper inspired us with ***Taking the Initiative - Why We Have To Start Planning for an Interstellar Future Now And Why You Should Be a Part of It.*** Organisations including I4IS plan a mission to the stars within 100 years, but the planning for this must begin now.

This will help protect humanity from existential risk, broaden our horizons and allow us to learn more about the Universe and our place in it. It is vital we begin planning now - envisaging a long future for humankind. This is not just for governments, everybody has the power to make a difference and help build a better future. Keith is editor of Astronomy Now magazine and a member of the Board of I4IS.


Chris Welch

Keith took over the chair and Professor Chris Welch of the International Space University (ISU) told us about the interdisciplinary project to define a century-long roadmap to interstellar travel, ***100 Years to Interstellar Travel***. The ISU is the only higher educational institution in the world focusing exclusively on the development of space. In 2015 ISU and I4IS will launch this project to define a 100-year roadmap to interstellar

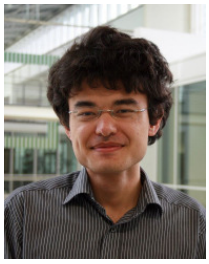
travel. Chris is Professor of Astronautics and Space Engineering at the ISU in Strasbourg, Vice President of the British Interplanetary Society and Deputy Chair of the I4IS Advisory Committee.


Rachel Armstrong

Rachel Armstrong, with ***Living Starships***, explained how life and machines can explore the cosmos in partnership. Currently, living things and machines are regarded as entirely separate and some futurists predict that things with soft wet bodies will be replaced by efficient machines formed from hard dry structures more suited to extra-terrestrial and interstellar environments. But can an ecology of relationships between living and mechanical systems do a better job? Rachel is Professor of Experimental Architecture at Newcastle University and a 2010 Senior TED Fellow.

Alastair Reynolds gave us ***Far Centaurus - the pros and cons of interstellar travel in science fiction***. He is one of our foremost writers of SF on interstellar themes. He was a space scientist at ESTEC, Noordwijk, studying pulsars and binary stars and is the author of 12 novels and winner of numerous awards. His Revelation Space series is set a far future where interstellar travel is well established and his most recent books, the Poseidon's Children sequence, are set in a near future with humanity just achieving interstellar capability.


Alistair Reynolds


Andreas Hein


Stephen Baxter

We ended with a panel session including all our speakers plus renowned interstellar novelist, Stephen Baxter, and Andreas Hein of Munich Technical University, our other Deputy Director, to discuss the general possibilities of interstellar flight. Kelvin, Chris and Rachel also spoke at the BIS conference earlier in the Convention so we had brilliant coverage.


Here is our conference chair, Keith Cooper, addressing the full house at the panel session. Alastair Reynolds is in the foreground

The Atmosphere

The Monolith was quite something - nearly 4m high, that's 13 feet to the Brits and Americans! Clearly visible up the stairs from the bar and almost as iconic as Dr Who's police box!

The monolith was in the exact proportions of the Clarke / Kubrick original - 12 by 22 by 32 or 1:4:9. One side in the authentic dark sheen and for the other.....

...here is the youngest space cadet watching an ISS astronaut cut his hair! We hope and believe we inspired all ages to an interstellar future.

And Terry Regan's model of the BIS Daedalus starship was a big attraction on the BIS stand next door. Here is Alastair Scott, BIS President, explaining it. Daedalus remains the most complete design for a starship.

We had a lot of interest at the stand and you may be reading this because you signed up for our newsletter when you visited the stand.

Here is Kelvin being interviewed - fortunately that camera can't see those cables, scaffold

Executive Director Kelvin F. Long talks to the media

Terry Regan's picture of the monolith screen showing the space station from 2001

tower, projector mount and other assorted messy technology! Find it on YouTube at http://youtu.be/CjTQ738P1Gk

On the last day we wound down a bit and some guys selling micro-drone quadcopters did brisk business. The real expert was Jeremy Nickless of Reaction Engines Limited, the Skylon company,

who was so pleased with his own piloting he handed us all REL t-shirts showing their amazing Synergetic Air Breathing Rocket Engine!

The Stand

On the convention stand the Monolith was the star (so to speak!). 4 metres high, it stood out like a beacon across the huge area of book, art and technology stands and it mesmerised visitors to the stand and i4is staff alike. Many of the 2001 film excerpts shown on it were of course accompanied by the Blue Danube and despite 4 days almost continuous film projection we never tired of it!

