

PRINCIPIUM

The Newsletter of the Initiative for Interstellar Studies

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PLANET HOP FROM

TRAPPIST-1e

Scientia ad sidera
Knowledge to the stars

VOTED BEST "HAB ZONE" VACATION WITHIN 12 PARSECS OF EARTH

Editorial

Welcome to Principium, the quarterly newsletter about all things interstellar from i4is, the Initiative for Interstellar Studies - and now our US-based Institute for Interstellar Studies.

Our Guest Introduction for Principium 17 is *Advanced Ion Propulsion Systems for Interstellar Precursor Probes* by Angelo Genovese. Angelo is a propulsion engineer with many years of experience and he specialises in these very high specific-impulse reaction propulsion systems.

Looking just a little further ahead Tishtrya Mehta asks *Is the Alcubierre Drive the answer to Interstellar Travel?* Tishtrya is new to i4is but will surely become a major contributor to our work.

We bring you the first part of a major new work by Dmitry Novoseltsev, *Engineering New Worlds: Creating the Future*. This is a vision of the massive prospect of Interstellar Engineering. Subsequent parts will appear in our August & November issues.

Interstellar News this time covers the upcoming *UK Space Conference 2017* - May 30 - June 1, in Manchester, UK, where i4is will be talking Teachers, Outreach and Industry and the *Interstellar Flight workshop in New York*, 13-15 June 2017 - The Foundations of Interstellar Flight organised by i4is and the Center for Theoretical Physics (CTP) at the New York City College of Technology. Posters for both these events follow the News.

We also report on the latest *Schools Outreach* by i4is in UK and update on i4is *Project Glowworm* - with some new images of the Cubesat and chipsats by Efflam Mercier. And we have a letter from Satinder Shergill with his thoughts on the *i4is Interstellar Engineer* course 2016. And *Stop Press* congratulations for the \$500,000 NASA grant to Tau Zero Foundation.

On the wider cultural side we have an Album Review of new music inspired by interstellar and i4is. A review of the latest album from multi-talented Alex Storer, *Infinity of Space* by that longest-established of space artists, David Hardy. Patrick Mahon contributes a Book Review, *Starlight, Starbright: Are Stars Conscious?* by Professor Greg Matloff. Greg is known principally for his pioneering work in interstellar studies but here he speculates a little further with thinking inspired by the cosmic ideas of Olaf Stapledon.

If we are to build a space-based economy and culture then our resources need to be regulated by law. Sam Harrison of i4is and the International Space University (ISU) and Linda Dao of the ISU summarise a poster session, *Ensuring Equal Global Economic Opportunity and Security through Space Resource Law*, which they delivered during the United Nations / International Astronautical Federation Workshop on Space Technology for Socio-Economic Benefits in September 2016.

Our front and back covers this time reflect very different aspects of the outward urge of our species. You may have heard of the multi-planet system discovered by the 'TRAnsiting Planets and Planetesimals Small Telescope' (TRAPPIST) in Chile. NASA have imagined a tourist poster for the system. It's our front cover graphic. And we summarise and speculate in a News Feature by Patrick Mahon. This month's rear cover is a graphic from the Global Trajectory Optimisation Competition Portal (GTOC) by ESTEC, the technology arm of the European Space Agency, sophia.estec.esa.int/gtoc_portal.

Richard Osborne's *Orbital Mechanics in SevenEves* by Neil Stephenson is postponed. We hope to have this in the near future.

Next time we will have much to report on -

- Foundations of Interstellar Flight, New York, June
 - UK Space 2017, Manchester in May/June
 - Second Interstellar Studies elective at the International Space University, Strasbourg, May
- And we will have Part 2 of Dmitry Novoseltsev's visionary *Engineering New Worlds: Creating the Future*.

Comments on i4is and all matters interstellar are always welcome. Write to me!

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

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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.

Advanced Ion Propulsion Systems for Interstellar Precursor Probes

In this article, Angelo Genovese, Senior Electric Propulsion Engineer at Thales Deutschland, and Director of Experimental Programs at i4is, discusses how the descendants of our existing ion thrusters, propelling spacecraft like Dawn to Vesta and Ceres, can take us very much further.

INTRODUCTION

For more than 30 years, the space community has proposed an interstellar heliopause probe to investigate the outer regions of the heliosphere and the very local interstellar medium (LISM). Voyager 1 is the first human-made object to venture into interstellar space; it crossed the heliopause, the boundary separating solar and galactic plasmas, in August 2012 at 120 AU from the Sun, 35 years after the launch from Cape Canaveral in 1977. However, today its measurement capabilities are very limited, and in 5-10 years the on-board power will be too low for the probe to operate any scientific instrument further; at that time Voyager 1 will still be at less than 150 AU. The minimum required distance to reach the unperturbed "virgin" interstellar medium is expected to be at least 200 AU. A trip time of 25-30 years, within the professional lifetime of a scientist or engineer, is the target mission duration for a real LISM probe equipped with modern scientific instruments.

Few existing propulsion technologies can be extended to achieve this challenging mission. Electric propulsion (EP) is one of them, probably the most promising one together with the various space sail concepts (solar, laser, microwave, magnetic, electric). In order to reduce the propellant mass and consequently the spacecraft mass to reasonable values while keeping the travel time down to a scientist career lifetime, the specific impulse must be higher than 5,000 seconds even for a scientific mission to 200 AU, just outside the solar system heliosphere.

1. Electric Propulsion Historical Background

EP is a technology which allows for much higher exhaust velocities than conventional chemical propulsion, resulting in a major reduction of the propellant mass for a given space mission. This leads either to a significant decrease of the launch mass of a spacecraft or to larger payloads. In general, EP comprises all types of propulsion in which a certain amount of propellant is ionized

and then accelerated by electric or magnetic fields, or both. It was first conceived more than 100 years ago by the American physicist Robert H Goddard (1882-1945) who, as early as 1906, addressed the problem of producing "reaction with electrons moving with the velocity of light" and wrote down his thoughts on this problem in his notebook [1]. He was considering electrons and not ions because the concept of the ion, as an atomic-sized particle possessing a net positive charge, had not been fully established at that time. His visionary ideas culminated in a US Patent ("Method and means for producing electrified jets of gas", No. 1,163,037, filed in 1917) which represents the world's first documented electrostatic ion accelerator intended for propulsion.

Almost at the same time on the other side of the world Konstantin Eduardovitch Tsiolkovsky (1857-1935), a self-taught Russian school teacher of Kaluga, Russia, published his first statement on the possibilities of EP: "It is possible that in time we may use electricity to produce a large velocity for the particles ejected from a rocket device" in 1911 [2].

The third space travel visionary who independently developed the idea of EP was Hermann Oberth. Born in Romania, he studied physics in Germany and, in 1929, he published the all-time astronautics classic "Wege zur Raumschiffahrt" (Ways to Spaceflight).

The whole final chapter, "Das elektrische Raumschiff" (the Electric Spaceship), was about EP, predicting its future role in propelling spaceships to distant targets. This book was like a bible for an entire generation of space enthusiasts, among which there was a brilliant student of Oberth, Wernher von Braun. When von Braun was brought to the United States as part of Operation Paperclip in order to continue the work on the V-2 rocket at Fort Bliss, Texas, he asked his assistant Ernst Stuhlinger to review Oberth's research on EP: "Professor

Oberth has been right with so many of his early proposals; I wouldn't be a bit surprised if we flew to Mars electrically" [3]. Stuhlinger immersed himself in EP theory, and in 1954 he presented a paper at the 5th International Astronautical Congress in Vienna entitled, "Possibilities of Electrical Space Ship Propulsion", where he conceived the first Mars expedition using solar-EP [4]. The spacecraft design he proposed, which he nicknamed the "Sun Ship", had a cluster of 2000 ion thrusters using caesium or rubidium as propellant. He calculated that the total mass of the "Sun Ship" would be just 280 tons instead of the 820 tons necessary for a chemical-propulsion spaceship for the same Mars mission. In 1955 he published: "Electrical Propulsion System for Space Ships with Nuclear Source" in the Journal of Astronautics, where he replaced the solar-electric power system with a more powerful nuclear reactor (Nuclear Electric Propulsion - NEP). In 1964 Stuhlinger published the first systematic analysis of EP systems: "Ion Propulsion for Space Flight" [3], while the physics of EP thrusters was first described comprehensively in a book by

Robert Jahn in 1968 [5]. The first in-space demonstration of electric propulsion was an ion engine carried on board the SERT-1 (Space Electric Rocket Test) spacecraft, developed by NASA Lewis Research Center and launched on 20 July 1964; however, its complexity and the long development needed to demonstrate the lifetime required by EP missions (several thousands of hours) have long delayed its use as a standard propulsion system for commercial and scientific space applications. The first EP system demonstrated in space as primary propulsion is the one used by NASA's Deep Space 1 spacecraft, launched from Cape Canaveral on October 24, 1998; the NSTAR ion thruster, developed at NASA Glenn (see Table 1), provided a ΔV of 4.3 km/s using less than 74 kg of xenon. It thrusted for 678 days, far longer than any propulsion system had ever been operated in space. Primary power for the mission was produced by an innovative solar array technology, the Solar Concentrator Array with Refractive Linear Element Technology (SCARLET), which generated 2.5 kilowatts at 1 AU. The next NASA scientific mission to use NSTAR engines is the DAWN spacecraft; it was

launched in 2007 and it is the first spacecraft to orbit 2 solar system bodies thanks to its EP system, the protoplanet Vesta and the dwarf planet Ceres. DAWN is propelled by three NSTAR ion thrusters firing one at a time. The whole spacecraft is powered by a 10 kW (at 1 AU) triple-junction gallium arsenide photovoltaic solar array. The DAWN spacecraft reached Vesta in 2011 and Ceres in 2015 with just 400 kg of xenon, performing a total ΔV of 10 km/s, far more than any previous spacecraft has achieved with on-board propellant.

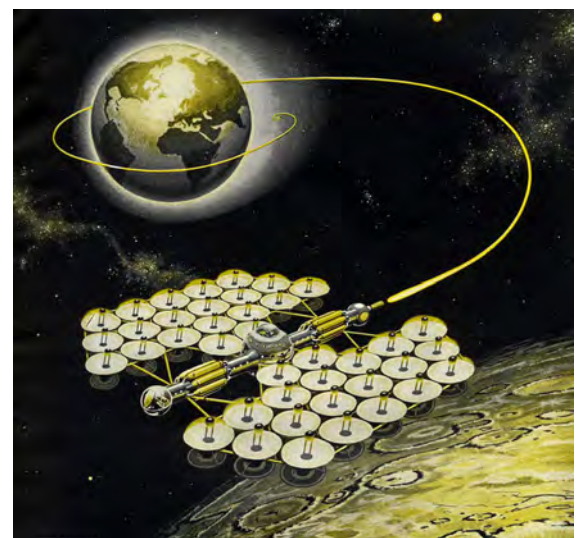
2. Ion Thruster State-of-the-Art

Ion thrusters use a variety of plasma generation techniques to ionize a large fraction of the propellant. These thrusters then utilize biased grids (from a few kV to more than 10 kV) to electrostatically extract ions from the plasma and accelerate them to high velocity. Ion thrusters can provide very high specific impulses (from 2000 to over 10,000 s) compared to other electric thruster types; hence, they are the best candidate for interstellar precursor missions [6].

Table 1 shows a list of ion thrusters with their main characteristics and their technology readiness level (9



Figure 1. Left: Ernst Stuhlinger (seated, left) poses with Hermann Oberth (center) and Wernher von Braun (seated right); on the background US General Holger Toftoy and Robert Lusser (image: NASA Marshall Space Flight Center). Right: Stuhlinger's "Sun Ship" (Image: Frank Tinsley/American Bosch Arma Corporation.)



corresponds to a flight-proven technology); notice how the specific power, the electric power per unit thrust, rapidly increases with increasing I_{sp} , as clearly shown in Figure 4. This drawback is particularly severe for interstellar precursor missions, which require very high specific impulses in order to reduce the propellant mass to acceptable values. Unfortunately, the power source mass increases rapidly with increasing Specific Impulse (I_{sp}), cancelling the advantage of a reduced amount of propellant. Hence, an advanced EP system for interstellar precursor missions needs a power source with very low specific mass α , expressed as mass per unit electrical power ($\ll 50 \text{ kg/kWe}$).

The innovative Dual-stage 4-Grid Ion Thruster has been proposed by Fearn (2000, [7, 8]) in order to extend gridded ion thruster performance to very high specific impulses, thus enabling interstellar precursor missions. Four grids are used instead of the usual three-grid arrangement in order to separate the ion extraction and acceleration processes (done simultaneously in current systems). This enables very high ion beam potentials to be put on the grids in the acceleration stage, thereby significantly increasing exhaust velocity, specific impulse, power density and thrust density. Fearn calculated that, using a

beam potential of 70 kV and a propellant with a mean atomic mass of 4.5 AMU (compounds of hydrogen with carbon and nitrogen), a specific impulse as high as 150,000 s is achievable. Using xenon (131.3 AMU), the specific impulse is almost 30,000 s, as shown in Figure 4. Applying higher beam potentials it is possible to get even higher specific impulses with xenon, with the drawback of higher specific power values.

3. Interstellar Precursor Missions with SEP

Loeb (2011, [10]) has proposed a combination of solar electric propulsion (SEP) with radioisotope electric propulsion (REP) in order to reach the goal of 200 AU within 25 years. The SEP stage for a heliopause probe is based on the exploitation of increased solar radiation flux and gravity by first going to the inner solar system and building up momentum there. The German RIT-22 ion thruster has been selected for the SEP stage; six RIT-22 thrusters running at +5 kV with a specific impulse of 7377 s. The propellant storage and feed system, electronic components and thermal control parts are mounted within the bus structure. The LISM probe with the REP-stage is mounted on top of the hexagonal SEP stage (see Figure 5).

After launch, the SEP-thrust is used to lower the perihelion by thrusting in anti-flight direction. The perihelion height is now lowered below Earth orbit but not closer than 0.7 AU, thus avoiding the need for a heavy thermal shield. Close to perihelion, when the solar panels provide maximum electrical power to the propulsion system, the probe is accelerated with maximum thrust. The SEP-stage's propellant is depleted after 831 days at a Sun distance of 3.05 AU, resulting in a heliocentric SEP-burnout velocity of 30.5 km/s (see Figure 6).

The REP stage will use RIT-10 ion thrusters. Performance variations of the REP/SEP combination resulted in a preferable beam voltage of 1.5 kV and specific impulse of 3810 s. With a power of 592 W and a xenon flow of 0.558 mg/s, the RIT-10 thruster delivers a thrust of 21 mN. Four RIT-10 engines are envisaged, running one after the other and thus, accelerating the LISM probe continuously for nearly 10 years ($\Delta V = 8 \text{ km/s}$).

