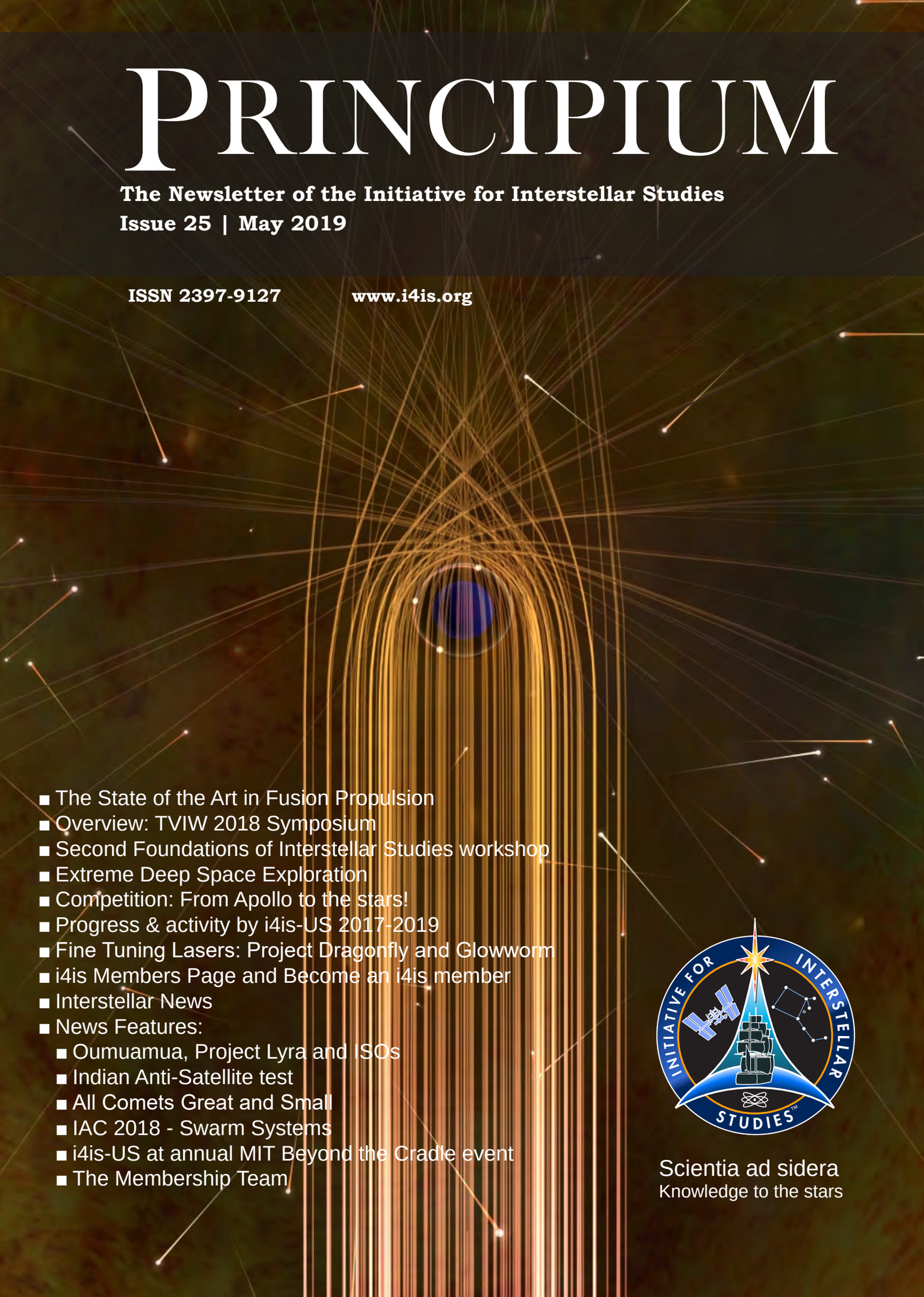
PRINCIPIUM

The Newsletter of the Initiative for Interstellar Studies
Issue 25 | May 2019

ISSN 2397-9127 **www.i4is.org**



Scientia ad sidera
Knowledge to the stars

Editorial

Welcome to issue 25 of ***Principium***, the quarterly newsletter about all things interstellar from i4is, the ***Initiative*** and ***Institute for Interstellar Studies***.

Our Introduction feature is *The State of the Art in Fusion Propulsion*, part 1 of an essay by Kevin Schillo, University of Alabama Huntsville (page 4).

Our front cover is a reminder of the recent first imaging of a black hole, a visualisation of the photon trajectories which produced the image. Our back cover is an impression of the Large Synoptic Survey Telescope (LSST), a vital new tool in finding incoming comets and interstellar objects.

We now feature a table of contents which, as you see, range from the latest i4is work on our Glowworm LEO laser-push demonstrator to an introduction to the team which implemented our membership scheme.

We announce the *Second Foundations of Interstellar Studies Workshop (FISW)* 27-30 June 2019 (page 18). Also in this issue Patrick Mahon exhorts us to *Become an i4is member* (p23) and we have the first *i4is Members Page* (p17) with a few examples of the members-only content we have already made available. And with the 50th anniversary of Apollo 11, we announce a little *Competition: From Apollo to the stars!* (p29). Our technical team reports Fine Tuning our Lasers:

Updates on Project Dragonfly and Glowworm (p48) and the final item is a letter from T Marshall Eubanks with a *Warning from Oumuamua?* (p53)

The feature on *Nomadic Planets* is postponed to next time when we will also have *The State of the Art in Fusion Propulsion - Part 2*, a *News Feature: The Principium Team* and Terry Regan's *Mariner 2 Spacecraft model - part 1: The research phase.*

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

JOIN i4is at i4is.org/membership

For Members of i4is

Members have access to -

Networking - i4is.org/members/networking-opportunities

Principium preprints- i4is.org/members/preprints

Videos - i4is.org/videos

More in *The i4is Members Page* - page 17

CONTENTS

Membership of i4is

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

All at i4is.org/membership.

Please print and display the poster on page 3 (white background for easy printing and 80% discount for students). Other variants are all at -

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

Keep in touch!

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

Become part of our professional network on LinkedIn www.linkedin.com/groups/4640147

Follow us on Twitter at @I4Interstellar

And seek out our followers too!

Contact us on email via info@i4is.org.

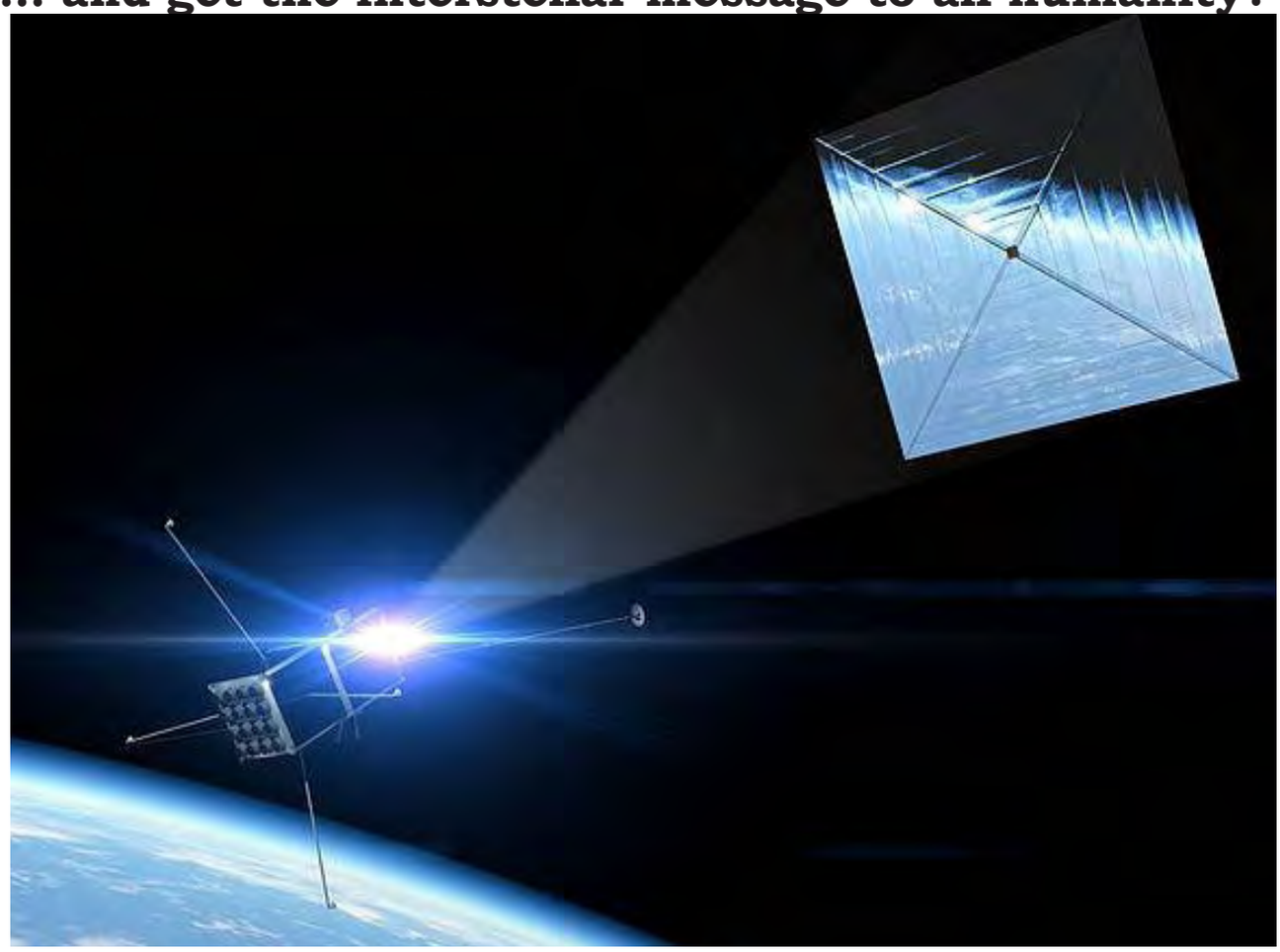
Back issues of Principium, from number one, can be found at www.i4is.org/Principium