John Davies and Gillian Norman

Where next?

Well, I have told the tale backwards so it's easy to say "repeat from above"! And we have! - hi Dysprosium 2015! That's the UK annual SF convention over the Easter Weekend - we may have seen you at Heathrow? This has been our tale of the Worldcon. How we got there is another tale with lots of thrills and spills amongst all the hard work.

More about that in our next issue.

What's in Principium 10

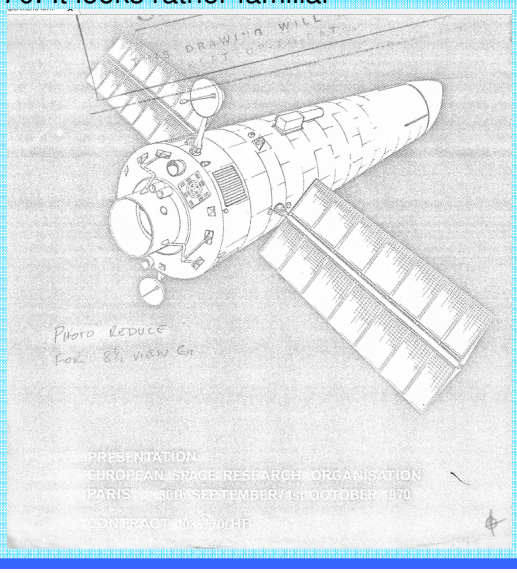
In the next issue of Principium we will be looking at the work of our colleagues at Icarus Interstellar, in particular their ***Project Voyager***, a new interstellar trajectory and mission planning tool. We will be recounting the other thought-provoking sessions from our ***Wormhole symposium*** and extending the Wormhole theme in this issue with ***"Wormhole - Stargates tunnelling through the cosmic neighbourhood"*** by Eric Davis of the Institute for Advanced Studies at Austin. We participated in the ***2014 Tennessee Valley Interstellar Workshop (TVIW)*** with our own science fiction design workshop and there will be an account in this issue. We also aim to ponder the interstellar ***implications of the Rosetta comet probe*** and its Philae lander. We have our fingers crossed for Philae to see the Sun and wake

up before this issue! And we will be celebrating the ***Shackleton 2 high altitude balloon project*** led by our friends, Sam Harrison and Daniel Parker, complete with a "selfie" of the i4is logo taken against black space and a very clear curve of the earth. And we will wrap up the ***Science Fiction Worldcon 2014*** story with an account of the thrills, spills and sheer hard work which went into organising this, our biggest event so far. And we'll report on smaller, but still prominent, presence at the annual ***UK Eastercon, Dysprosium***, at London Heathrow airport so if you could not jet in and see us this Easter then you see how we reached out again to the imaginative SF community.

More about our front and back covers

Stavros Hios: JOURNEY TO THE CENTER OF OUR GALAXY
The image shows a view of an illuminated, old sailing ship and the glow of the Milky Way as observed from the island of Paros, Greece, in the Aegean Sea. Since the Moon was in the new phase and because this area (southernmost point of Paros) is quite isolated, the night sky was nearly pitch black. The camera is facing in the direction of the constellation of Sagittarius -- toward the centre and densest portion of the Milky Way.
Find more of his work at www.flickr.com/photos/94980357@N02/.

NASA:STS-82 Shuttle Mission Imagery, STS081-E-5937 The Hubble Space Telescope (HST) begins its separation from Discovery following its release. **The HST is celebrating 25 years since its launch on the Shuttle**
One of the i4is team worked on an early study for a shuttle payload in 1970. It looks rather familiar -



Mission Statement

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 Statement

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

Values Statement

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.

Front cover: "Journey to the Center Of Our Galaxy", Stavros Hios, www.flickr.com/photos/94980357@N02/8667134176/

Back cover: Hubble Space Telescope begins its separation from Discovery following its release, spaceflight.nasa.gov/gallery/images/shuttle/sts-82/html/s82e5937.html

Editor: John I Davies / Kelvin F Long
Layout: John I Davies - based on the vision of Adrian Mann

www.i4is.org

We'd love to hear from you, our readers, about your thoughts on Principium, the i4is or interstellar flight in general.
Come along to Facebook, Twitter(@I4Interstellar) or LinkedIn to join in the conversation!

The Initiative For Interstellar Studies is a pending institute, incorporated in the UK May 2014 as a not-for-profit company limited by guarantee (number:09062458)