Payload mass is assumed to amount to 35 kg. Eleven different scientific instruments are foreseen including a radar system and a camera to observe Kuiper belt objects along the trajectory. To power the thrusters, the scientific instruments, the telemetry, and housekeeping, four advanced

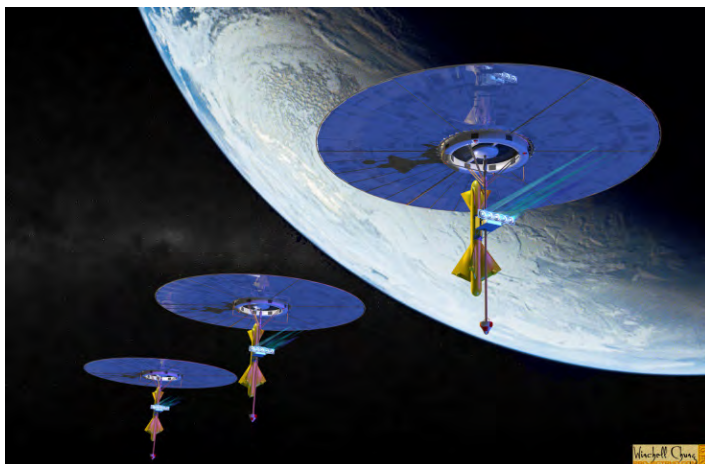
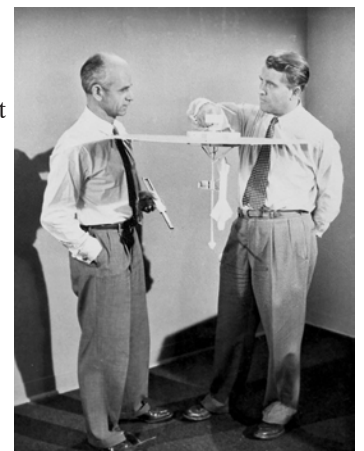


Figure 2. Left: Stuhlinger's proposed fleet of 10 nuclear-electric manned spacecraft for the 1957 Walt Disney television program "Mars and Beyond" (credit: © Winchell Chung). Right: E Stuhlinger and W von Braun pose with a model of the 1957 nuclear Mars spacecraft (image: NASA Marshall Space Flight Center).



radioisotope batteries (specific mass of 8.5 W/kg) would be required delivering 648 W at BOM (Beginning Of Mission) with a total mass of 76 kg. An Advanced Stirling Radioisotope Generator (ASRG) with a length of 62 cm has specifications close to the requirement.

With the described SEP+REP propulsion system and a capable launcher like the Ariane 5 ECA with a launch energy C_3 (hyperbolic excess energy) = 45.1 km²/s², which corresponds to a hyperbolic excess velocity of 6.7 km/s, a flight time of 27.5 years to 200 AU is achievable. Finally, making use of a Jupiter Gravity Assist (JGA) between the SEP phase and the REP phase results in a flight time of 23.7 years, with

a burn-out speed of 47.4 km/s (10 AU/yr), as shown in Figure 6.

In conclusion, SEP combined with REP enables us to send a spacecraft within less than 25 years to a solar distance of 200 AU. However, in 2013 NASA decided to cancel the ASRG development program due to budget cuts; hence, it is not clear if and when a sufficiently advanced RTG will be available for this kind of mission.

With just the SEP stage, the Ariane 5 ECA launch and the Jupiter Gravity Assist, a final speed of 8.4 AU/yr (2.3 times Voyager 1's speed) could be achieved; the SEP Probe would then reach 200 AU in 27 years, using state-of-the art technology (TRL ≥ 6). Furthermore, using an

SLS launch with a four-engine Exploration Upper Stage could give more than 350 km²/s², thus significantly reducing the flight time.

4. Interstellar Precursor Missions with NEP

The Thousand Astronomical Unit (TAU) mission was an interstellar precursor mission concept, studied by JPL scientists in the late 1980s, with the potential for enabling an unmanned probe to reach a distance of 1,000 astronomical units (0.016 light years) within a 50-year trip time [11]. The challenging ΔV needed (> 100 km/s) can be achieved with an advanced nuclear reactor in the 1 MWe class with a specific mass of 12.5 kg/kWe and a full-power operating (thrusting) time of 10

Table 1:
Characteristics of ion thrusters including their Technology Readiness Level (TRL)

Engine	Specific Impulse (s)	Required Power (kW)	Thrust (mN)	Specific Power (kW/N)	Verified Lifetime	TRL	Mission
NSTAR	3300	2.3	92 max	25	30,000h (3.4 years)	9	Deep Space 1, Dawn
RIT-10 (10 cm-dia)	3810	0.59	21	28	23,000h (2.6 years)	9	EURECA, ARTEMIS
RIT-22 (22 cm-dia)	4760	5.8	175	33		7	IHP probe
NEXT	4100	7	236 max	30	48,000h (5.5 years)	7	NASA Flagship, New Frontiers
NEXIS (57cm-dia)	7000	20	440	45	2000h	5	JIMO (cancelled)
HiPEP	6000-9600	25-50	460-670	55-75	2000h	5	JIMO (cancelled)
DS4G (laboratory prototype, 30kV)	15000	0.61	5.4	90-110		3	
DS4G (predicted, 70kV)	28000	240	1500	160		1	400 AU mission (Fearn 2008 [22], Advanced TAU)



Figure 3.

The 20 kW Nuclear Electric Xenon Ion thruster System (NEXIS) developed at NASA-JPL for the Jupiter Icy Moons Orbiter (JIMO), later cancelled (both courtesy of NASA).

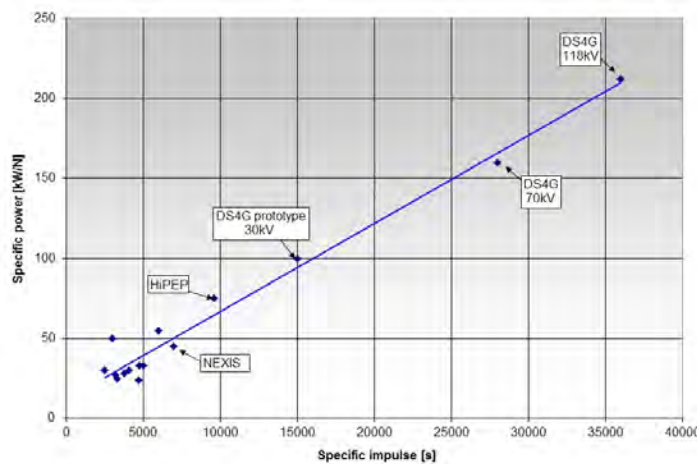


Figure 4.

The required electric power per thrust unit rapidly increases with the specific impulse (dots are measured or predicted values from Table 1, propellant used is Xenon).

Credit: Angelo Genovese

years. The ion thrusters required would have a specific impulse I_{sp} of 12,500 s, a thrust of 6.8 N, an input power of 490 kW, and a burn time (per thruster) of 2 years. As two thrusters would have to fire simultaneously to provide the total thrust of 13.6 N, and taking into account a 20% redundancy, a cluster of 12 thrusters was considered to perform the mission.

How realistic is the TAU mission?

- Today a space nuclear reactor can be realized with a specific mass of 30 kg/kWe. An advanced nuclear reactor using a Brayton conversion cycle can be developed with a specific mass of 10 kg/kWe within 20 years (Berend, 2012 [12]).

- NASA’s HiPEP ion thruster has demonstrated a specific impulse of ~ 10,000 s (TRL 5); the TAU ion thruster can be developed within the next 20 years.

5. Interstellar Precursor Missions with LEP

A high-power laser beam coming from an in-space laser power transmitter is aimed at a photovoltaic (PV) collector on the target spacecraft, where it is converted to electricity for a high-power EP system (see Figure 7, left). This type of space propulsion is called Laser-powered Electric Propulsion (LEP). The PV collector/converter on the spacecraft can be tuned to the laser wavelength, thus achieving high monochromatic

conversion efficiencies, currently ~ 50% with the potential to reach 80% in the near future (Bett, 2008 [13]).

Tsiolkovsky had clearly anticipated laser-powered propulsion in this quote from 1926: “We may have a case when, in addition to the energy of ejected material, we also have an influx of energy from the outside. This influx may be supplied from Earth during motion of the craft in the form of radiant energy of some wavelength” [14]. As regards the in-space laser power transmitter, it is already possible to build a large array of laser emitters capable of creating a combined high power laser beam (Lubin, 2015 [15]), see also Figure 7, right.

Laser-Powered TAU Mission

The TAU mission can greatly profit from the LEP concept. Instead of a huge nuclear reactor with a mass of 12.5 tons (1-MWe class with a specific mass of 12.5 kg/kWe), we could have a light monochromatic PV collector with 50% efficiency and a specific mass of just 1 kg/kWe. This allows us to use a more advanced ion propulsion system based on 12 high-power ion thrusters (each 2 MW, ~50,000 s specific impulse, 6.8 N thrust) using the same thrusting strategy as for the original TAU mission. The much higher

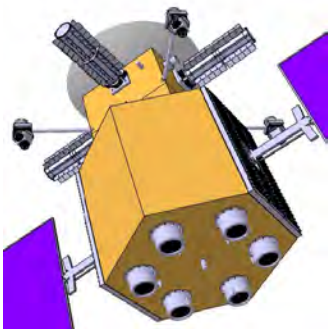
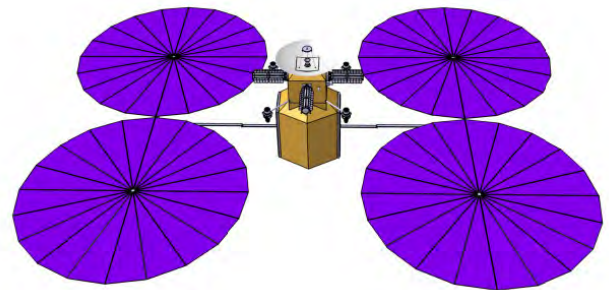


Figure 5.
Left: SEP stage with 6 RIT22 ion thrusters, with the LISM probe on top of it.
Right: the SEP stage equipped with 4 light-weight solar arrays
Both credit Loeb, H. W., et al.[10]



specific impulse allows a substantial reduction in propellant mass from 40 tons to 10 tons, leading to a TAU initial mass of just 23 tons instead of 62 tons. The final burnout speed is 240 km/s (50 AU/yr), which permits the mission to reach 1000 AU in just 25 years. This is possible assuming that the laser beam is constantly illuminating the PV collector with at least 8 MW (4 MW are needed by the two 50,000 s ion thrusters firing simultaneously) during the whole thrusting time of 10 years up to a distance of 230 AU. This

is a huge distance to keep a laser beam focused on the spacecraft collector; this challenging issue has been investigated by Forward and Landis [16, 17].

SUMMARY

Electric Propulsion is a major candidate for the propulsion system of near-term interstellar precursor missions:

- » The present EP performance level can enable a 200 AU mission to the undisturbed interstellar medium with a trip time of < 30 years.
- » Advanced EP concepts (DS4G, Isp = 50,000 s) can be powered

by a medium-size space laser array (8 MW) enabling a 1000 AU mission with a trip time of just 25 years.

- » The laser-powered EP concept has the potential of significantly reducing the development time of the most visionary missions like Planet 9, FOCAL, TAU, Oort Cloud.

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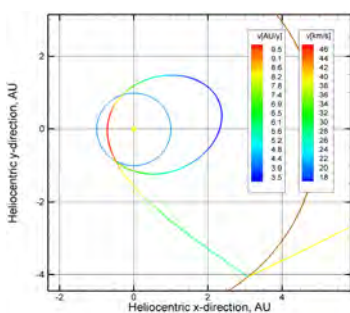


Figure 6.
Left: SEP+REP transfer to 200 AU with a gravity assist at Jupiter. Credit Ohndorf, A. et al [18].
Right: Exploration Upper Stage for the SLS launcher Credit: Boeing.



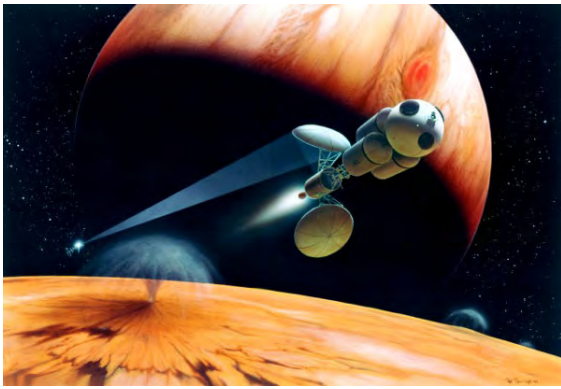
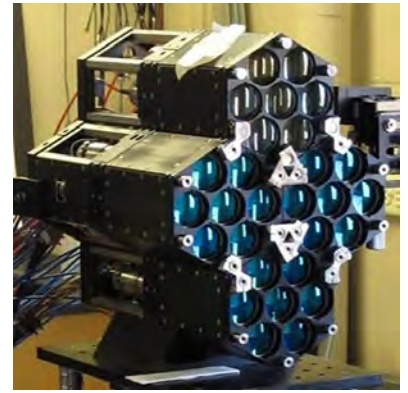


Figure 7.

Left: a laser beam illuminates the PV collector of a high-power EP spacecraft (source: http://www.projectrho.com/public_html/rocket). Right: array of 21 laser emitters generate and steer a combined beam (Courtesy of DARPA).



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About the Author

Angelo Genovese is Director of Experimental Programs at the Initiative for Interstellar Studies. Angelo has a Master’s Degree in Aerospace Engineering (specialising in Space Propulsion) from the University of Pisa, Italy (1992). He has been an Electric Propulsion Engineer at the Italian space propulsion research centre “Centrosazio” in Pisa, developing Field Emission Electric Propulsion (FEEP) ion thrusters for ultra-precise positioning of scientific spacecraft. In 2000 he moved to the Austrian Research Centres in Vienna, Austria, where he contributed to an Indium FEEP Micro-propulsion System from breadboard to qualification level for the ESA mission LISA Pathfinder. Since 2009 he has been working at Thales Deutschland, Ulm, Germany, on the development of the innovative ion thruster HEMPT, suitable for new-generation telecom satellites and advanced scientific missions. Angelo has published more than 50 papers in conferences and scientific journals including JBIS, and he contributed to two patents on Indium FEEP ion thrusters. Profoundly interested in advanced space propulsion systems for interstellar precursor missions, he is a Corporate Member of the Initiative for Interstellar Studies (i4is), in particular involved in the Technical and Educational Committees. He has contributed to the i4is book “Beyond the Boundary” with a chapter on advanced electric propulsion. Angelo is also a member of BIS, Icarus Interstellar, Mars Society and the Planetary Society.

Interstellar News

John Davies with the latest interstellar-related news

i4is Sustainability Committee

Sustainability is a buzz word nowadays. According to Kajikawa (2008) sustainability encompasses three dimensions: the economic, environmental, and the social. As a space organization, we asked ourselves the question how we can interpret sustainability in a unique way in order to make unique contributions.

The i4is Sustainability Committee has the objective of conducting R&D and education at the intersection between space and sustainability. More specifically, our focus areas are:

- Sustainable space economy: Building up a sustainable space economy via asteroid mining, manufacturing in space, etc.
- Sustain and Spread life in space: building environments for space colonization, seeding celestial bodies, etc.
- How space can contribute to a sustainable Earth: reduce pollution on Earth, move industrial activities into space etc.

In 2016 / 2017, we have conducted two studies on a sustainable space economy, focusing on manufacturing in space and asteroid mining. You find below a short description of these studies.



“The recent developments in space commercialization and the entry of new private entities of various size has re-opened the question of in-space manufacturing. This paper examines the viability of a broad set of initial use cases for in-orbit manufacturing around the Earth in particular, involving technologies that can be developed within 3-5 years. These include large aperture spacecraft or components, components for traditional satellites, standards-based components and nanosatellites such as cubesats, and serial production commercial satellite use cases among others.”



“Recent studies suggest that Near-Earth Asteroids (NEA) supposedly contain enough volatile and high value minerals to make the mining process economically feasible Most proposed projects for asteroid mining, however, involve single spacecraft that are traditionally large and expensive. As an alternative approach, asteroid mining could be based on multiple small spacecraft, another emerging trend in the space sector, which could enable a higher degree in reliability and a potentially lower cost of operation and a smaller chance of single point failures. Nonetheless, limited analysis on the asteroid mining capability of small spacecraft was conducted so far.”

We are currently collecting proposals for projects for these areas. Anybody interested in contributing to the committee is highly welcome to contact us via info@i4is.org

Ref: Kajikawa, Y. (2008) Research core and framework of sustainability science. Sustainability Science, 3(2).

UK Space Conference
May 30 - June 1, Manchester, UK

We'll be at both the ESERO Teachers Conference and the UK Space Outreach event alongside the UK Space Conference 2017 to talk to industry experts, space leadership, teachers, ESERO and STEM Ambassadors about interstellar. Find out more at ukspace2017.co.uk.