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

JOIN I4IS ON A JOURNEY TO THE STARS!

Do you think humanity should aim for the stars?

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



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

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

Join us and get:

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

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

80% discount for full time students!

The State of the Art in Fusion Propulsion

An Essay by Kevin Schillo, University of Alabama in Huntsville

Kevin Schillo introduces and surveys fusion-based propulsion systems. There are many live concepts for fusion and many of them are applicable to spacecraft propulsion. Kevin has based this on the extensive literature search he did for a dissertation in support of his PhD research. This is the first of two parts. Part 2 will appear in Principium 26, August 2019.

Introduction

Since the discovery of the vast energy that can be released in nuclear reactions, scientists and engineers have developed concepts in which nuclear fission and fusion systems may be used for spacecraft propulsion. In a fission reaction, a heavy element splits into lighter nuclei, releasing large amounts of energy. In nuclear fusion, light nuclei are joined together to form a heavier nuclei. Both have been researched extensively for spacecraft systems. The primary advantage that fission has over fusion is that fission systems may be used on spacecraft with existing technology in the form of nuclear thermal or nuclear electric systems. While fusion propulsion is currently beyond our current technological capabilities, the energy released by a fusion system is significantly greater than what is offered in fission. For this reason, fusion propulsion systems have been explored extensively over the past several decades.

In a fusion propulsion system, the plasma exhaust from fusion reactions can be converted directly to thrust, eliminating the need to generate electricity that would be needed for an electric propulsion system. A fusion system would be capable of sending a spacecraft to the furthest reaches of the solar system and possibly beyond far more rapidly than any other propulsion system that can be expected to be developed.

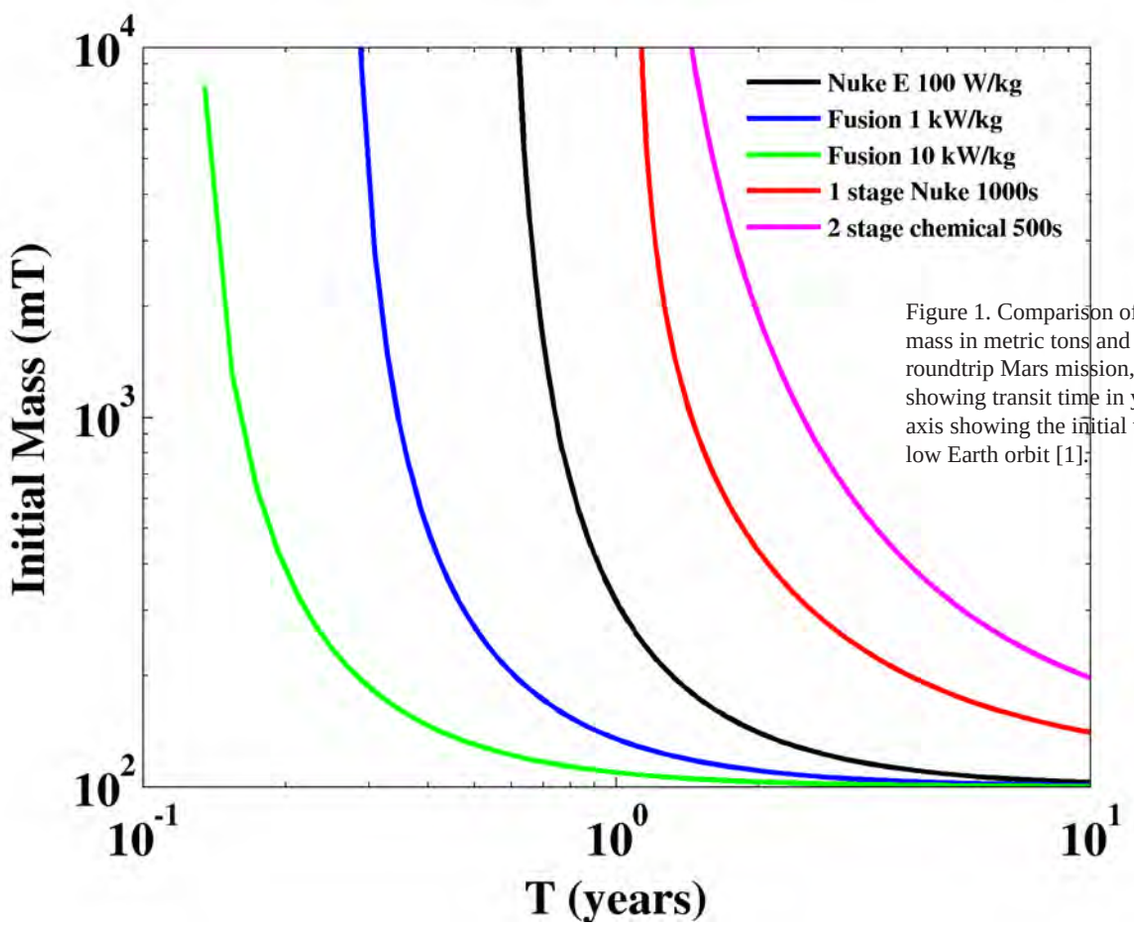


Figure 1. Comparison of initial spacecraft mass in metric tons and transit times for roundtrip Mars mission, with the x axis showing transit time in years and the y axis showing the initial vehicle mass in low Earth orbit [1].

Studies by Cassibry et al [1], Miernik et al [2], and Adams et al [3] in the 2000s and 2010s have shown that fusion propulsion rapidly reduces interplanetary trip times when compared to other propulsion systems for spacecraft. This can be seen in figure 1, which compares the initial spacecraft mass in low Earth orbit and the corresponding transit times required for a roundtrip Mars mission for different propulsion systems. It is extremely difficult for a chemical propulsion system to be used for a human piloted mission due to the corresponding long transit times. Nuclear thermal and nuclear electric propulsion systems could allow for two-year manned Mars missions. A fusion propulsion system with specific powers of 1-10 kW/kg could enable roundtrip Mars missions lasting less than a year.

Compared to other propulsion systems, fusion offers significant payload mass and short transit times. Fusion propulsion has also been identified as an attractive candidate for making interstellar missions possible.

Early History of Nuclear Propulsion

One of the earliest nuclear propulsion concepts explored was Project Orion, in which a spacecraft carries a large number of nuclear explosives. The explosives are ejected one at a time and detonated at a certain distance from the vehicle. Plasma from the explosion impinges upon a pusher plate at the spacecraft's rear and propels the vehicle forward [4]. A vehicle design concept for Orion [5] is shown in Figure 2.