But the **Outreach** event will allow us to extend this to talk to everybody who has an interest in space. We believe the interstellar vision can inspire not only school students but everybody. And this is not just Science, Technology, Engineering and Maths but also wider subjects and creative activity in all its forms. Register at discover-space.eventbrite.co.uk and come and join us where you see our banner.

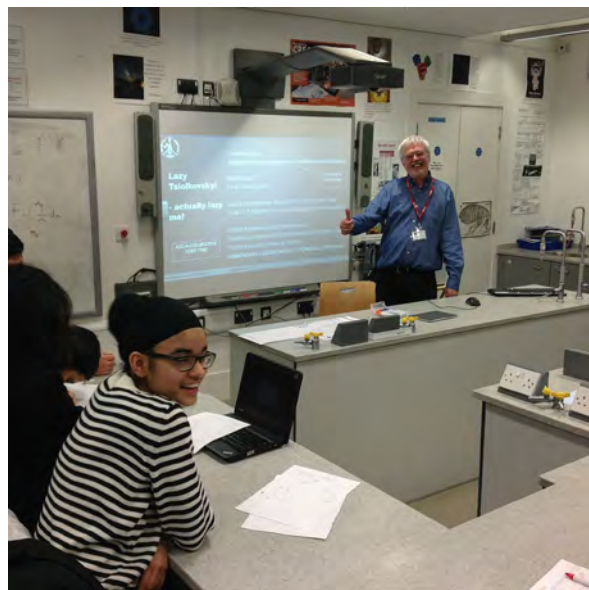


[Interstellar flight workshop in New York, 13-15 June 2017](#)

The Foundations of Interstellar Flight workshop will take place 13-15 June 2017 in New York City at the New York City College of Technology (www.citytech.cuny.edu). The final programme is now announced. Programme including abstracts, registration and accommodation at www.citytech.cuny.edu/physicsworkshop. It includes 27 papers from experts based in UK, USA, Italy, Germany, Russia and Canada on topics as diverse as the *Fusion Fuel Resource Base in our Solar System* and *Combined Thermal Desorption and Electrical Propulsion of Sailcraft*. The three days concentrate on Energetic Reaction Engines, Sails

And Beams and Breakthrough Propulsion respectively. Presenters include some of the most influential people working in interstellar R&D including Philip Lubin of UCSD, Robert Freeland of Icarus Interstellar, Harold G White of NASA Eagleworks and, of course, our own Kelvin F Long. There is an accompanying dinner and arts event, COSMOS IMAGININGS, June 12, 2017, hosted by the Institute for Interstellar Studies and City University New York at the Harvard Club of New York City. For enquiries contact info@i4is.org.

Posters showing the event, conference programme and social/arts event follow this News.



John at Featherstone High School. One of the 2016 Interstellar Challenge winning team in the foreground having as much fun as John. Picture courtesy of teacher Ragee Tarabi, Featherstone High School

The i4is team at Tech City College Terry Regan, John Davies and Jerry Clark



[Schools Outreach](#)

At i4is we love doing work in schools. Since the last Principium we have been at two London schools. It would be great to extend this UK-wide so please get in touch to help us match our work in and around London.

Featherstone High School, in Feltham, West London, were the winners of the first i4is Interstellar Challenge for schools last year. Ms Jeyachandran, Head of Applied Sciences, invited us to help in their Science Week this year. On the day, physics teacher Mr Tarabi coordinated a group of the brightest STEM enthusiasts and John Davies set them the challenge of deriving Tsiolkovsky's equation directly from Newton's second law, paralleling the method in John's spreadsheet approximation to Tsiolkovsky. Mr Tarabi gave them a quick refresher on integration and they came close to an answer. Well Done!

If you know a derivation which does not use conservation of momentum then email John - john.davies@i4is.org.

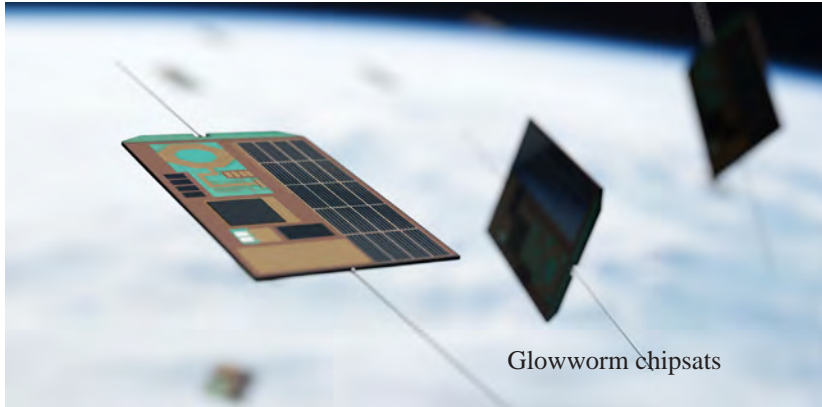
The Featherstone students included the Challenge winning team. It was great to meet them to chat about their ambitions.

Tech City College, London, is a very new school with big ambitions. It's on City Road (remember the song, *Pop goes the Weasel?*) between Islington and the City, a classic London area of mixed social classes and cultures. Deputy head Alton McDonald invited i4is to the College STEMfest and three of the team spent a brilliant day talking to staff, students and visitors. Many requested Principium and we welcome them all to our readership from this edition forward.

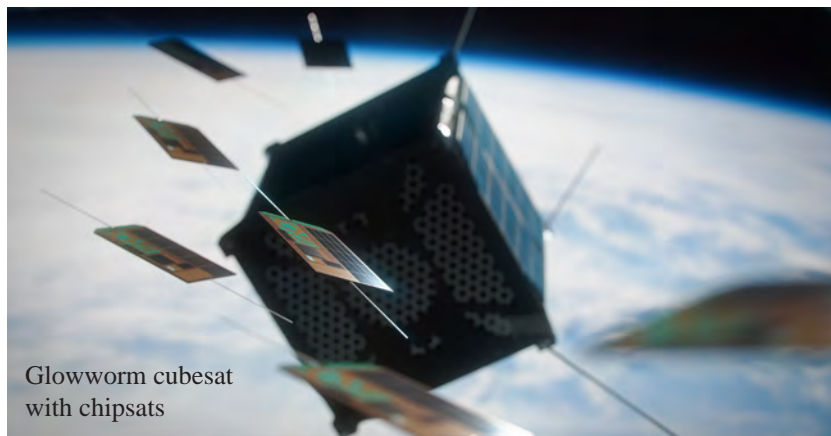
i4is Project *Glowworm*

Project Glowworm (i4is.org/what-we-do/technical/project-glowworm) is the latest i4is project. The project is led by Andreas Hein, i4is Technical Committee, and Stefan Zeidler, i4is Enterprise Committee. We introduced this laser push demonstrator in P16, February 2017 - including the project plan.

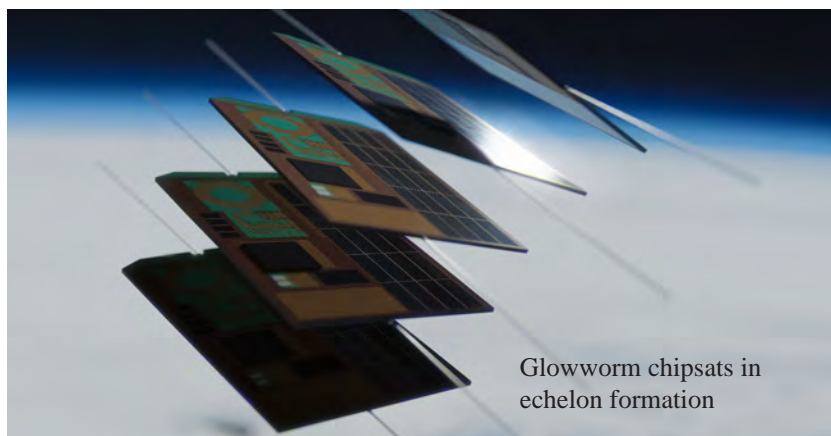
Our good friend Efflam Mercier has been inspired to create more beautiful art by our project. We present some of his images here.



Glowworm chipsats



Glowworm cubesat with chipsats



Glowworm chipsats in echelon formation

NASA Grant Award to Tau Zero Foundation

As P17 went to press, we learned that NASA has awarded a \$500,000 grant to the Tau Zero Foundation for a 3-year study titled “Interstellar Propulsion Review.” Unlike prior studies, which were based on a specific mission concept, this study is an overall comparison between the different motivations, challenges, and approaches to interstellar flight. More at www.centauri-dreams.org/?p=37577

Congratulations from i4is to both TZF & NASA on this major contribution to interstellar vision and planning.

LETTER to the Editor

Thoughts on Starship Engineer 2016 from Satinder Shergill

Both days of the workshop were excellent. Starting with an introduction to different spacecraft systems, starship designs with associated calculations and case studies, the first day culminated with a group activity made up of several tasks including the design of a starship. The tasks allowed much of the theory that had been introduced to be applied and introductory knowledge to be built upon. It was great to have so many different people representing a wide range of ages and backgrounds coming together to work on the design of the starship.

The presentations and discussions assessed feasibility from an engineering and physics standpoint, after which the remainder of the session was dedicated to the design of a starship. This session differed from the previous day, in that it allowed the group to play with some of the more far out, longer term, ideas that still require engineering solutions before they can truly be considered as achievable. Many different scenarios and mission designs were discussed in terms of destination, crew sizes, life support, structures and propulsion. The wide range of individuals involved meant that many different perspectives were shared, with everyone working in smaller groups within their chosen subsystem. I thoroughly enjoyed both days.

Satinder Shergill, MSc Cranfield, teaches science at Space Studio West London and is researching for a PhD at Cranfield.



FOUNDATIONS OF INTERSTELLAR STUDIES

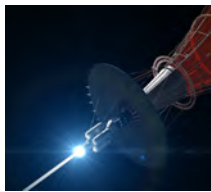
Workshop on Interstellar Flight

CUNY City Tech, New York, USA • June 13 - 15 2017

At the start of this new millennium we are faced with one of the greatest challenges of our age - can we cross the vast distances of space to visit other worlds around other stars? At the end of the last century the idea of interstellar travel was considered one of science fiction. In recent times that has changed and interstellar flight has received much interest. This is particularly since the discovery of many planets outside of our Solar System around other stars. Indeed, we now know that an Earth sized mass planet orbits one of our closest stars, Proxima b. In addition, national space agencies and private commercial industry are beginning to turn their attention to the planets and beyond. It is time to start considering the bold interstellar journey and how we might accomplish it. Yet, this challenge presents many difficult problems to solve and who better to address them than the global physics community. The Institute For Interstellar Studies (I4IS) and the Center for Theoretical Physics (CTP) at City Tech have partnered to bring together some of the best minds in the fields of physics to address some of the fundamental problems associated with becoming an interstellar capable civilisation.

Program:

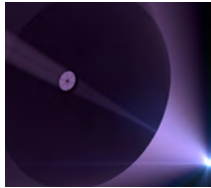
DAY 1: ENERGETIC REACTION ENGINES



Any engines which involve the ejection of matter or energy rearwards from the vehicle for thrust generation. e.g. electric, plasma, nuclear thermal, fission, fission-fragment, fusion, antimatter catalyzed fusion, antimatter. Specific problems for focus might include:

1. Credible fusion ignition physics models for high gain.
2. Practical methods for Achieving Antimatter Catalyzed Fusion.
3. Mitigation and shielding methods for large radiation fluxes from energetic engines.
4. The design of large magnetic fields for use in space transportation.
5. Efficient acquisition and mining methods for large quantities of fuels.

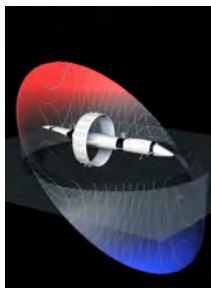
DAY 2: SAILS AND BEAMS



Any concepts which involves the transfer of momentum via photons or particle beams, e.g. solar sails, laser sails, microwave sails, particle beamers, stellar wind pushers. Specific problems for focus might include:

1. Achieving a stable structure and light-sail geometry for beam riding.
2. Mitigating the effects of interstellar dust and ionization.
3. Dissipation of heat buildup on sail from a laser beam or high velocity close solar flyby.
4. The design of low mass, thin, materials for (high g) sail concepts.
5. Systems Architectures, fabrication and Construction Methods for ground and Space Based Beaming methods.

DAY 3: BREAKTHROUGH PROPULSION



Any breakthrough propulsion concepts, an area of technology development that seeks to explore and develop a deeper understanding of the nature of space-time, gravitation, inertial frames, quantum vacuum, and other fundamental physical phenomena with the overall objective of developing advanced propulsion applications and systems that will revolutionize space exploration. Specific problems for focus, but not limited to, might include:

1. Proposed methods for mining energy from the Quantum Vacuum.
2. The generation and control of large negative energy densities, derivation of space-time metrics to reduce negative energy requirements, and/or higher dimensional physics models.
3. Emergent gravity/emergent quantum mechanics models, pilot wave theory, or other new approaches to reconciling Quantum Mechanics and General Relativity which leads to new space-time transport solutions.
4. Space drive concepts that generate force by interactions with the vacuum/space-time.
5. Experimental approaches/findings related to the exploration of breakthrough propulsion concepts.

Sponsored by:

BREAKTHROUGH
INITIATIVES



LEAD ORGANIZING COMMITTEE:

Professor Roman Kezerashvili, Co-Chairman,
rkezerashvili@citytech.cuny.edu
Kelvin F. Long, Co-Chairman, Kelvin.Long@i4is.org
Elena Ancona, Secretary, elena.ancona@gmail.com

CUNY New York City College of Technology, Atrium Amphitheatre,
Namm building, 300 Jay St, Brooklyn, NY 11201, USA

For registration and any enquires please see the web link below or contact the event secretary Elena Ancona: elena.ancona@gmail.com
<http://www.citytech.cuny.edu/physicsworkshop> or call: 718 260 5277/5276

Program for the Workshop of Interstellar Flight

June 13-15, 2017, New York, NY USA

12th June 2017, Opening dinner at the Harvard Club of New York City – 1800-1900.

Free of charge for all registered participants. (<https://www.hcny.com/>)

13th June 2017, DAY 1: Energetic Reaction Engines

08.15	Late registrations		
08.30	Opening by Organizing Committee		
08.40	Welcome by Session Chairman: Kelvin F. Long		
08.50	1. The Fusion Fuel Resource Base in our Solar System	Robert G. Kennedy III	Institute for Interstellar Studies US
09.30	2. Heat Transfer in Fusion Starship Radiation Shielding Systems	Michel Lamontagne	Icarus Interstellar
10.10	3. Plasma Dynamics in a Z-Pinch Fusion Engine	Robert Freeland	Icarus Interstellar
10.50	Coffee break		
11.10	4. Continuous Grid Inertial Electrostatic Confinement Fusion	Raymond J. Sedwick et al.	University of Maryland
11.50	Workshop Discussion Session		
12.30	Lunch break		
13.30	5. Direct Fusion Drive for Interstellar Exploration	Samuel Cohen et al.	Princeton Plasma Physics Laboratory
14.10	6. High Beta Cusp Confinement: A Path to Compact Fusion	Regina Sullivan	Lockheed Martin Skunk Works
14.50	7. Laser-Powered Electric Propulsion for Interstellar Precursor Missions	Angelo Genovese	Initiative for Interstellar Studies
15.30	Coffee break		
15.50	8. Positron Propulsion for Interplanetary and Interstellar Travel	Ryan Weed et al.	Positron Dynamics Inc.
16.30	9. Combined Thermal Desorption and Electrical Propulsion of Sailcraft using space environmental effect	Elena Ancona and Roman Ya. Kezerashvili	New York City College of Technology
17.10	Workshop Discussion Session		
17.50	Chairman Summary		

14th June 2017, DAY 2: Sails and Beams

08.40	Welcome by Session Chairman: Harold White		
08.50	1. Solar Sail Propulsion: A Roadmap from Today's Technology to Interstellar Sailships	Les Johnson & Edward E. Montgomery	Tennessee Valley Interstellar Workshop and MontTech LLC
09.30	2. Enabling the First Generation of Interstellar Missions	Philip M. Lubin	UC Santa Barbara
10.10	3. The Andromeda Study: Some Design Solutions for Project Starshot	Andreas M. Hein et al.	Initiative for Interstellar Studies
10.50	Coffee break		
11.10	4. Solar System Escape Mission with Solar Sail Spacecraft in the Framework of Post-Newtonian Gravitational Theory	Olga L. Starinova and Irina V. Gorbunova	Samara National Research University
11.50	Workshop Discussion Session		
12.30	Lunch break		
13.30	5. Effects of Enhanced Graphene Reflection on Performance of Sun-Launched Interstellar Arks	Gregory L. Matloff	New York City College
14.10	6. Gram-Scale Nano-Spacecraft Entry into Star Systems	A. A. Jackson	Lunar and Planetary Institute
14.50	7. Rigid Light Sail Dynamics and Control for Launch and Acceleration Using Controlled Optical Metamaterials	Eric T. Malroy	NASA Johnson Space Center
15.30	Coffee break		
15.50	8. The Prediction of Particle Bombardment Interaction Physics due to Ions, Electrons and Dust in the Interstellar medium on a Gram-Scale Interstellar Probe	Kelvin F. Long	Institute for Interstellar Studies
16.30	9. Accelerator Technologies for Simulation of Dust Impacts at Starflight Velocities	Andrew J. Higgins	McGill University
17.10	Workshop Discussion Session		
17.50	Chairman Summary		
20.00	Workshop Dinner		

15th June 2017, DAY 3: Breakthrough Propulsion

08.40	Welcome by Session Chairman: Roman Kezerashvili		
08.50	1. Pilot Wave Model for Impulsive Thrust from RF Test Device Measured in Vacuum	Harold G. White	NASA Johnson Space Center
09.30	2. Mach Effect Gravitational Assist Drive	Heidi Fearn et al.	California State University Fullerton
10.10	3. Entanglement and Chameleon Acceleration	Glen A. Robertson	GAResearch LLC
10.50	Coffee break		
11.10	4. Tests of Fundamental Laws and Principles of Physics in Interstellar Flight	Roman Ya. Kezerashvili	New York City College of Technology
11.50	Workshop Discussion Session		
12.30	Lunch break		
13.30	5. An Epitaxial Device for Dynamic Interaction with the Vacuum State	David C. Hyland	Texas A&M University
14.10	6. Pressing Hydrogen to Exotic Quantum States	Ranga Dias	Harvard University
14.50	7. Self-Sustained Traversable Wormholes and Casimir Energy	Remo Garattini	Initiative for Interstellar Studies UK and University of Bergamo
15.30	Coffee break		
15.50	8. Human Exploration of The Solar System as a Precursor to Interstellar Travel: Outlook & Realities	Ralph L. McNutt Jr.	Johns Hopkins University
16.30	9. First Stop on the Interstellar Journey: The Solar Gravity Lens Focus	Louis Friedman and Slava G. Turyshev	The Planetary Society and California Institute of Technology
17.10	Workshop Discussion Session		
17.50	Chairman Summary		

Poster Presentations displayed during the workshop

COSMOS IMAGININGS

June 12, 2017

Hosted by the Institute for Interstellar Studies
and City University New York



Artists Work Exhibited:

Adrian Mann

Alex Storer

C Bangs

Alexandra Limpert

Carmela Tal Baron

David A Hardy

Kari Weatherbee

Rick Sternbach

Organizer: Kelvin F. Long

Art Co-ordinator: C Bangs

Reception: Monday, June 12, 6-9 pm

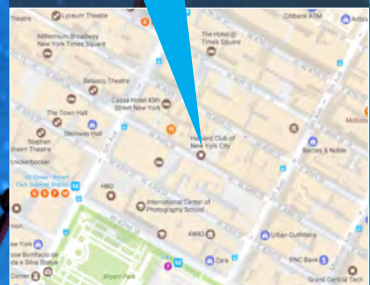
Attendance by invitation only.

The evening will be accompanied by a buffet dinner, wine and a 3-piece classical orchestra.

Cambridge Room, Harvard Club of New York City, 35 West 44th Street, New York, NY 10036.

For enquiries contact info@i4is.org

The Harvard Club of New York City is located at 35 West 44th Street between 5th Avenue and the Avenue of the Americas (aka 6th Avenue) in Manhattan.



Supporting the Foundations of Interstellar Flight Workshop 13-15 June, 2017
<http://www.citytech.cuny.edu/physicsworkshop/>



DISCOVER SPACE IN MANCHESTER

10:00 – 15:00, 31 MAY 2017

11:00 – 15:00, 1 JUNE 2017

MANCHESTER CENTRAL CONVENTION COMPLEX

DISCOVER SPACE is the unmissable, free-to-attend, day out this half term. Held alongside the UK Space Conference 2017, DISCOVER SPACE will host a series of fun and educational activities, hands-on interactive exhibits, talks and showcases to capture the imagination and inspire young people to pursue careers in science, engineering and technology.

Recommended for families with children aged between 5 and 16 – school groups welcome.

REGISTER HERE

We expect there to be high demand for the DISCOVER SPACE days and recommend families register ASAP to avoid disappointment.

discover-space.eventbrite.co.uk

Sponsored by



FURTHER INFORMATION

Please contact info@ukspace2017.co.uk should you have any questions.



Image provided by ESA/NASA

NEWS FEATURE - NASA announces that TRAPPIST-1 system has largest number of 'Earth-like' exoplanets

Patrick Mahon

Exoplanets are looking like the rule for star system but TRAPPIST-1 represents a feast fit for an astronomical king! Deputy Editor Patrick Mahon summarises the story so far but there is more coming and we'll keep Principium readers informed in future issues.

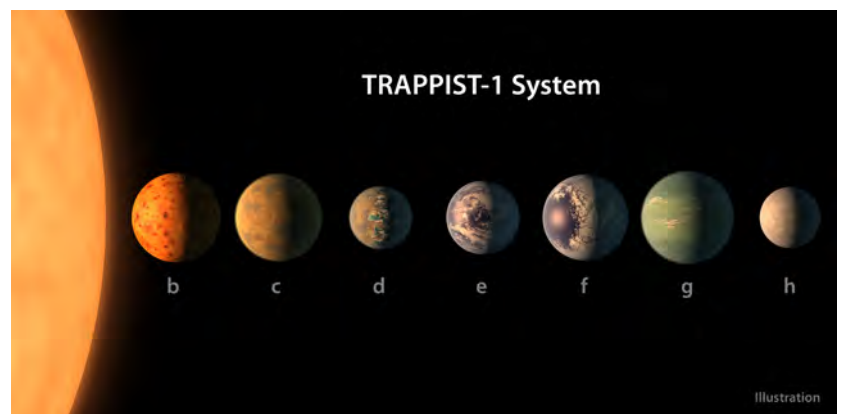
On 22 February 2017, NASA held a press conference to announce that the red dwarf star TRAPPIST-1, located some 39 light years from Earth in the constellation of Aquarius, is orbited by seven rocky planets, each of similar size to the Earth. All seven are located in or near the so-called 'habitable zone', at distances from their parent star where the planets would potentially be warm enough for liquid water to exist on their surfaces, although this is much more likely for three of the planets than the other four. The system, so-named because it was discovered in 2016 by the 'TRANSiting Planets and Planetesimals Small Telescope' (TRAPPIST) in Chile, was originally thought to have three exoplanets but further observations by NASA's Spitzer Space Telescope and several ground-based telescopes

discovered another four. All seven planets were discovered because they transit their star, passing in front of it periodically and reducing very slightly the amount of the star's light seen by our telescopes. Careful analysis of the transit signals has enabled the project team to calculate six of the seven planets' size, mass and density, confirming that they are most likely each small, rocky worlds like Earth, rather than large gas giants like Jupiter. The seventh is believed to be a small, icy world, although this is yet to be confirmed. Future observations should enable us to determine which, if any, of the planets has an atmosphere. Principium readers should not get too excited about the chances of finding life, however. The planets orbit sufficiently close to their star that they are likely to be

tidally locked, always presenting the same face to the star, like our Moon does to Earth. The parent star is also relatively young, at around 500 million years old, and it is known that similar stars of this age frequently produce high energy flares that would probably be detrimental to the formation of life on any of the planets orbiting it. Nonetheless, the TRAPPIST-1 system should provide a great testing ground for exoplanet studies for many years to come. Full details of the discovery were published the same day in an academic paper in the leading scientific journal *Nature* (*Seven temperate terrestrial planets around the nearby ultracool dwarf star TRAPPIST-1*, Gillon et al, www.eso.org/public/archives/releases/sciencepapers/eso1706/eso1706a.pdf).

The three planets e, f, and g could harbour water oceans on their surfaces, assuming Earth-like atmospheres (see Gillon et al, cited above).

Image Credit: NASA/JPL-Caltech





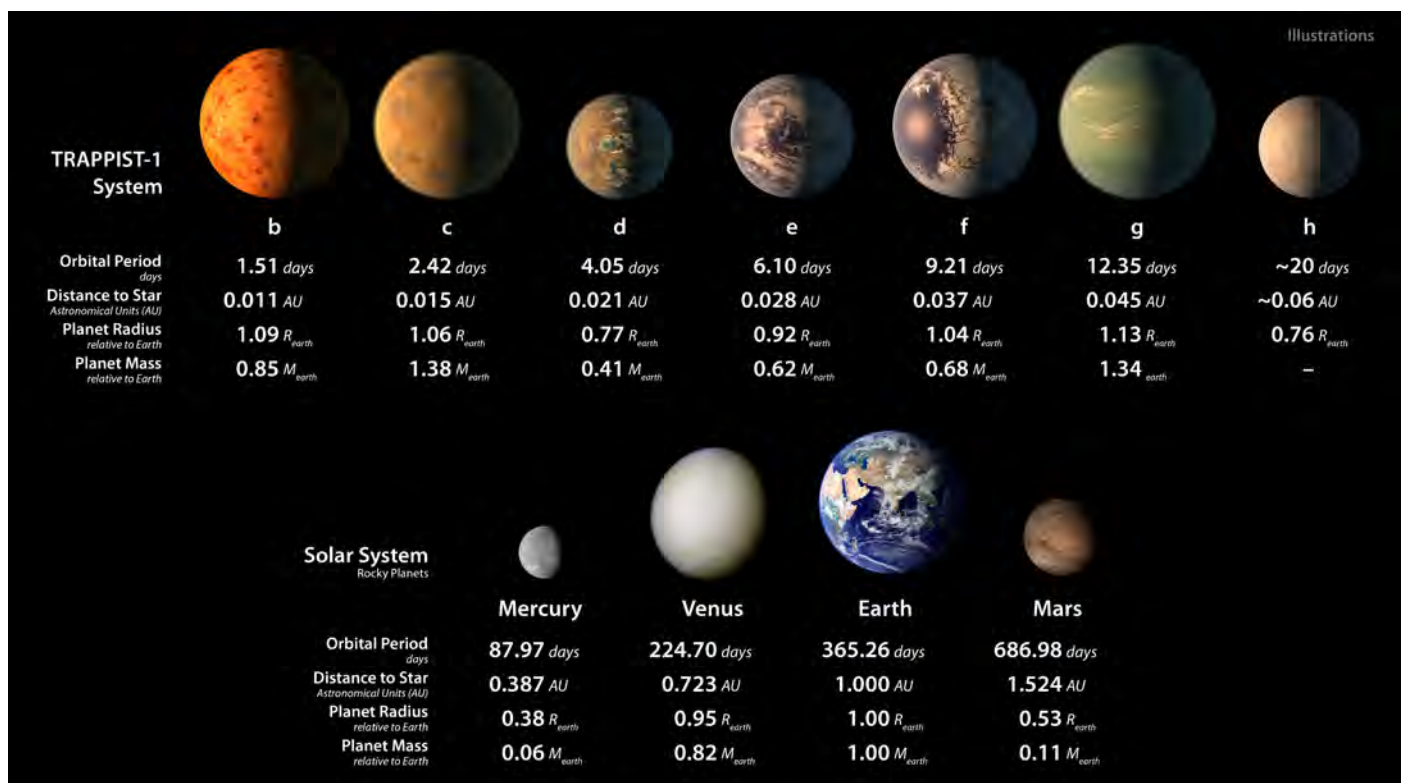
A travel poster - NASA imagines holidays in the Trappist-1 system.

The system is about 40 light years away so even our digital descendants would need to take an 80+ year vacation! Or the Grand Tour might become fashionable again to these long-lived beings? There is a very high probability that we will find even more fascinating systems long before we may become these long-lived light-borne beings.

Or maybe we will defeat that horrible little letter, *c*? More about FTL by Alcubierre's ideas elsewhere in this issue (*Is the Alcubierre Drive the answer to interstellar travel?* Tishtrya Mehta), about Digital Persons as interstellar travellers in Principium 12/13 and about AI starships in our previous issue, Principium 16.

Poster credit: NASA-JPL/Caltech

TRAPPIST-1 Statistics Table - what the TRAPPIST-1 planetary system may look like, based on available data. The seven planets of TRAPPIST-1 with orbital periods, distances from their star, radii and masses compared to Earth and (bottom row) with Mercury, Venus, Earth and Mars
www.jpl.nasa.gov/spaceimages/details.php?id=PIA21425 Credit: NASA/JPL-Caltech



Is the Alcubierre Drive the answer to Interstellar Travel?

Tishtrya Mehta

Will interstellar travel ever be possible?

It has been noted in the past that due to the rate of technological advance, a so-called ‘technological growth rate’, it would be more efficient to wait until a future time to begin any interstellar travel to ensure the earliest arrival. Any craft launched before this time would be overtaken by more advanced, quicker means of travel, and any later would simply waste time. It was projected by Kennedy¹ that the optimal launch date for a Daedalus craft², which could reach a star system six light years away in 145 years (see A Bond et al, Project Daedalus for further reading), would be in 2641, by which time technology would be advanced enough to power such a space ship. This is known as a wait calculation but assumes many variables and ignores the possibility of unexpected revolutionary advances. The future of space travel may be as foreign to our society as the Watt steam engine to the Tudors.

Conversely the technology needed may already be available; there are several proposed means of interstellar flight that do not violate any known physical laws, with the real barriers being the sheer quantity of fuel and energy needed to power such crafts. As previously mentioned, a Daedalus craft, which relies on on-board fusion of Helium-3 to accelerate a 54,000 tonne spaceship to 0.12c, would be a possible candidate but struggles in feasibility when one considers that 92% of the mass would be fuel alone, quantities of which aren’t found on Earth.

Some other concerns for crewed mission are ethical; due to a minimum journey duration of over a century, astronauts would have to leave the Solar System knowing they would never see their destination and children would be born and raised in space with no choice as to their future. Short of a world ship³, the best option may be found in the proposed Alcubierre Drive⁴ which manipulates space-time itself to enable FTL travel. This would make return journeys to distant star systems possible in arbitrarily short time frames. This avoids much of the ethical and fuel related problems.

The Alcubierre drive

The Alcubierre drive proposed in 1994 specifies how a stress-energy metric tensor can be constructed such that a spacecraft could sit inside a ‘bubble’ of locally flat spacetime, with the fabric of space contracted in front and expanded behind it (Figure 1), causing the body to ‘fall’ towards its destination without the need for further fuel. This would allow such a body to travel at any arbitrarily large velocity, even exceeding the speed of light ‘c’ relative to outside observers. This doesn’t violate the Einsteinian postulate that

Figure 1: *Expansion of the normal volume elements.* From *The warp drive: hyper-fast travel within general relativity*. Miguel Alcubierre. Department of Physics and Astronomy, University of Wales, College of Cardiff. Published in: *Class. Quantum Grav.* 11-5, L73-L77 (1994). Image from arXiv:gr-qc/0009013v1 5 Sep 2000



no information, via energy or mass, can travel faster than c , as it is space which is warping and carrying a ship, which is locally stationary to its surrounding region of flat spacetime.