During the 1970s, research done at the Los Alamos National Laboratory investigated using a laser to initiate fusion detonations in fuel pellets [6]. The Los Alamos team also researched three different designs for systems that would convert energy from a fusion explosion into propulsive thrust. The first design was a pusher plate very similar to that which was investigated for Project Orion. For this design, a fuel pellet is detonated at a certain distance from the spacecraft and a pusher-plate absorbs the shock of the explosion, imparting momentum onto the spacecraft. As with Orion, the researchers

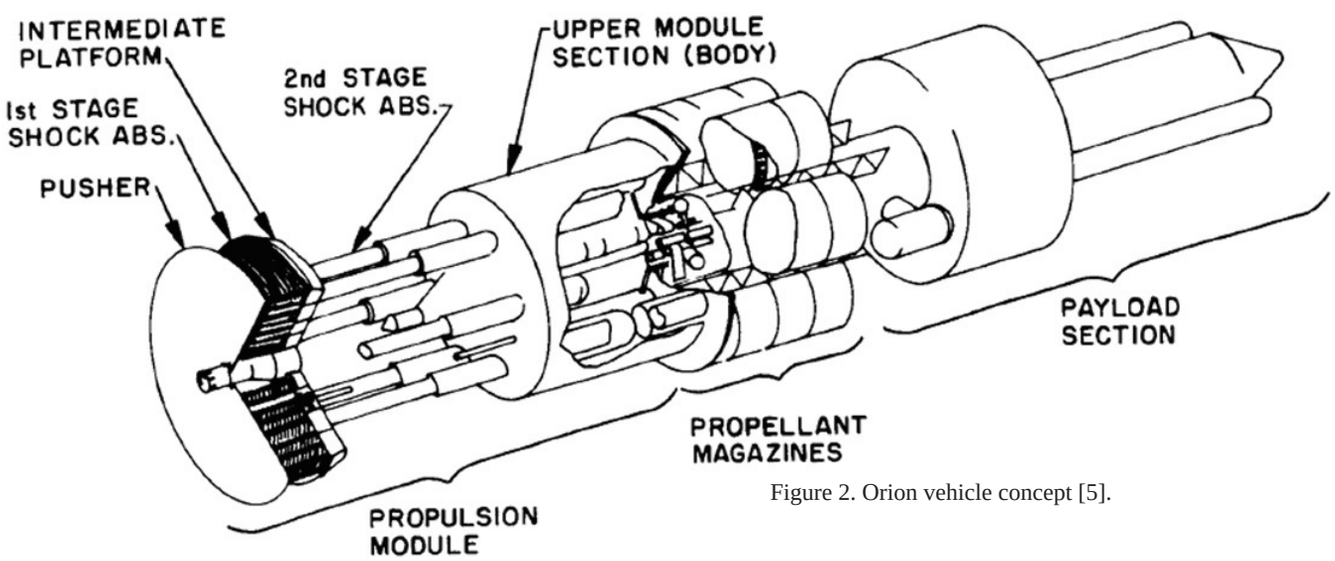


Figure 2. Orion vehicle concept [5].

realized that ablation and spallation of the pusher-plate material may have imposed performance limitations. This was addressed with the second design that the Los Alamos team investigated, which involved using superconductive coils to generate powerful magnetic field lines parallel to a conductive pusher-plate. As plasma from an explosion expands, it pushes the magnetic field lines against the pusher-plate, inducing a current in the conductive material and increasing the magnetic field strength. The increase in magnetic pressure would slow down the plasma and then accelerate it away from the pusher-plate, imparting momentum onto the spacecraft while also protecting the pusher-

plate from particle impingement. This would enable higher propellant particle velocities and a higher specific impulse than that offered by a conventional pusher-plate.

The third design investigated had the fusion detonation occurring inside a pressure vessel, with the propellant then being expelled through a conventional rocket nozzle. A number of methods exist for controlling the expansion of the fusion plasma. In one concept, the pressure vessel is filled with liquid hydrogen, and then an explosive device is detonated at the center of the vessel. This causes a shock wave to propagate through the hydrogen until it reaches the walls of the vessel. The wave is reflected back and forth between the center and the wall of the pressure vessel until equilibrium is reached, losing kinetic energy as it increases the internal energy of the hydrogen. The heated hydrogen is then expanded through the nozzle, generating thrust. Once the pressure vessel empties, it is refilled with hydrogen, and the cycle is repeated. However, there are a number of disadvantages with this concept, which include a lower specific impulse and performance than that offered by a pusher-plate.

The Medusa was another nuclear propulsion concept investigated at Los Alamos by Johndale Solem in the 1990s. In this concept, a large lightweight gossamer sail is placed in front of a spacecraft, with a long cable used to connect the two structures together. The spacecraft would then eject nuclear pulse units forward, which would detonate between itself and the sail. Material from the explosion would then impart an impulse on the sail, propelling it forward and pulling the main spacecraft along with it. The specific impulse of Medusa was reported as being on the order of 50,000 to 100,000 seconds. An advantage Medusa has over Orion is that the sail would be far less massive than Orion's pusher plate. Another advantage is that the sail could utilize more of the pulse unit's momentum than the pusher plate [7].

Research that was conducted at the Lawrence Livermore National Laboratory also investigated using laser-induced fusion microexplosions for spacecraft propulsion [8]. This design had fusion microexplosions occurring inside a thrust chamber onboard the spacecraft. A single magnetic coil would then be used to redirect the plasma from the explosions to generate the desired thrust and to avoid having the plasma come into direct contact with the structure of the vehicle. This provided a specific impulse ranging from 100,000 to 1,000,000 seconds.

Building on the research done at Lawrence Livermore National Laboratory, Hyde developed a concept for an interplanetary spacecraft that utilized laser-drive fusion with a superconducting magnet in the thrust chamber [9]. The propulsion system was assumed to have a jet efficiency of 42%, and would be capable of sending the spacecraft on a roundtrip mission to Mars in forty-five days, albeit with virtually no payload onboard. A thrust efficiency of about 65% was reported by Hyde.

Winterberg later proposed using a relativistic electron beam instead of a laser to initiate fusion microexplosions [10]. The microexplosions would occur within a concave magnetic mirror produced by superconducting magnetic fields. The specific impulse generated by this system was found to be on the order of 100,000 seconds.

The research that Winterberg conducted served as motivation for Project Daedalus, one of the most ambitious spacecraft design concepts explored. This design study was conducted by the British Interplanetary Society in the 1970s, and the objective of the project was to design a spacecraft capable of performing a flyby mission to Barnard's Star. The propulsion system of Daedalus involved injecting fusion fuel pellets into a reaction chamber and then hitting them with powerful electron beams to initiate fusion reactions. As the fusion plasma expands, it compresses magnetic field lines within the reaction chamber, transferring kinetic energy from the plasma to the magnetic field. The field lines are compressed until the magnetic pressure is equivalent to the dynamic pressure of the plasma, after which the direction of the plasma's motion is reversed and it is ejected from the reaction chamber, imparting momentum onto the spacecraft. The design of Daedalus had two propulsive stages, with each one intended to operate for about two years and have a specific impulse within the range of about 1,000,000 seconds. This would accelerate the spacecraft to about 12% of the speed of light, allowing it to reach Barnard's Star within a fifty-year timeframe [11].

A similar study conducted by NASA and the US Naval Academy was Project Longshot. The objective of this study was to design an unmanned probe capable of rendezvousing with the Alpha Centauri system within a one-hundred year timeframe. A long-life fission reactor capable of generating 300 kilowatts would be used to power the spacecraft's systems, as well as start and restart

the fusion reactions. Like Daedalus, the propulsion system of Longshot also involved igniting a fusion fuel pellet with high-energy particle beams, with the resulting fusion plasma being magnetically channelled out of a nozzle to generate thrust. The specific impulse was also expected to be on the order of 1,000,000 seconds [12].

Twenty-First Century Concepts

The VISTA concept, explored by Orth at Lawrence Livermore National Laboratory, was a spacecraft intended to be used for a 145-day roundtrip manned voyage to Mars with a payload mass of 100 tonnes. The propulsion system of VISTA also utilized a laser to initiate fusion microexplosions, and a thrust chamber with two magnetic coils. Once injected into the thrust chamber, deuterium-tritium fuel capsules would be ignited with a 5 MJ laser, with the energy released being 200 to 1,500 times greater than the energy of the laser. Half of the fusion energy released would be in the form of neutrons, one-fourth in the form of X-rays, and one-fourth in the form of charged plasma debris. Only the plasma debris can be used for propulsion, and consequently, only about 9% of the total energy produced would be used for propulsion. The specific impulse of VISTA was on the order of 17,000 seconds, and had a thrust efficiency of about 60% [13].