The Alcubierre metric

Using the usual 3+1 formalism, the Alcubierre Metric can be defined as -

$$ds^2 = -dt^2 + (dx - v_s f(r_s) dt)^2 + dy^2 + dz^2$$

where $f(r_s)$ can be approximated to a top hat function when the lapse function, which dictates the interval of proper time in hyperspaces near to the bubble⁴, is large. Alcubierre defined the lapse function to be equal to 1. This implies that timelike curves normal to any hyperspaces concerned would be geodesics which, when one considers that all freely moving particles move along geodesics in curved spacetime, the craft can be thought of as free falling through space. Hence local acceleration is equal to zero.

Alcubierre points out in his paper that the trajectory of the

craft can be shown to be a timelike curve where $-d\tau = dt$ - where τ is proper time, by substituting $x = x_s(t)$ in to the metric. This proves that the coordinate time as measured inside the moving craft would be equal to the proper time as measured by outside observers, there can be

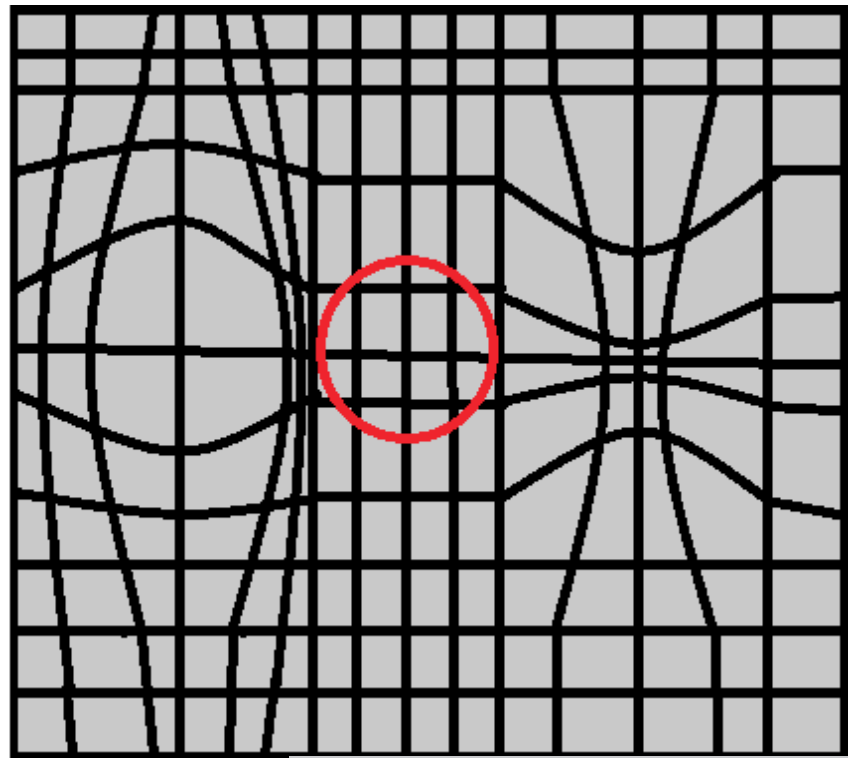


Figure 2
Visual representation of how one may conceptualise the stretching and shrinking of spacetime behind and in front of the spaceship respectively. Where the fabric of spacetime can be conceptualised as a 2 dimensional sheet, from a 'top' view it would appear that the overlaid grid shows the sheet being extended and scrunched, relative to the bubble (represented by the red circle) where inside the spacing of the grid is uniform and unaffected. In this case the direction of motion is towards the right hand side of the diagram.
Credit: Tishtrya Mehta

At a glance: The Casimir Effect.

The uncertainty principle (see 'Further Reading' for more details) theorises the existence of virtual particles of various undeterminable energies spontaneously coming into existence and rapidly annihilating with a virtual twin antiparticle. According to -

$$\Delta E \Delta T > \frac{\hbar}{2}$$

- it can be seen that particles of higher energy have shorter life spans and vice versa. The Casimir effect occurs when two metal plates are placed approximately 1 micron apart, resulting in an attractive force between the plates. Casimir and Polder proposed that the effect could be understood by conceptualising that the gap in between the plates restricts photons to have de Broglie wavelengths smaller than 1 micron, whilst photons outside the plates had no such restrictions. Hence fewer particles 'exist' within the gap than outside. This results in a pressure gradient as more virtual photons are created outside the gap resulting in behaviour analogous to an attractive force. The region within the gap can therefore be understood to locally have a negative energy density.

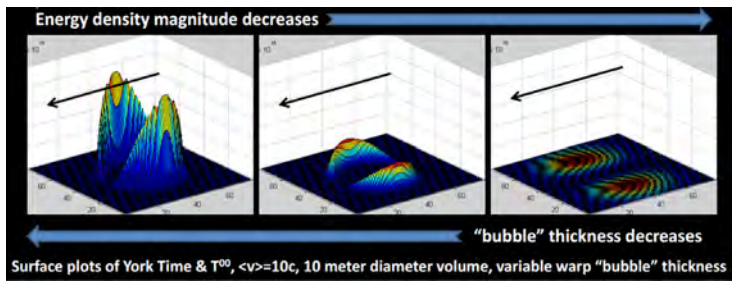


Figure 3

Diagram by White from Warp Field Mechanics 101⁸, showing T^{00} (magnitude of energy density) for a given average velocity of the bubble. It shows an inverse relationship between bubble thickness and energy density where increasing the area available to the spaceship (via decreasing the thickness of the bubble wall) leads to an increase in energy required. This is explored further in "Difficulties in Finding Negative Energy Densities". More about "York Time" in Warp Field Mechanics 101 - Credit: NASA, White

no time dilation occurring due to the motion of the locally flat spacetime region. Hence the proper acceleration, in addition to the local acceleration as mentioned earlier, along the trajectory can always be seen to equal zero.

ENERGY REQUIREMENT FROM TENSOR:

Through manipulation of this metric, it can be shown⁵ that T^{00} (which is the term representing the energy density in a stress-energy tensor) is given by

$$T^{00} = -\frac{c^4}{8\pi G} \frac{v_s^2(x^2 + y^2)}{4g^2r_s^2} \left(\frac{df}{dr_s}\right)^2$$

when measured by an outside observer, where g is the determinant of the metric tensor. As this energy density is negative, the drive requires exotic matter in the form of negative mass, or equivalent negative energy-mass, to travel using the drive.

Negative energy densities, though counter-intuitive, have been experimentally observed through the Casimir Effect (see previous page) lending hope to scientists who believe the drive can be constructed. However the amount of energy experimentally produced by the dynamical Casimir effect⁶ was far from what is currently predicted to be required by the drive. An initial estimate of the amount of exotic mass (or an equivalent amount of energy produced by

matter - antimatter annihilation) required was in the ballpark of $2 \times 10^{27} \text{ kg}^7$ (approximately 300 Earth masses). This was subsequently significantly decreased by Van Den Broeck¹⁰ and it has been further proposed that none at all may be needed, in his and Richard Juday's Warp Field Interferometer experiment which will be discussed later.

DIFFICULTIES IN FINDING NEGATIVE ENERGY DENSITIES

White's earlier findings⁸, built on Ford and Pfenning's work⁹, show that by optimising bubble topology for this model, a compromise between energy density and the size of the ship can be reached. It was shown that for an increase in the width of the 'wall' of the 'bubble' containing the flat region of space-time, the magnitude of energy density required decreases.

This can be conceptualised if one considers the warp bubble and its surrounding ring to look like a doughnut (with the ship in the bubble akin to the hole in the doughnut). As one expands the width of the doughnut in a given fixed volume container, the hole in its centre gets smaller. This same principle applies to a warp bubble; as the walls of the bubble increase in size (requiring less energy) the bubble decreases in area. Therefore, White and his

team have altered the metric to require substantially less energy, forgoing a large area for the ship to rest in. This puts a restriction on the size of craft that can be placed within this bubble, limited by the amount of energy that can be produced.

This restriction was improved upon by Van Den Broeck in his 1999 paper¹⁰ which showed that the initially proposed energy required to sustain a warp bubble was much less than originally thought, if one takes advantage of the original geometry of the problem. This was done by keeping the surface area of the bubble constant, but expanding the volume inside.

The most recent estimates require somewhere around 1000 kg of exotic mass¹¹, which reintroduces the warp from fantasy to an unlikely but not unreasonable exploit. The remaining difficulties are physical (see next paragraph) and financial with NASA reporting a cost of around \$62.5 trillion US dollars per gram¹² of exotic matter. Thus it seems until production of exotic matter becomes more efficient and affordable, building a device on a scale whereupon manned interstellar travel can take place, is impossible with our current technologies.

Additionally, acquiring such a relatively large quantity of exotic matter may be physically

forbidden. Whilst vacuum fluctuations temporarily and only slightly violate energy conservation laws, on a scale of a few milligrams this is widely regarded as being forbidden. Negative energies, and by extension negative masses, behave in extremely odd ways that would violate fundamental processes on the large scale. Bonnor concluded in 1989 that ‘runaway motion’ would occur, as he stated in his paper ‘Negative Mass in general relativity’¹³: negative mass would repel both negative and positive mass alike, causing self-accelerating motion. Thus he “preferred to rule it out by supposing that inertial mass is all positive or all negative”. Therefore it is the popular scientific belief that the production of particles with negative mass on any significant scale is non-physical as it would violate several conservation laws.

Approaches using little to no exotic matter

Krasnikov¹⁴ put forward a paper describing how a wormhole, constructed by a similar alteration of the space time metric, could theoretically be held open by exotic matter produced only by the vacuum fluctuations, needing truly minimal quantities. Similarly, further refinements to

the Van Den Broeck metric have been suggested¹⁵ by Loup et al in a 2001 paper, which would reduce the negative energy needed by several orders of magnitude, though none as of yet have an experimental backing to prove that any results from creating such quantities could be ‘used’ in any meaningful way.

As mentioned previously, the White-Juday Warp Field Interferometer experiment¹⁶ may circumvent this problem by requiring either no or extremely small amounts of particles with negative mass. The experiment is attempting to determine if space is embedded in higher dimensions using an interferometer to measure the curvature of spacetime, similarly to the method employed to detect gravitational waves using LIGO¹⁷. The set up employs a modified Michelson interferometer using a helium-neon laser emitting a beam which is split into two paths and re-joined, where one path is exposed to a device designed to warp spacetime, such as a high voltage electric field.

If successful, a warp bubble could be produced and higher dimensions exploited to carry a craft, by creating a bubble with an expanded interior, similar to the TARDIS described in the sci-fi television show Doctor Who.

Results so far from this experiment have been

inconclusive¹⁸ and the experiment is being refined with more sensitive equipment. If proven to be correct it could revolutionise space travel entirely.

Overview

Whilst fashioning such a metric tensor to allow FTL travel is within what is physically allowed by the laws of nature, it remains to be seen if such a device could be manufactured. Many scientists¹⁹ believe due to the sheer amount of exotic matter needed to power the drive, the Alcubierre drive can be used as little more than a thought experiment to educate students about the nature of spacetime.

With current technology it seems as though the warp drive is a long way from construction if it can be created at all. Even if successful results are found for craft not requiring exotic matter, such as the White-Juday Interferometer experiment, it remains to be seen whether space warp bubbles could ever be produced on any scale that would fit a manned spacecraft. Due to the consensus in the scientific community that such a scale of exotic matter is unlikely to be produced, it is unlikely humanity will develop a warp drive in the manner initially suggested by Alcubierre. However this shouldn’t mean that research towards developing the technology should be altogether halted; there is much to be gained

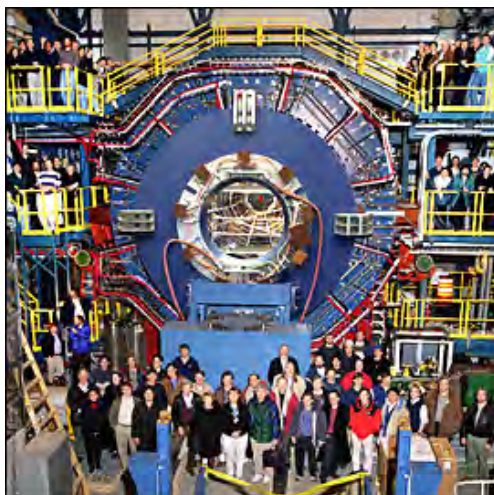


Figure 4
A team of scientists at the STAR Detector at the Relativistic Heavy Ion Collider (RHIC) in New York, USA. The STAR detector discovered the heaviest known anti-nucleus in 2010 and carries out research on exotic matter. Image courtesy of Brookhaven National Laboratory (bnl.gov). From an online article by BNL hosted on their website at www.bnl.gov/newsroom/news.php?a=111075

from research into the nature of spacetime and investigating whether space is indeed embedded into higher dimensions. Until such topics are better understood the warp drive can be used as a tool to understand and question the nature of the universe around us and should not be permanently banished into science fiction.

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About the Author

Tishtrya Mehta is a final (fourth) year student studying Physics and Mathematics (Hons) | University of St. Andrews. She will be doing postgraduate work in Solar Physics in the coming academic year. This Review Article was produced as part of her work in Transferable Skills for Physicists at the University of St Andrews. St. Andrews is the oldest of the four ancient universities of Scotland.

ALBUM REVIEW

Infinity of Space

by *The Light Dreams*.

Reviewed by David A Hardy, FBIS

Download: thelightdreams.bandcamp.com/album/infinity-of-space
- with an illustrated PDF booklet - also iTunes and Amazon



In the words of the artist (and he is an artist, in both senses of the word), Alex Storer, *Infinity of Space* is ‘an album of instrumental music inspired by space travel and science fiction, released in support of the Initiative for Interstellar Studies (i4is).’ And it certainly does what it says on the tin.

Please forgive me if I step back in time here; you will see the point, I promise! From the time when I first started painting space art – back in the dim mists of the 1950s – I always listened to music while I was working. I needed it, as a sort of aural wallpaper which could help fill the vacuum and create the right background for whatever world or scene in space I was painting. So at first it was mostly orchestral music;

not surprisingly, Holst’s *The Planets* suite was high on the playlist, as was Dvorak’s *The New World* symphony, etc. (At other times, when the mood was not so important, I would play rock ‘n’ roll; stars like Buddy Holly, the same age as myself, were just becoming famous, and indeed I aspired to become a guitarist myself! I also loved – and still do – instrumental guitar music such as that of The Shadows.)

But it was not until the 1970s, when I started to hear music from *Alpha Centauri* and *Phaedra* by Tangerine Dream on the more progressive rock stations (John Peel, Alan Freeman), that I became aware of the kind of music I realised I had *really* been waiting for, created on keyboards and synthesisers. Vangelis and Jean Michel Jarre followed, along with Mike Oldfield and Rick Wakeman. But in more recent years it seemed that there was nothing new in such music, and I was just playing the same stuff that I’d been listening to for years. . . . Until I met Alex Storer. I think it was Alex’s digital science-fictional art that I saw first, but then I discovered that, as a self-taught musician, he was writing and producing his own, original instrumental keyboard music. I have never ceased to be amazed at his inventiveness, virtuosity, and sheer musicianship. Comparisons are, they say,



Alex at the keyboard. Credit David A Hardy



INFINITY OF SPACE

The new album from
The Light Dreams in support of The
Initiative for Interstellar Studies
 (i4is.org)

“THE DEPTHS OF SPACE
 are lonely. The immensity of
 a limitless cosmos stretches
 away into infinite chasms
 which the human mind finds
 hard to comprehend...”






thelightdreams.bandcamp.com/album/infinity-of-space

odious, but Alex has taken the type of ethereal sounds the artists above created, and made them his own, with his own compositions. I have seen his work evolve over the years.