The FIREBALL (Fusion Ignition Rocket Engine with Ballistic Ablative Lithium Liner) concept explored at Marshall Space Flight Center consists of an Orion-like spacecraft that uses a pusher-plate, shock absorbers, and a magazine of pulse-units. For propulsion, a lithium liner and a dense field reversed configuration (FRC) plasmoid of deuterium and tritium are ejected from the main spacecraft. The liner slows the FRC, compressing and heating it until fusion reactions occur [14]. This is illustrated in Figure 3.

Similar to the Orion, plasma resulting from the nuclear reactions presses upon a pusher plate and imparts propulsive momentum onto the vehicle.

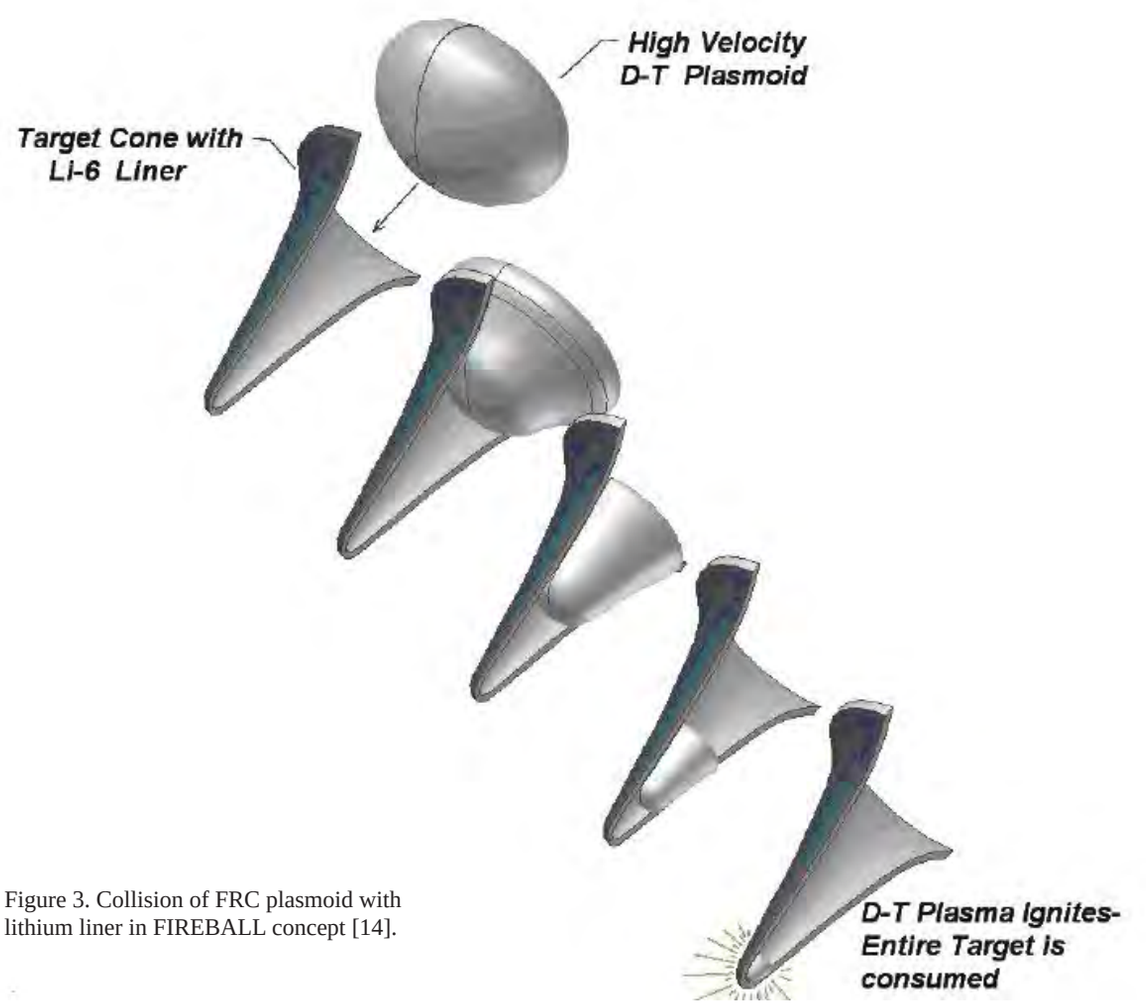


Figure 3. Collision of FRC plasmoid with lithium liner in FIREBALL concept [14].

Part 2 of Kevin Schillo's essay will appear in Principium 26, August 2019

Works Cited - with open access sources cited where available

[1]	J. Cassibry, R. Cortez, M. Stanic, A. Watts, W. Seidler, R. Adams, G. Statham and L. Fabisinski, "Case and Development Path for Fusion Propulsion," Journal of Spacecraft and Rockets, vol. 52, no. 2, pp. 595-611, 2015. (fuelrfuture.com/wp-content/uploads/2014/05/Development-Path-for-Fusion-Propulsion1.pdf)
[2]	J. Miernik, G. Statham, L. Fabisinski, C. Maples, R. Adams, T. Polsgrove, S. Fincher, J. Cassibry, R. Cortez, M. Turner and T. Percy, "Z-Pinch fusion-based nuclear propulsion," Acta Astronautica, vol. 82, pp. 173-182, 2013. (no open access available)
[3]	R. Adams, R. Alexander, J. Chapman, S. Fincher, R. Hopkins, A. Philips, T. Polsgrove, R. Litchford, B. Patton, G. Statham, P. White and Y. Thio, "Conceptual Design of In-Space Vehicles for Human Exploration of the Outer Planets," 2003. (ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20040010797.pdf)
[4]	B. Wagstaff, "A Spaceship Named Orion," Air & Space, Smithsonian Institute, 1988. (no open access available)
[5]	"Nuclear Pulse Space Vehicle Study," George C. Marshall Space Flight Center, Huntsville, AL, 1964. (ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19760065935.pdf)
[6]	J. D. Balcomb, L. Booth, T. Cotter, J. Hedstrom, C. Robinson, T. Springer and C. Watson, "Nuclear Pulsed Space Propulsion Systems," LA-4541-MS, Los Alamos Scientific Laboratory, Los Alamos, NM, November 1970. (inis.iaea.org/collection/NCLCollectionStore/_Public/05/098/5098140.pdf)
[7]	J. C. Solem, "Nuclear explosive propulsion for interplanetary travel: Extension of the MEDUSA concept for higher specific impulse," Journal of the British Interplanetary Society, vol. 47, no. 6, p. 229–238, 1994. (no open access available)
[8]	R. Hyde, L. Wood and J. Nuckolls, "Prospects for rocket propulsion with laser-induced fusion microexplosions," AIAA Paper No. 72-1063, December 1972. (no open access available)
[9]	R. A. Hyde, "A Laser Fusion Rocket for Interplanetary Propulsion," in 34th International Astronautical Federation, Budapest, Hungary, 10-17 October 1983. (no open access available)
[10]	F. Winterberg, "Rocket propulsion by thermonuclear micro-bombs ignited with intense relativistic electron beams," Raumfahrtforschung, vol. 15, pp. 208-217, 1971. (no open access available)
[11]	A. Bond, A. Martin and et al., "Project Daedalus – The Final Report on the BIS Starship Study," Journal of British Interplanetary Society, 1978. (no open access available)
[12]	K. Beals, M. Beaulieu, F. J. Dembia, J. Kerstiens, D. L. Kramer, J. R. West and J. A. Zito, "Project Longshot: An Unmanned Probe To Alpha Centauri," U S Naval Academy. NASA-CR-184718, 1988. (ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19890007533.pdf)
[13]	C. Orth, "VISTA - A Vehicle for Interplanetary Space Transport Application Powered by Inertial Confinement Fusion.3," Lawrence Livermore National Laboratories: Livermore, California, 2003.(related open access paper: e-reports-ext.llnl.gov/pdf/239979.pdf)
[14]	A. K. Martin, R. H. Eskridge, P. J. Fimognari and M. H. Lee, "FIREBALL: Fusion Ignition Rocket Engine with Ballistic Ablative Lithium Liner," AIP Conference Proceedings, vol. 813, no. 1, pp. 783-794, 2006. (no open access available)

About the Author

Kevin Schillo obtained a Bachelor of Science degree in aerospace engineering from the University of Central Florida and a Master of Science in aerospace systems engineering from the University of Alabama in Huntsville. Throughout his career Kevin has worked for NASA, the Center for Space Nuclear Research, and HyperV Technologies researching and designing rockets, satellites, nuclear reactors, and nuclear fusion concepts. He is currently pursuing a PhD in aerospace systems engineering at the University of Alabama in Huntsville researching plasma jet driven magneto-inertial fusion.

Kevin is also an aspiring science fiction author with a collection of short stories. The Tabernacle of Legion is his first novel. He is currently writing the sequel to The Tabernacle of Legion and another novel.