On a few tracks of *Infinity of Space* Alex has brought in a friend, Sheffield musician Peter Rophone on electric guitar, which adds literally a new dimension to his music, and it works. Some of it quite ‘rocky’, at other times almost acoustic and melodic. There is also sometimes a stronger and heavier percussion track and bassline than on some previous albums. So in this music Alex has brought together all of my previous musical preferences!

If you are looking (or listening) for an album which really captures the magic of space, spaceflight, alien worlds and the vast yet vibrant emptiness of the universe, you need look no further – you’ve found it.

About the Reviewer and the Artist

David A Hardy is the longest-established space artist in the West, having been first published in 1952. He illustrated his first book – *Suns, Myths and Men*, with another great member of the BIS, Patrick Moore – in 1954 at the age of 18. He is equally well-known for his science fiction work. He is a long established friend and collaborator with the British Interplanetary Society and has contributed to the work of i4is since its foundation.

More about David at i4is.org/who-we-are/interstellar-artists/david-a-hardy

His personal website is at www.astroart.org

Alex Storer is a professional graphic designer with a background in fine art and hand-rendered illustration and an extensive record of work in both traditional techniques and digital work. He is the honorary musician for the Initiative for Interstellar Studies, and has produced several albums in association with i4is.

His personal website is at www.thelightdream.net

BOOK REVIEW

Starlight, Starbright: Are Stars Conscious?, by Greg Matloff

Reviewed by Patrick Mahon

Published 2015, ISBN: 9781627340809

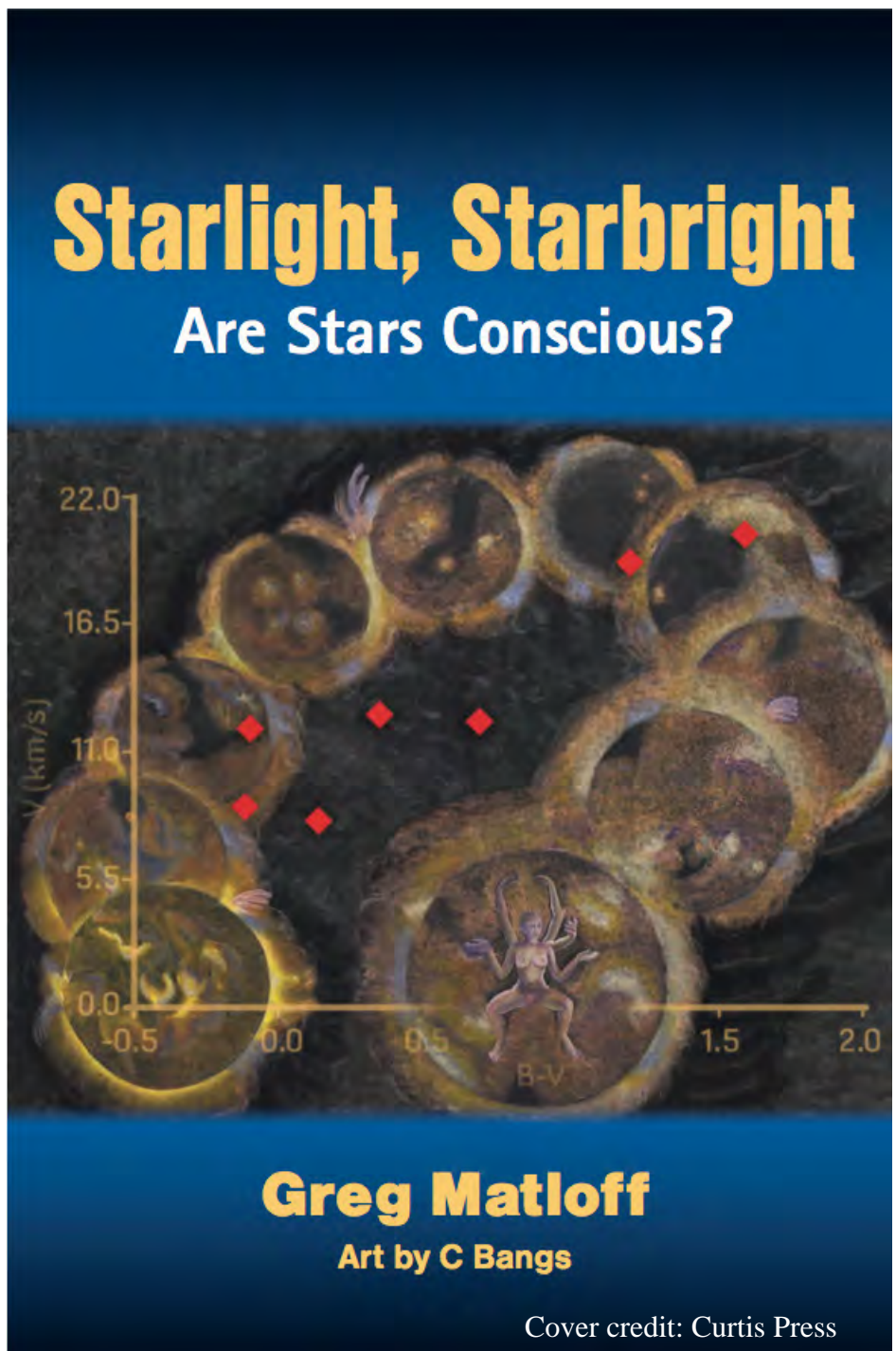
Paperback: Curtis Press, www.curtis-press.com/product/star-light-star-bright-are-stars-conscious

Hardback and Ebook: Universal Publishers, www.universal-publishers.com/book.php?method=ISBN&book=1627340807

Professor Gregory L Matloff is a familiar figure in the interplanetary and interstellar propulsion studies community, having written many papers on solar sail design and other propulsion technologies. I first encountered his name in the early 1990s, whilst still at university, when I read *The Starflight Handbook* [1], a popular treatment of the options for interstellar travel which he co-authored with science journalist Eugene Mallove in 1989.

Knowing that Matloff is a Professor of applied physics made his authorship of the current title seem a little strange. Why would a man whose previous work has been defined by a rigorous scientific approach to solving concrete engineering problems write a book on the esoteric topic of stellar consciousness?

Matloff is upfront in answering this question in the book's introduction, explaining that he has been led to this point by several concerns. First, he believes that one aspect of the current paradigm in astrophysics is wrong. This is the insistence that ordinary matter, which makes up all the stars, planets and other features of the visible



Cover credit: Curtis Press

universe with which we're familiar, comprises only one-twentieth of the total mass of the universe. In this model, around 68% of the remainder is 'dark energy', which is supposed to drive the accelerating expansion of the universe, while the other 27% is 'dark matter', which is needed to explain why the way stars rotate in galaxies doesn't seem to follow Newton's laws of motion [2]. Matloff suspects that this 'Emperor' of astrophysics may in fact have no clothes, and has been looking for an alternative to dark matter in particular.

Second, stung by a previous failure to publish some surprising theoretical conclusions on the lifetimes of gas giant exoplanets ('Hot Jupiters') orbiting close to their star, which were subsequently proved correct by observation, Matloff insists that the duty of a scientist is to publish his or her findings, regardless of any concern for the potential impact on the author's reputation.

The final spur was an invitation from i4is Executive Director Kelvin F Long to contribute to a 2011 Symposium, organised by the British Interplanetary Society at their London headquarters, in honour of the British science fiction writer and philosopher Olaf Stapledon. Matloff's contribution [3] focused on the metaphysical speculations around stellar consciousness in Stapledon's most famous novel, *Star Maker* [4]. He contended that Stapledon's ideas might not just be the idle musings of an SF author but might have a basis in physical reality, providing an alternative to dark matter as an explanation for the anomalous motion of stars within galaxies. Crucially, Matloff argued that recent advances in observational astronomy might soon be sufficient to move such

a discussion out of the realms of philosophy and into that of experimental physics.

Since that 2011 Symposium, Matloff has expanded on his ideas for a popular audience in three places, beside the book currently under review: a 2012 blog post on Paul Gilster's well-known Centauri Dreams website [5], an essay on SF publisher Baen's website [6] and a more recent 2015 blog post on Centauri Dreams [7]. All three are freely available on the web and provide excellent introductions to the main ideas presented here.

Before getting into the detail of the text, I would just note that each chapter of the book is preceded by a full colour artwork created by the author's wife, artist C Bangs, and inspired by the topics under discussion. These images are striking and repay repeated study.

The book itself is divided into four parts. 'Part I: Ancient Nights' deals with the historical evolution of our ideas about the stars, starting with prehistoric beliefs and the monuments such as Stonehenge that were based on them, moving through the naming of the constellations after gods and other mythical figures, and ending with the mystery cults that grew up during the Dark Ages between the fifth and fifteenth centuries.

'Part II: Of Neurons, Tubules, and Molecules' moves on to the nature of consciousness, summarising the views of influential seventeenth century thinkers like René Descartes through to twentieth century giants like Carl Jung and Erwin Schrodinger. Matloff then rehearses the basics of quantum mechanics, including the importance of a conscious observer to many philosophical

interpretations of quantum theory, and uses them to introduce the theories of Sir Roger Penrose and others about a quantum theory of consciousness. This leads on to a discussion of the research funded by the CIA in the 1970s into psychokinetic effects – the alleged ability of some humans to move or deform objects using only the power of thought, most famously exemplified by the Israeli magician Uri Geller. I'm sure that many sceptics will dismiss this as an episode of cold war fantasy, but Matloff knows serious people on both sides of this highly controversial debate and his treatment of it is balanced and reasonable. Part II ends with a discussion of the rise of the global environmental movement from the 1960s onwards, prompted partly by the image of Earth taken by the Apollo 8 astronauts, and how this developed into James Lovelock's theory of Gaia, which some have interpreted as ascribing conscious intent to the Earth as a self-regulating ecosystem.

In 'Part III: Fictional Bright Stars', Matloff reviews the place of stellar consciousness in literature, covering poetry and science fiction in particular, and then focusing in on the literary inspiration for this book, Olaf Stapledon and his 1937 novel *Star Maker*.

Finally, in 'Part IV: The Astronomer's Search', which occupies the second half of the book, Matloff lays out his central argument. After summarising the reasons why dark matter has been proposed as an explanation for the anomalous motion of stars within galaxies, he reviews the three main solutions that have been proposed, and the evidence that casts doubt on each. The first two are different hypotheses for what dark matter is made

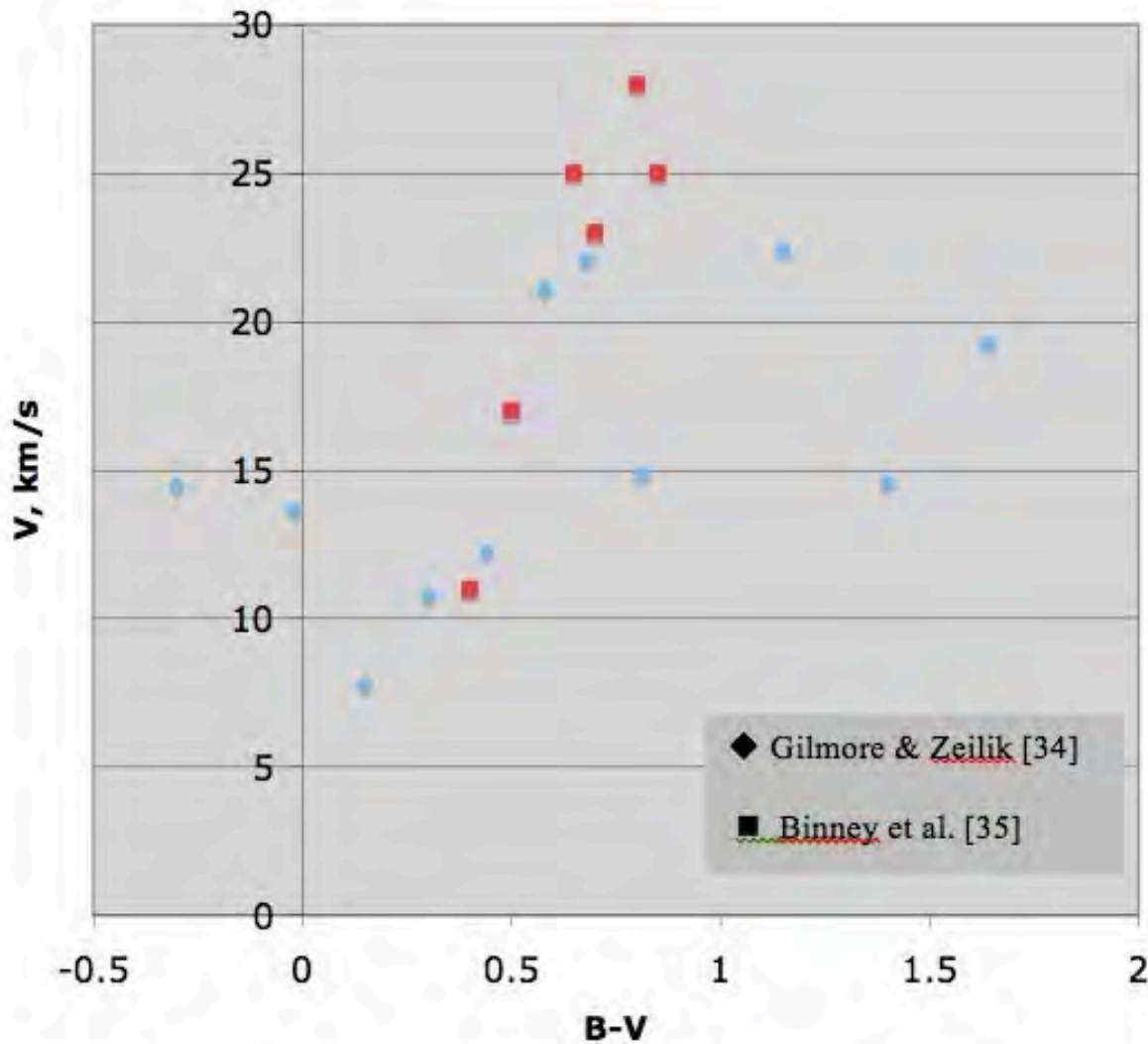


Figure 1: Solar motion in the direction of galactic rotation against colour index [6]

of, each with an equally cheesy acronym: MACHOS (Massive Compact Halo Objects) and WIMPS (Weakly Interacting Massive Particles). The third approach instead proposes that our laws of stellar motion require slight modification at galactic distances, and is known as MOND (Modification of Newtonian Dynamics). Having explained why the evidence for each of these theories is weak or contradictory, Matloff then puts forward his own alternative. This is based on a little-known finding by a Russian astronomer, Pavel Parenago (1906-1960). Parenago's Discontinuity, as it is known, is shown graphically in Figure 1, taken from Matloff's 2012 Baen

article [6]. Note that two separate datasets are shown, in blue and red, but these should all be considered together in interpreting the graph.

In this graph, the x-axis measures how hot the star is, with the hottest blue-white stars appearing on the left, and the coolest red stars appearing on the right. The y-axis measures excess velocity in the direction of travel. Parenago's discontinuity occurs at roughly $B-V = 0.6$, where stars are a little hotter and bluer than our own Sun. What the graph shows is that the cooler, redder stars to the right of this point rotate around the galaxy around 20 kilometres per second faster, on average, than the hotter, bluer stars to the left.

Based on this anomaly, Matloff proposes a radical explanation. He asserts that the discontinuity occurs at just the point where stars become cool enough for molecules to form in their outer layers. In Part II of the book, one of the theories covered suggested that the entire universe is imbued with an underlying quantum consciousness field. Matloff's theory is that the molecules in the outer layers of cooler stars can interact with this field and enable their star to gain a primitive level of consciousness. This manifests itself in a herding instinct, as seen for example in some single-celled bacteria, so that the cooler, redder stars rush after each other at a higher speed than the bluer

stars around them that, being too hot for molecules to form in their atmospheres, do not interact with the quantum field and thus do not become conscious.

This is the core of Matloff's argument. Part IV then discusses the means by which these conscious stars might be able to speed themselves up. The leading candidate here would be a unidirectional stellar jet (these have actually been observed), presumably controlled by the star's primitive mind. Matloff then considers the other proposed explanations for Parenago's discontinuity, and notes that ESA's Gaia telescope, launched in late 2013 and tasked with producing the most accurate map of our galaxy to date, covering some one billion stars, should produce data of sufficient accuracy that we will be able to decide scientifically which of these various explanations for Parenago's discontinuity is in fact correct.

Greg Matloff is an engaging and confident writer, and this book presents an interesting and attractive argument on behalf of his new theory. As a book reviewer, I enjoyed the read and would encourage others, whatever their initial views about the subject, to give the book a go.

At the same time, I retain a level of healthy scepticism about Matloff's central thesis, given that it is pretty revolutionary in its implications. Given this position, I did do a little background reading while writing this review, and I was slightly surprised to find that one of the authors whose

data Matloff uses in Figure 1 above, James Binney of Oxford University, appears to have a much more prosaic explanation for Parenago's discontinuity than the one that Matloff has ascribed to it. According to a paper by Binney in 2000 [8], the natural interpretation of the anomaly is as follows:

'Bluewards of the discontinuity stars have main-sequence lifetimes shorter than the age of the solar neighbourhood, while redwards of it lifetimes exceed this. Consequently, any tendency of the velocity dispersion of a stellar group to increase over time will cause [star velocity] to increase with $(B - V)$ at $(B - V) < 0.6$ because in this range the age of the oldest stars contributing to [star velocity] increases with $(B - V)$. Conversely, [star velocity] should be independent of $(B - V)$ redward of the discontinuity.'

In simple terms, this appears to say that Parenago's discontinuity is simply an artefact of the data, linked to the age of the solar neighbourhood, and not connected to the temperature at which stellar atmospheres become cool enough to form molecules.

Now, I should be absolutely clear that I stopped studying physics 23 years ago, and my PhD topic was quantum mechanics, not astrophysics, so I may have misunderstood what Binney is saying, or I may have missed Matloff's response to this point in his book. Nonetheless, I think there is probably more work to be done here to raise Matloff's ideas from the realms of metaphysical

speculation to those of hard science.

However, in concluding, I can't help but thank Greg Matloff for having written this book. The current state of astrophysical theory is somewhat confused and under such circumstances it is always worthwhile having our presumptions challenged by radical thinking, whether it turns out to be correct or not. If humanity is to achieve interstellar flight, which is of course the objective of i4is, we need more radical thinking, not less.

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About the reviewer

Patrick Mahon is Deputy Editor of *Principium*, and i4is Programme Manager. He works in the waste and resources sector. He was encouraged to study mathematics and physics at university after falling in love with astronomy and spaceflight when Sir Patrick Moore gave a talk to his school's astronomy club in 1981, the same year as the first Space Shuttle flight. As well as reviews, he writes science fiction in his spare time.

Engineering New Worlds: Creating the Future

Dmitry Novoseltsev

Dmitry Novoseltsev (ДМИТРИЙ НОВОСЕЛЬЦЕВ) is Deputy CEO of the Siberian Mechanical Engineering, Non-Profit Partnership (www.npsibmach.ru). His article, which will appear over the next three issues of Principium, considers a number of different approaches to increasing the likelihood of intelligent life developing anywhere else in the Universe. The first two parts are in this issue. In Part 1, he points out that the structure of the Universe does not make it a particularly encouraging place to generate intelligent life. In Part 2 he outlines a two-step project intended to increase the probability of intelligent life forming in the proto-planetary systems around stable stars in our galactic neighbourhood. In the next issue of Principium he will move on to Part 3, discussing the Shkadov thruster (see [Moving Stars: The Shkadov Thruster www.centauri-dreams.org/?p=29579](http://www.centauri-dreams.org/?p=29579)), "star machines" and the architecture of galaxies. In the subsequent issue, Part 4, Cosmological Natural Selection, will discuss an engineering approach to the creation of a world and Part 5 will speculate on a history of the future we might desire – to create worlds.

1. The current state of play: an "uncomfortable" Universe

To begin with, it is necessary to state a not very encouraging fact: the Universe in which we live is not very suitable for intelligent life. This fact was noted by Carl Sagan in "Pale Blue Dot" [1].

Most of the baryonic matter is concentrated in the stars, and most of these stars are too hot and unstable to support

the existence of at least some complex forms of organization of matter. The remaining cold matter is largely concentrated in planets. But among more than a thousand authentically identified exoplanets, as well as dozens of planets and satellites across the solar system, so far no known planet, with the exception of the Earth, has been found suitable for the development of civilization.

Moreover, a significant part of the Earth's surface is of limited use for humans – for example, the oceans, deserts, mountain chains above 5000 metres and the polar caps. Sustaining intelligent life on Earth now, and especially in the past, was a problem, and its preservation and further development is still not guaranteed. There is thus every reason to assume that the distance

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



between cosmic civilizations (CC) in the known universe is very large. However, the use of simple and technically feasible means such as a solar sail and its modifications, could allow us in the distant future, if there is time and sufficient motivation, to radically change the situation - at least within our Galaxy and the local cluster of galaxies.

Source of information for Part 1:

1. Sagan, Carl. Pale Blue Dot: A Vision of the Human Future in Space. - 1 st. - New York: Random House, 1994.

2. "Catalysis": the spread of life

The simplest solution, available with the level of technological development that has already been achieved or may be achievable in the near future, is a significant increase in the probability of the appearance of biological life in the nearest galactic space. Formally, this corresponds to an artificial correction to the probability of the existence of technologically advanced civilizations, defined by the well-known Drake equation:

$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$,
 where N = number of CC, ready to come into contact;

R^* = the number of stars formed per year in our galaxy;

f_p = the proportion of stars that have planets;

n_e = the average number of planets (and satellites), with suitable conditions for the emergence of civilization;

f_l = the probability that life appears on a planet with suitable conditions;

f_i = the probability that intelligent forms of life appear on a planet on which there is life;

f_c = the ratio of the number of planets having intelligent

inhabitants which are detectable, to the number of planets that have intelligent life;

L = the lifetime of a technological civilization.

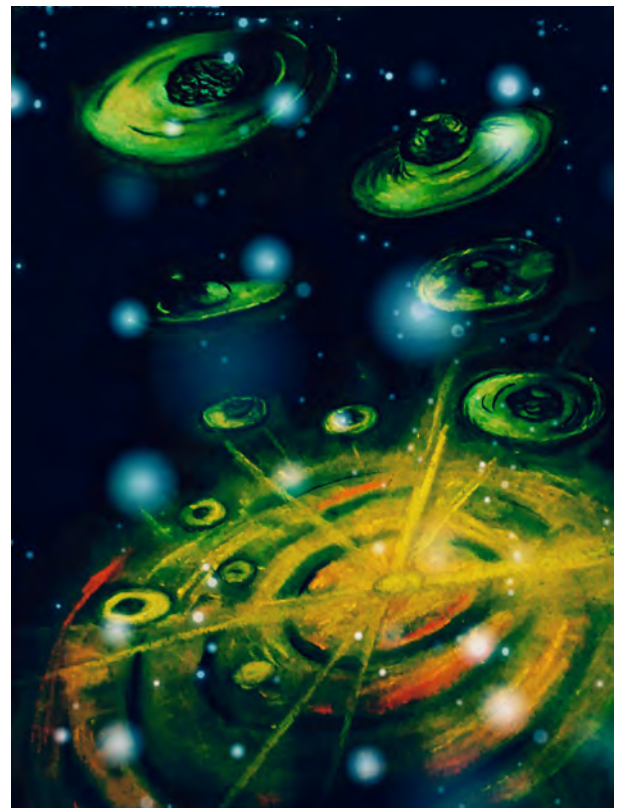
Our artificial correction to N is then due to a direct increase in the value of f_l and, indirectly, f_i and f_c . One of the options may be the project "Catalysis" - a public project in the field of space exploration, with unlimited duration.

The purpose of this project is the creation of favourable conditions for the development of intelligent biological life elsewhere in the known galaxy, including taking into account the possibility of its extinction on Earth and in the solar system, with minimal cost and using available or near future technologies and technical solutions.

The project implementation includes two consecutive stages, the first of which is mandatory, the second - desirable.

The **First phase** of the project is the creation of the "Fleet of Life".

This involves sending to known stable stars with protoplanetary disks a fleet of automatic spacecraft – the "Sowers" - which are simple low-speed solar sail vehicles with a high resource of construction. "Sowers" are carriers of catalysts for organic synthesis of the base components (bases) of RNA and DNA from the gas in the protoplanetary disk. Subsequently, spontaneous synthesis of RNA (and possibly the simplest DNA) is carried out on the catalyst surface from these components and their self-replication. By the time of the physical destruction of the "Sowers", the process of self-replication in the protoplanetary



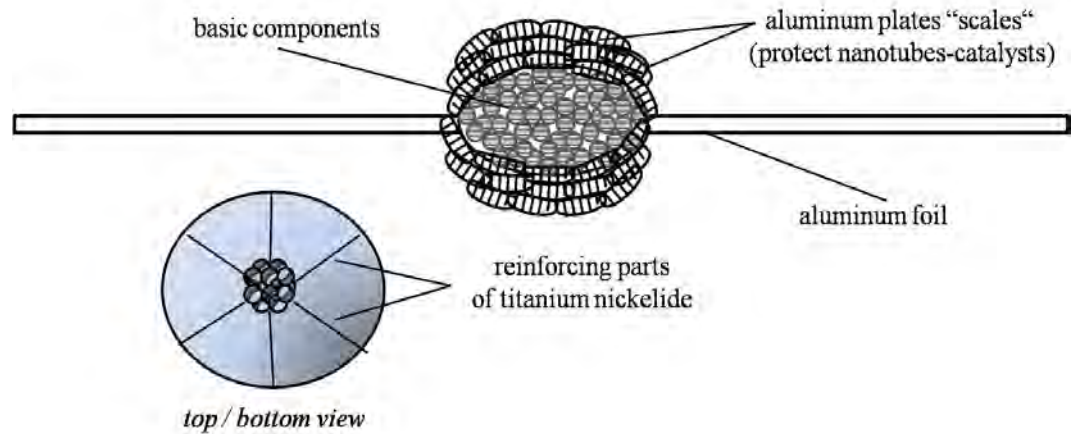
disk must become autocatalytic. As a result, the protoplanetary gas cloud in the "habitable zone" of the star becomes saturated with the simplest biological life, extending to the surface and atmosphere of all the emerging exoplanets and their satellites. Unlike the known conditions in our solar system, in the new planetary system, the probability of life development initially tends to one. At the same time, several potential complex biospheres are formed at once, and the period of their development into complex ecosystems, with the possibility of the existence of potentially intelligent species, is reduced by approximately 1-2 billion years due to exclusion of the pre-biological stage.

Taking into account the open-ended duration and probabilistic nature of the goal, the project should be implemented through an r-strategy – ie through the use of large groups of the same type, using as much as possible simple and cheap devices. The key element of the "Sower" is the biocatalyst. Taking into account their low temperature

**THE SPACECRAFT IS MADE
IN THE FORM OF A ELM-TREE SEED (ULMUS)**

cross sectional view

"Sowers" visualised by
Dr Anna V Sedanova



stability, though, this means that the possibility of launching vehicles using only solar power, which is energetically advantageous for solar sails, is excluded - from a near-Solar orbit with a low perihelion (of the order of 0.01-0.03 AU) and preliminary heat-shielding [1], as well as the popular idea today of acceleration with focusing on the sail of solar, laser or microwave radiation [2]. At the same time, the aerodynamic braking of the "Sowers" at the target in the rarefied peripheral layer of the gas-dust disk with an exit to a relatively stable orbit in the "habitable zone" with temperature conditions favourable for biological synthesis is assumed. This suggests a low flight speed, of the order of 0.01% of the speed of light, with a consequent flight duration amounting to several million years. This, in turn, determines the choice of construction materials, with relatively low requirements for heat resistance, but high radiation resistance.

The main structural element is the sail cloth - in this case it is advisable to perform not from the traditional aluminium-based polymer film, but from aluminium foil. To ensure controllability,

the membrane can be reinforced with straps in the form of tapes made from a material with a shape memory, for example, titanium nickelide - their controlled contraction enables alterations to the geometry of the web. One side of the sail with high reflectivity provides thrust, the other is applied to the catalyst.

Taking into account the requirement for a long service life, it is not advisable to apply the catalyst directly to the membrane with a thin uniform layer, as it may be shed early. It is instead planned to build carbon nanotubes on the surface of the sail with a length on the order of 1 μm , with the inclusion of the catalyst in their walls. This will ensure not only its preservation, but also a much larger area washed by the gas environment of the protoplanetary disk. In addition, better conditions will be available in the future on this surface for the preservation and fixing of the first molecules capable of self-replication.

An interesting property of nanotubes is the ability to retain liquid water under certain conditions that are far from normal. This should allow for condensation from the gas of the protoplanetary disk and the

subsequent retention of liquid water inside the nanotubes, as well as some expansion of the possible area of biosynthesis within the disk relative to the traditionally understood "habitable zone" for the planets, which will allow a reduction in the requirement for accuracy of the "Sowers" guidance system.

When a protoplanetary disk is reached, the apparatus is "suspended" under the influence of gravitational and gas dynamic forces in the disk in the region of "dust traps" [3] in the zones of formation of future planets. Thus, the synthesized fragments of RNA and DNA propagating from the surface of the catalyst can condense on the surface of the dust particles, thereby increasing the active surface area on which biosynthesis is carried out.

The issue of navigation and precise guidance of vehicles still requires a solution. Taking into account the duration of the flight, the radiation load and the operational experience of modern space technology, the use of any complex electronic components must be excluded, in favour of the simplest reliable analogue devices. The probability of losing a number of devices is in this case compensated for by their

large numbers. Once it is technically achievable to develop a design with a specific gravity of the order of 1 g/m², "Sowers" with a sail area of one square kilometer will each have a weight of 1 tonne. It will be advisable to launch them simultaneously in a common launch container using conventional rockets and space technology.

More complicated is the braking scheme. The magnitude of the light pressure near the stars chosen as targets will be several orders of magnitude smaller than the aerodynamic resistance of the gas in the protoplanetary disk due to the partial absorption and dispersion of light by gas.

The effect of the solar sail in this case will be insignificant, especially since the "Sower" is oriented to the star with the dark side of the sail with a catalyst that is similar in structure to dark velvet due to nanotubes on the surface, and its reflectivity is extremely small.

For such an apparatus, an aerodynamic braking scheme will be optimal, in which there is a gradual decrease in speed due to the touching of the outer edge of the gas-dust disk, and the transition to a trajectory in the form of a tapering spiral, with a limitation to the intensity of deceleration caused by the criterion of the maximum allowable surface temperature, leading to entry into a stable orbit in the "habitable zone".

The **Second phase** of the project is the creation of a "Fleet of Memory".

This approach involves sending to the same stars as the "Fleet of



Life" a fleet of automatic vehicles - "Keepers" - which are simple low-speed solar sails with high resource structure. "Keepers" are the carriers of multiply redundant information messages that would allow any hypothetical intelligent inhabitants of the emerging planetary system to familiarize themselves with the culture of the civilization of the Earth at the level of cultural and scientific and technical development it was at when the mission was launched. In the optimal case, such information could stimulate the recipients to implement similar projects, which could make the process of propagation of one form of biological life autocatalytic.