Overview: TVIW 2018 Symposium

The Power of Synergy

D E Fields

The Tennessee Valley Interstellar Workshop is a long established contributor to the field of interstellar studies. In this article, David Fields follows up on *Promoting a Grand Transformation* by John D G Rather in P24 by giving us an overview of the whole event.

Genesis

The 2018 TVIW Special Symposium on The Power of Synergy (TPOS)[1] was held October 23-25 in Oak Ridge, Tennessee. The venue chosen was the Y-12 New Hope Center, a 400-seat world-class Conference Center worthy of the US Department of Energy research complex containing Oak Ridge National Laboratory and the Y-12 National Security Complex (Fig 1).

The 3-day Symposium started promptly on October 23, 2018. The organizers, together with TVIW staff and volunteers welcomed over 100 Symposium participants (Fig 2) to experience inspiring presentations, waves of catered food, facility tours, and wide-ranging conversations that extended into late-evening discussions over dinner. In contrast to past TVIW Symposia, this event was supported primarily by donations.

The TVIW Interstellar Mission and the Symposium Infrastructure

The TVIW Mission statement is to

> "facilitate interstellar research and exploration by hosting regular summit meetings, encouraging educational advances, publishing technical and scientific papers, and supporting literature and culture, all in the service of enhancing public understanding and dialogue toward interstellar exploration. TVIW will assist in building a technological, philosophical, and economic infrastructure that advances the goal of establishing outposts throughout the Solar System and, finally, achieving a pathway to the stars."

Past TVIW Symposia have focused on selected aspects of interstellar exploration. The 2018

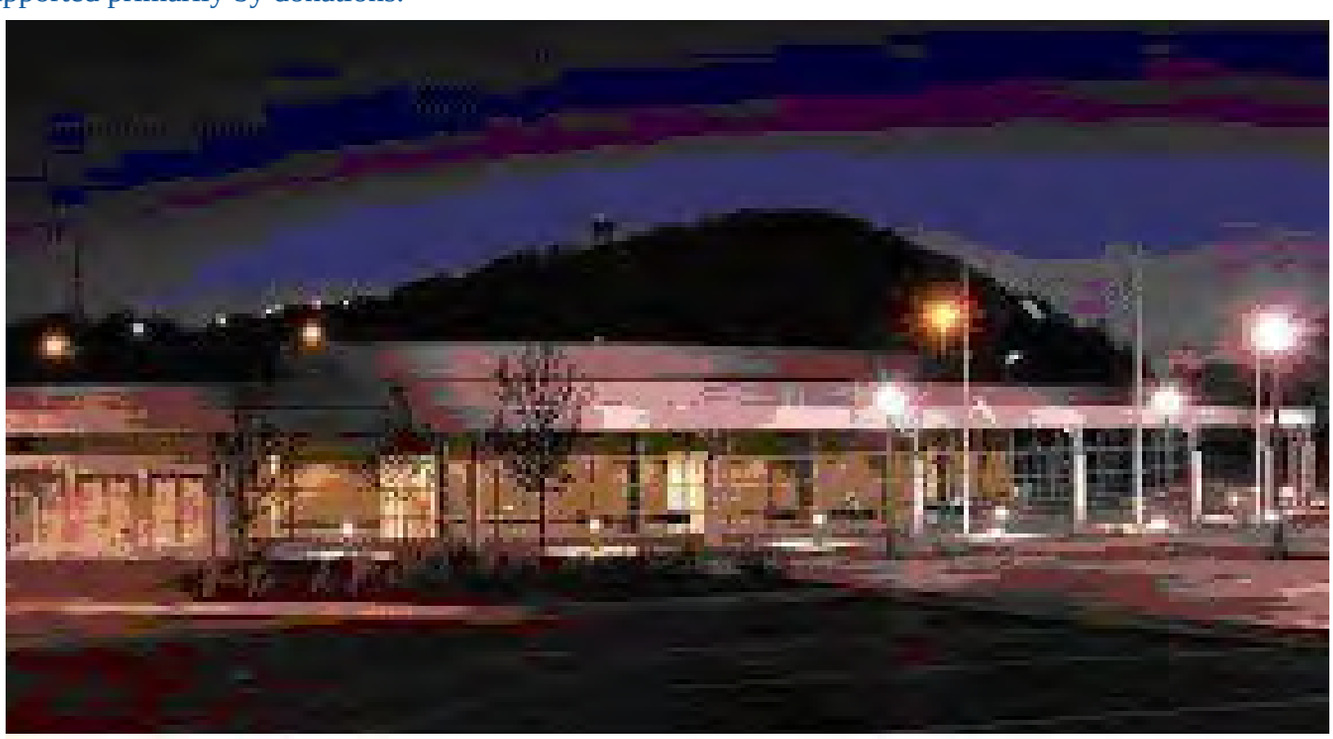


Figure 1. Located at the Oak Ridge Y-12 National Security Complex, one of the original Manhattan Project facilities, the New Hope center houses historic displays and a 400-seat auditorium.

Figure 2. Early morning attendees on Day 1 enjoyed breakfast fare and stimulating introductory presentations.

"Special Symposium" was different, focusing primarily on rekindling the US space effort by showing how a synergistic mix of key technologies might provide the underpinnings for a grand decadal effort for space exploration. Thus, TPOS was structured to energize public enthusiasm and governmental, industrial, and educational institutional support – for a serious space initiative akin to that of the Tennessee Valley Authority (TVA) hydropower initiative, the atomic energy/ weapon development effort, and the NASA Apollo Mission.

In contrast to these past Symposia, the 2018 TPOS Symposium focused on building and jump-starting a solar system infrastructure for Space. This transformational approach would employ a synergy of technologies with components judged ready or almost ready for application[II]. The first Symposium Theme was **Energy Systems for Power, Propulsion, and Space Industrialization**. This category included presentations addressing High Impulse Nuclear Propulsion & Power; High Efficiency Wireless Power Transmission, High Temperature Superconductor (HTSC) Applications; and Solar Power Satellites (SPS).

The second Theme was **Enabling & Enabled Systems (Manufacturing & Resources)**. Presentations in this category covered Large Scale 3-D Printing for Additive Manufacturing; Space Resources Utilization; Lightweight Large Aperture Optics; and Regenerative/Self-Sufficient Habitation Systems.

The third Theme, **Transformative Decadal Plan** compared the current situation, in which we are seen to be poised for a great leap into a space-based future, to a methodical approach which may offer far fewer benefits. Our situation may be compared to past opportunities for great efforts, such as those that led to the TVA program [III], which engendered regional energy and cultural shift in the Tennessee Valley and spurred development of the electric power grid; the atomic energy program, which developed industrial-scale isotope-separation technology in Oak Ridge, Tennessee prompting military, electrical power, and cultural shifts of global importance; and the Apollo program, which developed the Saturn 5 rocket in Huntsville, Alabama and justified building the US space infrastructure. Each of these three important transformative projects was decadal in duration, had important focus in the Tennessee Valley region, and was global in impact.

The final Theme, **Ultimate Paths to the Future (Science Fiction to Fact Relationships)**, offered a variety of viewpoints from diverse 'deep thinkers' as to how we might proceed with this grand transformative opportunity with which we are now presented. Initial answers as to how to chart a Decadal Plan were offered.

Each of the four Themes was followed by an interactive 'Sagan Discussion'*.

The agenda proceeded as shown in the schematic Figure 3.

All Themes were developed with participation

of the Theme ChairsIV. Video tapes of the presentations have been posted at tviw.us/ tpos-presentation-video-archive/Symposium Organization: A Cooperative Effort

Past TVIW Symposia have been organized by the TVIW Board, advisors, and volunteers. For TPOS, the Board established a contractual

* Carl Sagan famously employed the Sagan Discussion format at his 1971 conference at the Byurakan Observatory in old Soviet Armenia, which dealt with the Drake Equation. Sagan Discussions at TVIW events typically consist of five speakers who each give a short presentation staking out a position on a particular question.