The "Keepers" are more massive than the "Sowers" of the "Fleet of Life", to provide greater resources. Their sails will have a larger area with two retro-reflective sides, because braking should not be carried out aerodynamically in the protoplanetary disk, but, like overclocking, should instead use the light pressure on the far periphery of the system, where it will be possible to preserve the "Keepers" for several billion years, in a similar way to the nuclei of distant comets and

Kuiper belt objects in our Solar system. In this connection, it is possible that the surface facing the Sun during acceleration should be made darker than that facing the star during braking.

The large size and bright surface of the sail should facilitate the subsequent identification of the "Keeper" as an artificial object by the hypothetical intelligent inhabitants of the planetary system, if and when they arise. Since no effective armoring of the device is possible with the chosen acceleration method, the protection of information from radiation and erosion-dust damage should be ensured by applying it to the entire surface of the sail, with multiple redundancy provided by various means for various readability capabilities. Primary information for attracting attention can be applied directly to the surface in symbolic form, for example, by means of resistant coatings or perforations. The bulk of the information can be recorded in the material of the sail by means of scanning tunnelling microscopy with a recording density of more than 10²² bits / kg [4, 5].

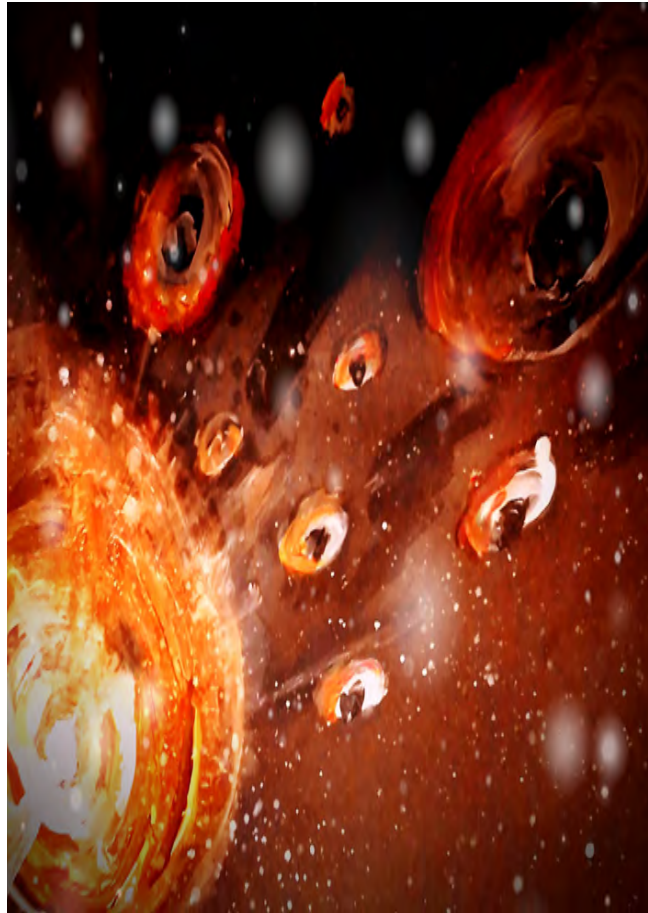
Such a high recording density provides interesting possibilities.

It is likely that the material that can be accommodated within the sails of the "Keeper" ships could include a complete decoding of the human genome (with epigenetic markers), as well as accurate models of the connectome of the brain and any materials related to the acquisition of personal information (memoirs). Such records, even after several billion years, would hypothetically allow CC to create adequate models of humanity from this data that would seem to be the closest real analogue to that described in a number of mythological systems for the "immortality of the soul." This ability to literally "leave your mark on the universe" could serve as an additional motivation for potential project participants.

For the vehicles of the "Fleet of Memory", which must remain far beyond the boundaries of the protoplanetary disk, a combination of aerodynamic braking and gravitational manoeuvres will be optimal. The "Keeper" should touch the outer edge of the disc with minimal intensity of aerodynamic heating, but the touch should be enough that the device slows down and is captured by the gravity of the star, moving to a very remote but closed orbit where it will experience minimal damage from photon, ion and dust interactions. Both manoeuvres will require very precise guidance.

It should be noted that since a large number of planetary systems have already formed potentially habitable exoplanets, like TRAPPIST-1 [6], it may also be appropriate to send "Keepers"

to them. Subsequent colonization of these planets may then be possible by distant descendants of humanity, or intelligent species created in this way, using unmanned probes with nuclear



power and electric rocket engines in the traditional way (described, for example, in the new science fiction novel by Boris Stern [8]). In this case, the "Keepers" will serve as points of access to the general information database containing the coordinates of the stars which have carried out the operation on the artificial stimulation of the development of intelligent life, as well as the standards of radio and optical communication, and determine the future of the galaxy for a single cultural code that will be highly desirable for the organization of interaction of various CC of "anthropogenic" origin in the future.

Ensuring that bioethics and

cultural ethics are addressed in the implementation of the project is assured by a restatement of the problem.

The implementation of the project is in no way a manifestation of the "expansionism" of modern earthly civilization. Adaptation of any known biological organisms, including extremophilic ones, to the gas environment of a protoplanetary disk is extremely unlikely. Even more unrealistic is their delivery or delivery of their DNA (RNA) capable of self-replication in this way, taking into account the duration of the flight and the radiation load. The implementation of the first stage of the project - the "Fleet of Life" - only shifts the possibility of the emergence and development of life on the emerging exoplanets, which then evolves in its own unpredictable ways, taking into account the

characteristics of the environment. Moreover, the implementation of the second stage of the project - the "Fleet of Memory" - is not a manifestation of "expansionism". In order to detect the "Keeper" apparatus on the far periphery of the planetary system, to reach it and consider its information, a hypothetical civilization will need to have a level of cultural, economic and scientific and technological development, at least equivalent to the modern human one. (Currently, if a similar facility were located at the boundaries of our solar system, it could probably be found while cataloguing the small bodies of the Solar system in the framework of the program to prevent asteroid

threats to Earth, ie approximately in the next 50 years. The ability to rendezvous and dock with the spacecraft in an attempt to read its information - especially if its orbit is significantly inclined to the ecliptic - is currently not realisable, since all known long-range space probes – the "Pioneers", "Voyagers" and "New Horizons" – already have a significant velocity when passing the Kuiper belt. But, probably such a manoeuvre could be implemented before the end of the XXI century). By this period, the "Keeper" will be an archaeological site, and its information will be of exclusively cultural interest, allowing addressees to find out some of the reasons for their existence, and, perhaps, to motivate similar actions by them. In that case, if the "Keeper" is the only artefact of modern human civilization in the planetary system for billions of years in the past, that will suggest that the descendants of its founders have by this point either disappeared or, in their own development process, have left this region of space. However, a more optimistic scenario is of interest.

In the short term, "Catalysis" is an extremely altruistic project, based on the voluntary participation of scientific, industrial and commercial organizations and many other stakeholders. The project planning horizon is much longer than the life of any individual, and perhaps the

species as a whole.

The project will not bring political, economic or scientific results in the near future, and therefore cannot be implemented by national space agencies in the framework of public budgets.

The project also will not give commercial results in the near future, and is unlikely to be implemented by private space companies (except for advertising purposes). However, some technology - production of high resource metal films, persistent and effective biocatalysts, recording media and information with a high density on the film carrier for long-term storage - could be widely commercialized.

From the point of view of potential investors or sponsors, the project is, of course, primarily altruistic, because for the lifetimes of the next generations there will not be any return on investment, beyond advertising and technology transfer. But in the long term, the situation may change. In the case of long-term sustainable existence of civilization on one of the remote stages of its development becomes a critical amount of available space in the Galaxy near the autonomous civilizations as independent sources of information, mainly "exo-humanitarian" nature [7]. This will directly affect the results of the project "Catalysis". We consider this question in the next section (see Part 3 of this article).

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About the Author

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

About the Illustrator

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

Ensuring Equal Global Economic Opportunity and Security through Space Resource Law

During the United Nations / International Astronautical Federation Workshop on Space Technology for Socio-Economic Benefits 23-25 SEPTEMBER 2016, Sam Harrison of i4is / ISU and Linda Dao of ISU presented their research on Space Resource Law.

We present an extract from their poster presentation at this workshop.

This research was funded by the Bournemouth University Global Horizons program

In 1967, the Outer Space Treaty was established stating, “Nations cannot claim sovereignty over the Moon or other celestial bodies.” In 2015, the United States Space Act stated that American space firms would have the right to sell the natural resources they mine from space. Though based on a similar framework to International Maritime Law, the challenge with the US Space Act of 2015 is that space mining requires a large degree of static industrial investment and involves the remote operation of highly sensitive machinery with a time delay.

Although asteroid mining will take decades to develop into a large commercial sector, it is the policy that is being outlined now, which will help to facilitate government and corporate investments in this large growing sector. Evidenced by large, commercial investments into Planetary Resources and Deep Space Industries, the governments of the United States and Luxembourg have also shown a high degree of interest, of which the latter has focused a €200,000,000 fund towards asteroid mining.

Many nations around the world were able to benefit from venture capital investments in the software and online industries, however space resource companies are only currently operating in a very selective group of countries (ie United States and Luxembourg).

Space law relating to resource mining is one of the key factors that is potentially holding back future investment in the space resource sector.

The threat to corporate investments towards asteroid mining infrastructure is posed by multiple organizations operating within close proximity to each other on the same space body and the threat of their operation on damaging another corporations equipment. Thus, it is likely that the company-based nations will look to enforce a legal system to ensure that only one company can operate at a given location to protect the delicate space assets in their control.

Increased discussion between governments is required to produce a legal framework that ensures the placement of proper regulations for asteroid mining. This framework would prevent a lawless “Wild West”-like industry from arising. Given the delicate and high value nature of the equipment involved for asteroid mining, the lack of current legal clarity could lead to an event where society is incapable of benefitting from an industry that has many wide-reaching economic promises. In addition, potential geopolitical tensions and enforcement issues could arise should something go wrong. With rising populations and increasingly scarce resources on Earth, asteroid mining has the potential to dramatically lower the



cost of precious metals and help support the wider space industrial infrastructures of many nations around the world.

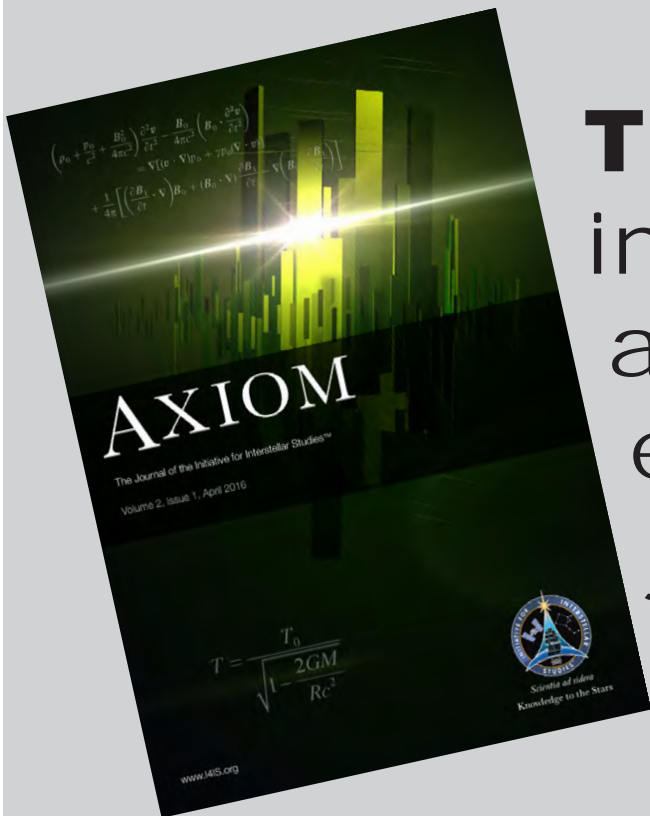
Applications of research to the interstellar field

Given that many of the technologies for space mining such as deep space navigation as well as electric propulsion systems have applications for interstellar flight and with the larger commercial market available close attention should be paid in the interstellar community to the policy developments in the growing space mining sector. In Australia alone The Mining Equipment, Technology and Services (METS) sector spent more than \$1.2 billion on R&D in 2013-14. The sector generates revenues of around \$90 billion annually, including exports worth \$15 billion. Even if a small percentage of this sector was to transition into space it could have major impacts on the development of a range of technologies with direct impact to the interstellar space community.

NEXT ISSUE

Engineering new worlds: creating the future Part 2
Report from Foundations of Interstellar Flight workshop, New York
Report from UK Space 2017, Manchester
Report from the second Interstellar Studies elective at the International Space
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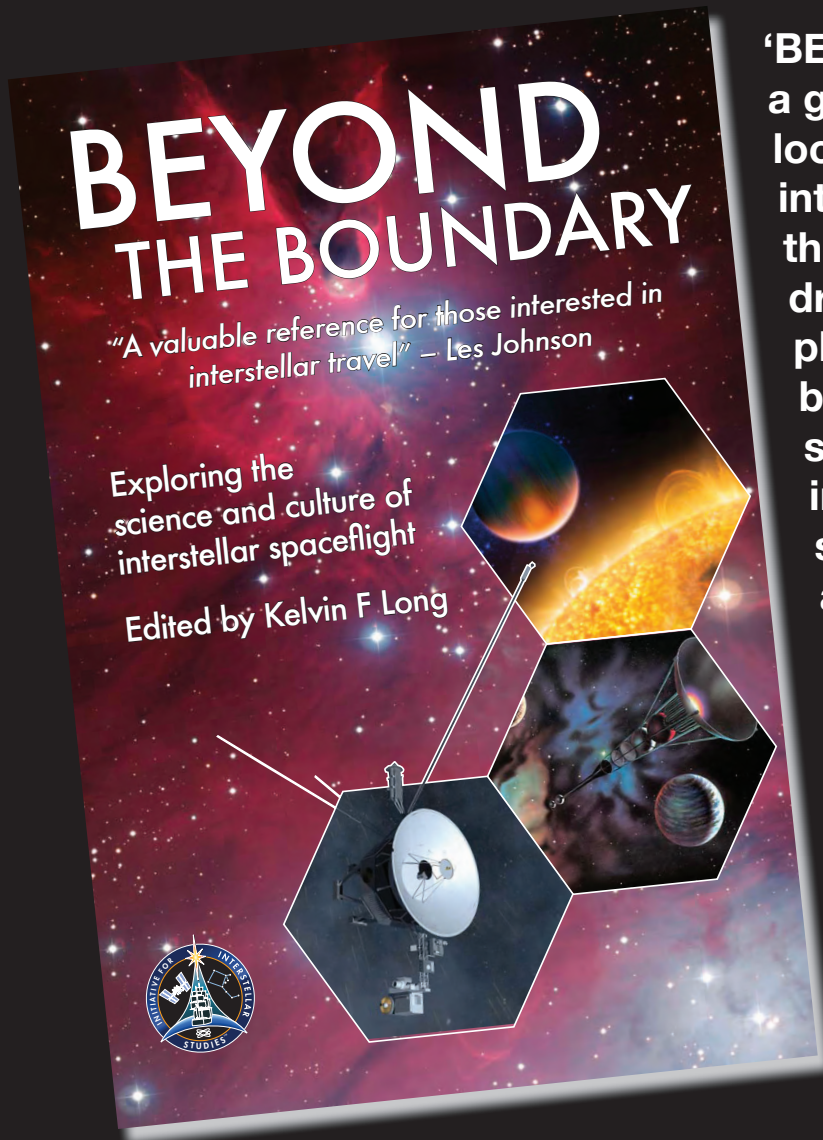
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Back cover: Graphic from Global Trajectory Optimisation Competition Portal (GTOC) Credit: ESA-ESTEC



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Scientia ad sidera
Knowledge to the stars