Day 1: Tuesday, October 23, 2018	
09:00 - 09:05	**Dean S. Hartley III, PhD** – Administrivia
09:05 - 09:13	**John D. G. Rather, PhD** - Symposium Welcome
09:13 - 09:18	**Edward "Sandy" Montgomery** - TVIW Welcome
09:18 - 09:39	**Morgan Smith** - Y-12 Keynote Address
09:39 - 10:00	**John Vonglis** - ARPA-E Keynote Address
10:00 - 10:10	**John D. G. Rather, PhD** - The Power of Synergy
Theme 1: Large-Scale Space Development	
10:10 - 10:36	**John Mankins** Realizing the Development and Settlement of Space
10:36 - 11:06	**Break**
11:06 - 11:31	**Franklin Chang Diaz, PhD** Living and Working in Space, an Astronaut's Perspective
11:31 - 11:56	**John Rather, PhD and John Mankins** James Powell: Creator of Particle Bed Reactors and Maglev
11:56 - 12:56	**Lunch**
12:56 - 13:21	**Michael Houts, PhD** Advanced Exploration with Nuclear Thermal Propulsion
13:21 - 13:46	**Joel Sercel, PhD** Capture & Uses of Small Asteroids
13:46 - 14:11	**John R. Adams** What We Know About Closed Human Ecosystems
14:11 - 14:41	**Break**
14:41 - 15:21	**Theme 1 Sagan Discussion**
Theme 2: Breakthrough Concepts & Technologies	
15:21 - 15:47	**Jason Derleth** NASA Innovative Advanced Concepts Program
15:47 - 16:12	**Jonathan K. Witter, PhD** Particle Bed Reactor Nuclear Thermal Propulsion Power
16:12 - 16:37	**Roger Lenard**
16:37 - 17:02	**Philip Lubin, PhD** Directed Energy Propulsion & Power Beaming
17:02 - 17:27	**Robert Bagdgian** Environmental Control & Life Support
17:27 - 18:27	**Reception**

Day 2: Wednesday, October 24, 2018	
08:00 - 09:00	**Pre-Meeting Tour**
09:00 - 09:05	**Dean S. Hartley III, PhD** – Administrivia
09:05 - 09:26	**Alan Icenhour, PhD** ORNL Keynote Address
09:26 - 09:52	**William Peter, PhD** Large-scale 3D Printing & Complex Structures
09:52 - 10:17	**Jeffrey Slostad** Persistent Space Platforms Bootstrapping Space Economy
10:17 - 10:47	**Break**
10:47 - 11:12	**Mark D. Carter, PhD** VASIMR Plasma Propulsion
11:12 - 11:37	**Ken Roy** Problem of Low Gravity Physiology: A Possible Solution
11:37 - 12:02	**Siefried Janson, PhD** Small Satellite Concepts at The Aerospace Corporation
12:02 - 13:02	**Lunch**
13:02 - 13:42	**Theme 2 Sagan Discussion**
Theme 3: Transformative Decadal Plan	
13:42 - 14:08	**Matt Hollingsworth** Making Big Ideas a Reality
14:08 - 14:33	**James T. Early, PhD** Transformative Decadal Plan
14:33 - 15:03	**Break**
15:03 - 15:28	**John D. G. Rather, PhD** Capture and Industrialization of Small Near Earth Asteroids
15:28 - 15:53	**John Mankins** Critical Importance of Affordable, Abundant Solar Energy
15:53 - 16:18	**A. C. Charania** Business Development Director, Blue Origin
16:18 - 16:43	**Dean S. Hartley III, PhD** How To Integrate It?
16:43 - 17:43	**Reception**

Day 3: Thursday, October 25, 2018	
09:00 - 09:05	**Dean S. Hartley III, PhD** – Administrivia
09:05 - 09:46	**Theme 3 Sagan Discussion**
Theme 4: Ultimate Paths to the Future Science Fiction to Fact Relationships	
09:46 - 10:12	**Catherine Asaro, PhD** Ultimate Paths to the Future
10:12 - 10:37	**Marc Millis** Sustaining Progress Beyond the Obvious
10:37 - 11:07	**Break**
11:07 - 11:32	**Arlan Andrews Sr. , PhD** CARPE:DIEM - Captured Asteroid Re-Purposing
11:32 - 11:57	**David Brin, PhD** Ultimate Paths to the Future
11:57 - 12:57	**Lunch**
12:57 - 13:22	**Ruth E. Kastner, PhD** Quantum Universe Properties
13:22 - 13:47	**Allen Steele** Science Fiction Author
13:47 - 14:27	**Theme 4 Sagan Discussion**
14:27 - 14:57	**Break**
14:57 - 15:07	**Catherine Asaro, PhD** – Award
Wrapup	
15:07 – 15:37	**Dean S. Hartley III, PhD** – Symposium Synthesis
15:37 – 15:47	**Edward "Sandy" Montgomery** – TVIW Futures
15:47 – 16:32	**John D. G. Rather, PhD** - Appraisal
16:32 – 17:32	**Reception**

Figure 3. The TPOS agenda was structured as 4 Themes, with each followed by a Sagan Discussion.

Figure 4. Attendees not involved in indoor conversations assembled for a group photo in front of the New Hope Center.

relationship in which the Symposium would be led by John Rather (Chairman) and Dean Hartley (Co-Chairman). The TVIW board[V] handled TVIW decisions. Fundraising and programmatic support was provided by a Planning Team[VI] that met weekly. Significant support was also received from volunteers[VII]. The local and extended Interstellar communities provided generous financial support and the DOE facility operators were welcoming and supportive.

Measures of Success

From the standpoint of need and potential, TPOS was a much-needed Symposium. In execution, it was well-conceived and focused. Presentations, tours, catered food were enjoyed by all. Travel funds to support a scholarship[VIII] were awarded. Several articles were written by a former ORNL (Oak Ridge National Laboratory) Review Editor, for publication in local news media[IX]. The meeting has been discussed in several venues[X,XI,XII], and an official Summary Report[XIII] is nearing publication.

Participants found the Symposium stimulating, thought-provoking, and energizing. They embraced the synergistic theme and evinced the spirit of the meeting as they stood under Tennessee skies for a group photo (Fig 3). Questions about the next Symposium were answered by providing some details of the next planned TVIW Interstellar Symposium XIV, which will be held Nov 10-15, 2019 in Wichita, Kansas. That will be the first TVIW Symposium to be held outside the Tennessee Valley.

The anticipated enthusiastic national response will hopefully be heard upon publication of meeting summaries, on-line video documentation of presentations, and continuation of follow-up discussions.

References

I tviw.us/tviw-symposium-on-the-power-of-synergy/

II tviw.us/tviw-2018-agenda/

III en.wikipedia.org/wiki/Tennessee_Valley_Authority

IV Theme Chairs were John Mankins, Jason Derleth, Matt Hollingsworth, and Catherine Asaro.

V The TVIW Board for 2018 consisted of David Fields, Paul Gilster, Martha Knowles (Sect/Treasurer), Doug Loss, and Sandy Montgomery (President), with advisors Les Johnson and John Rather.

VI The Planning Team consisted of David Fields, Martha Knowles, John Preston, Jim Rushton, D Ray Smith, and Mark Uhran.

VII Volunteers included Buck Field (Symposium Video Producer), Linda Fippin (Major Domo/ Volunteer Coordinator), Rob Fowler/John Preston (Videographers), Doug Loss (Registrar), Martha Knowles (Registration) Joe Meany (Publicity) and David Fields (Still Photography).

VIII The scholarship, awarded at the Symposium to Rishi Iyer, was in support of the Chesapeake Math Program (CMP).

IX A series of articles by Carolyn Krause has been published :

oakridgetoday.com/2018/10/22/power-of-synergy-space-symposium-at-new-hope-center-this-week/

www.oakridger.com/news/20181023/could-humans-live-on-planet-4-light-years-away

drdeanhartley.com/HartleyConsulting/INDUSTRY/TPOS.htm;

www.oakridger.com/news/20181227/3d-printing-structures-in-outer-space;

www.oakridger.com/news/20190103/can-us-colonize-moon-by-2030;

www.oakridger.com/news/20190103/why-we-should-go-to-space-safely

www.oakridger.com/news/20190111/technologies-needed-to-explore-settle-solar-system;

and four other articles not yet web-indexed. (Editor: Some www.oakridger.com pages may be security blocked from some locations. Please report your experience, positive or negative, to john.davies@i4is.org)

X Fields, D, HSWT 16, "Impressions of the 2018 TVIW "The Power of Synergy" Symposium". Feb 2019".

XI Rather, J and D Hartley, HSWT 16, "TVIW Power of Synergy Symposium Executive Summary -- Promoting a Grand Transformation" Feb 2019.

XII Rather, J, Principium 24, "The TVIW Power of Synergy Symposium".

XIII TVIW, "TVIW 2018 Special Symposium on The Power of Synergy: Final Report", tviw.us/tviw-symposium-on-the-power-of-synergy/

XIV tviw.us/2019-symposium/

About the Author

David Fields is Director of Tamke-Allan Observatory at Roane State Community College. He holds his MS and PhD (in Condensed Matter and Materials Physics) from the University of Wisconsin-Madison. He was with Lockheed-Martin Energy Systems Inc at Oak Ridge National Laboratory for 24 years, where he performed research in various nuclear and environmental areas. He served as guest scientist at the German Bundesgeshundheitsampt (Federal Health Office) and represented the International Atomic Energy Agency in Brazil, returning there to work at two federal research facilities and present a graduate-level course on Environmental Transport, Human Exposure, and Risk Evaluation. He subsequently consulted with NASA-MSFC, simulating performance of spacecraft radiation shields. David is president of ORION, Senior Researcher for i4is-US, Founding Board member of TVIW, JPL Solar System Ambassador, a past president of the Tennessee Academy of Science, and a former Director of the Society of Amateur Radio Astronomers (SARA). He has 186 publications and two patents. Current active research interests include EM transmissions through magnetized plasmas and developing a software-defined receiver for radio astronomy research. Recent publications considered Jovian Tesla Radio, Algorithm Defined Receivers, and Dyson Dots.

Dr David Fields

Interstellar News

John I Davies with the latest interstellar-related news

Masters Collaboration with University of York

April 2019 marks the start of the first i4is Masters project collaboration with York University, UK. i4is experts have supported Masters projects at the International Space University (ISU), Strasbourg, for a number of years and have also worked with Southampton University in UK but this is our first at York. i4is Education Director Rob Swinney will work with Dr Ben Dudson assisting a York student on a i4is Masters project on *Fusion Energy for Space Propulsion Systems*. Rob is building on his earlier relationship with the York Plasma Institute (www.york.ac.uk/physics/ypi).

Breakthrough Discuss 2019

Robert Kennedy, Andreas Hein, Nikolaos Perakis were invited to the annual Breakthrough Discuss conference this year. i4is co-founder and former Executive Director Kelvin F Long also attended as a member of the Breakthrough Starshot advisory committee. The meeting was held at the University of California (UC) - Berkeley on April 11 and 12.

The theme was "Migration of Life in the Universe" and the main presentations can be seen here.

There was also much informal discussion and the most relevant to the work of i4is was a reasoned objection to our Project Lyra proposals for a mission by conventional launchers to Oumuamua by Professor Abraham Loeb, Harvard. His grounds were two-fold -

Terminal Guidance: The precise location of Oumuamua would not be observable from Earth as interception approached and the Lyra probe would need some form of terminal guidance. The Lyra team currently propose an on-board telescope. Professor Loeb doubted a sufficiently large telescope could be carried by the probe.

Solar slingshot heat shield requirement: The Lyra proposals envisage a momentum gathering manoeuvre or "slingshot" around the Sun, an Oberth manoeuvre, to acquire the necessary intercept velocity. Professor Loeb doubted that a sufficiently efficient heat-shield could be provided given the required distance from the Sun

The Lyra team are considering this and will be publishing a response in the next few weeks.

At Breakthrough Discuss 2019 - left to right Robert Kennedy III, Dr Andreas M Hein, Nikolaos Perakis and Kelvin F Long.

Searches for Galactic Stream Interstellar Asteroids

Interstellar asteroids passing through the solar system are likely to come from known galactic dynamical streams. This fact can be used to help find them. T Marshall Eubanks of Space Initiatives Inc and i4is presented *Efficient Searches for Galactic Stream Interstellar Asteroids* at the 50th Lunar and Planetary Science Conference (2019) available at www.researchgate.net/publication/330765570_Efficient_Searches_for_Galactic_Stream_Interstellar_Asteroids and his presentation poster is featured below. More about Oumuamua and i4is Project Lyra in - *News Feature: Latest on Oumuamua, Project Lyra and Interstellar Objects* elsewhere in this issue.

i4is at the Royal Institution - 2019

i4is presented a one day summer school event at that oldest of UK scientific organisations, the Royal Institution (RI) in August last year (reported in Principium 23, November 2018). Feedback was very positive and the RI have asked us back. This time they want us to deliver not only to a 13-15 age group as last year but to a 16-18 group. So we'll be tuning up last year's show and adding more demanding material for that older, pre-university, age group. This time Satinder Shergill and John Davies will again be joined by Rob Matheson and we will also have our best practical engineer, Terry Regan. The school students can already apply via the RI website-

Summer Schools: Skateboards to starships (age 16–18) 10.30 am to 4.30 pm, Wednesday 7 August - www.rigb.org/whats-on/events-2019/august/summer-schools-skateboards-to-starships-age-16-1

Summer Schools: Skateboards to starships (age 13–15) 10.30 am to 3.30 pm, Thursday 8 August - www.rigb.org/whats-on/events-2019/august/summer-schools-skateboards-to-starships-age-131

Longer term we would like to roll this out to schools UK-wide - and via our colleagues in other countries, world-wide. Get in touch with john.davies@i4is.org.

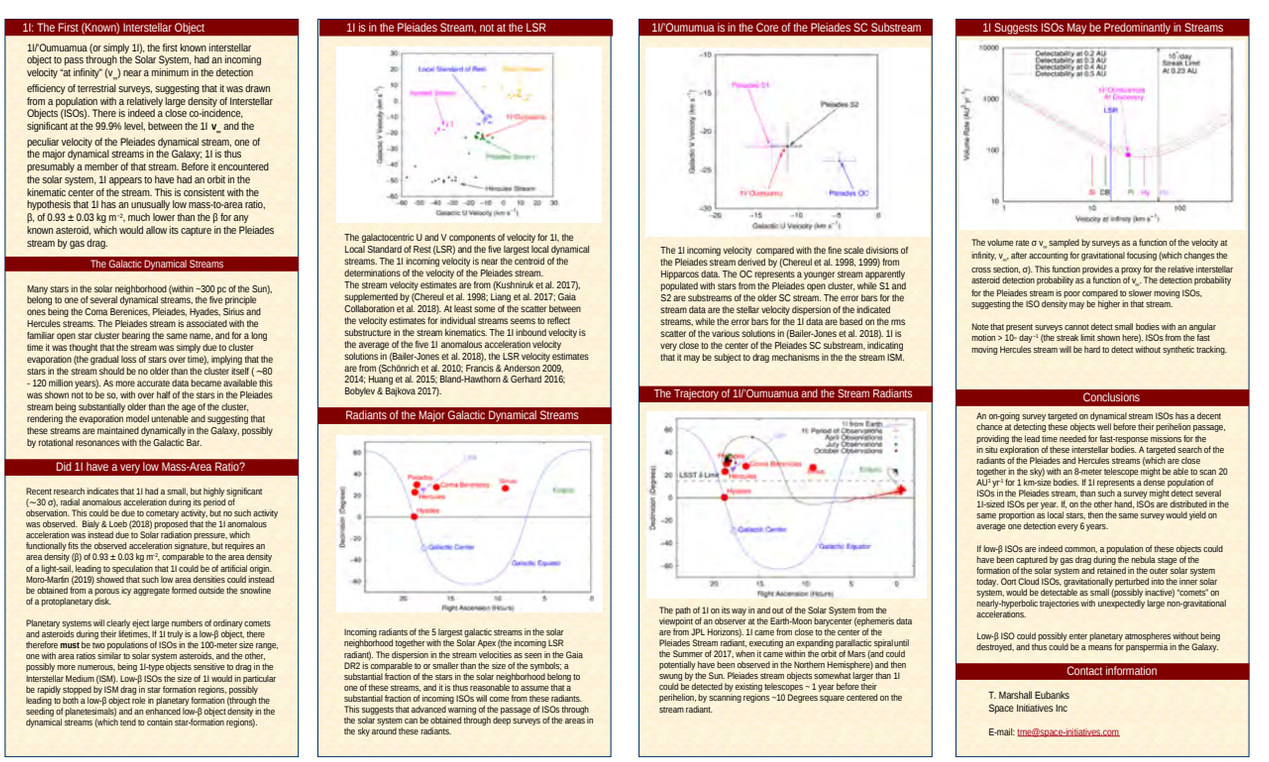
Ciel et Espace on Hein-Baxter AI for Interstellar

Ciel et Espace is the most wide-spread French astronomy and space magazine and can be found in almost any kiosk in France. The magazine recently featured Stephen Baxter and Andreas Hein's paper on AI for interstellar travel www.cieletespace.fr/actualites/podcast-les-sondes-interstellaires-intelligentes-d-andreas-hein.

Principium readers will recall the paper from Interstellar News in Principium 23, November 2018, *Artificial Intelligence for Interstellar Travel*, Andreas M Hein and Stephen Baxter

arxiv.org/pdf/1811.06526.pdf

Efficient Searches for Galactic Stream Interstellar Asteroids
T. Marshall Eubanks
Space Initiatives Inc, Clifton Virginia



ISU/i4is Elective Module – Chipsats

29 April to 10 May 2019 i4is will deliver an elective course module for the Masters programme at the International Space University (ISU) in Strasbourg. ChipSats are a new class of spacecraft of the size of a credit card or smaller. The relevance to tiny laser-pushed interstellar probes is obvious but they have many potential uses in the short term.

NASA Grant for Solar Gravity Lens Mission

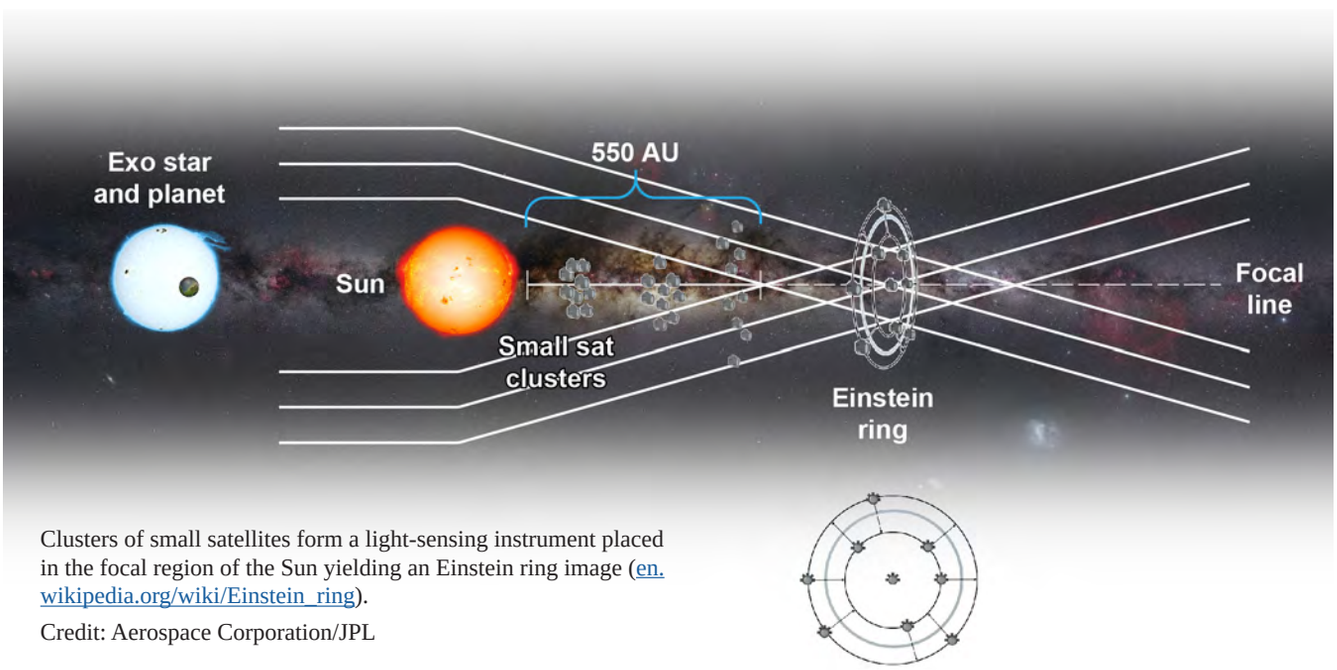
The Aerospace Corporation (aerospace.org) is working with the NASA Jet Propulsion Lab using a NASA grant to study the feasibility of a solar-gravity lens mission using a swarm of small spacecraft launched over a period of years to form a distributed optical detector at the solar gravitational lens point, about 550 AU from the sun (en.wikipedia.org/wiki/Gravitational_lens#Solar_gravitational_lens). This is about four times the distance of the Voyager 1 Probe (voyager.jpl.nasa.gov/mission/status) but the target journey time is about 20 years (aerospace.org/story/solar-gravity-lens-looks-exoplanets) so the study is examining propulsion ideas including solar sails. The acceleration and deceleration challenges will be obvious from the work of i4is Project Lyra researchers who have considered how to intercept the interstellar object Oumuamua.

Tau Zero Breakthrough Propulsion Study

The Tau Zero Foundation team of Marc G Millis, Jeff Greason and Rhonda Stevenson have completed and published their First Year Report on NASA-funded *Breakthrough Propulsion Study - Assessing Interstellar Flight Challenges and Prospects*. They report progress toward developing an evaluation process for interstellar propulsion and power options with the goal to contrast the challenges, mission choices, and emerging prospects for propulsion and power, to identify which prospects might be more advantageous and under what circumstances, and to identify which technology details might have greater impacts including the infrastructure expenses and prospects for breakthrough advances. Methodology includes a work breakdown structure to organize the information and associated list of variables and more detailed methods to convert the performance measures of disparate propulsion methods into common measures of energy, mass, time, and power. The whole report is available at ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20180006480.pdf.

More from Prof Claudius Gros on Genesis probes

Professor Gros has a new paper, *Why planetary and exoplanetary protection differ: The case of long duration Genesis missions to habitable but sterile M-dwarf oxygen planets* (arxiv.org/abs/1901.02286), based on his ideas for seeding of sterile planets (see reports from IAC 2018 in P23 and P24) and for deceleration of interstellar probes (see *Slow down!: How to park an interstellar rocket* by Tishtrya Mehta in P21). His new paper ranges from the ethics of panspermia to stellar evolution.



Clusters of small satellites form a light-sensing instrument placed in the focal region of the Sun yielding an Einstein ring image (en.wikipedia.org/wiki/Einstein_ring).

Credit: Aerospace Corporation/JPL

Human exploration beyond the Moon and Mars

The British Interplanetary Society (BIS) again looks beyond current planned space missions with a *Call for Papers: Putting Astronauts in Impossible Locations:* A one day Technical Symposium (27th November 2019) designed to explore the limits of human exploration far into the solar system and how to overcome the challenges involved. Papers via www.bis-space.com/2019/04/23/22070/call-for-papers-putting-astronauts-in-impossible-locations-a-1-day-technical-symposium

The Contact Paradox

Our friend and colleague Keith Cooper, editor of Astronomy Now magazine and former editor of Principium, has a new book out on 31st October this year. It's titled *The Contact Paradox - Challenging our Assumptions in the Search for Extraterrestrial Intelligence* We'll be reviewing it as soon as its available. In the meantime its available for pre-order at - www.bloomsbury.com/uk/the-contact-paradox-9781472960429. Our congratulations to Keith on this. His publisher, Bloomsbury, is mainly academic but is also famous for some novels about a young wizard you may have heard of.

David Hardy - Honorary FBIS

Long-renowned space artist David Hardy received the Honorary Fellowship of the British Interplanetary Society at the annual UK Science Fiction Eastercon. Gerry Webb, President of the British Interplanetary Society, announced this in recognition of the tremendous contribution David has made to astronautical art and the immense support he has given to he BIS over the decades. Gerry added 'The space artist has a vital role to play in bridging the gap, in the words of the motto of the British Interplanetary Society, “From Imagination to Reality”, a role which you have fulfilled to distinction!'

i4is congratulates David on this award and thanks him especially for his contributions to both our published papers and to Principium, notably the cover image in our last issue.

Gerry Webb, President of the British Interplanetary Society, presnts David Hardy with the Honorary Fellowship of the Society

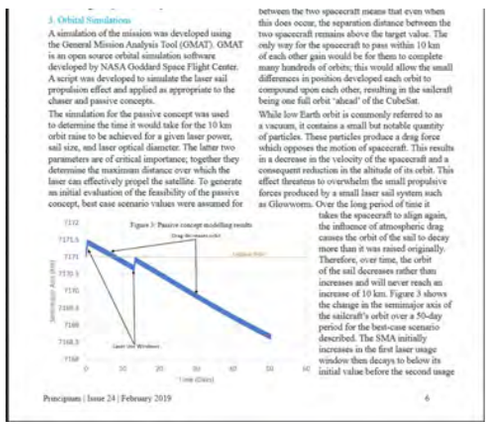
Credi: Chris Morgan / David Hardy

The i4is Members Page

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

Here's just a sample of what we have. We'll be listing more in the next issue of Principium and in our members' email newsletter.

You need to login with your i4is identity to access this. If you are not yet a member then here's the way to sign up - i4is.org/membership - or to simply find out more about membership.



Principium preprints

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

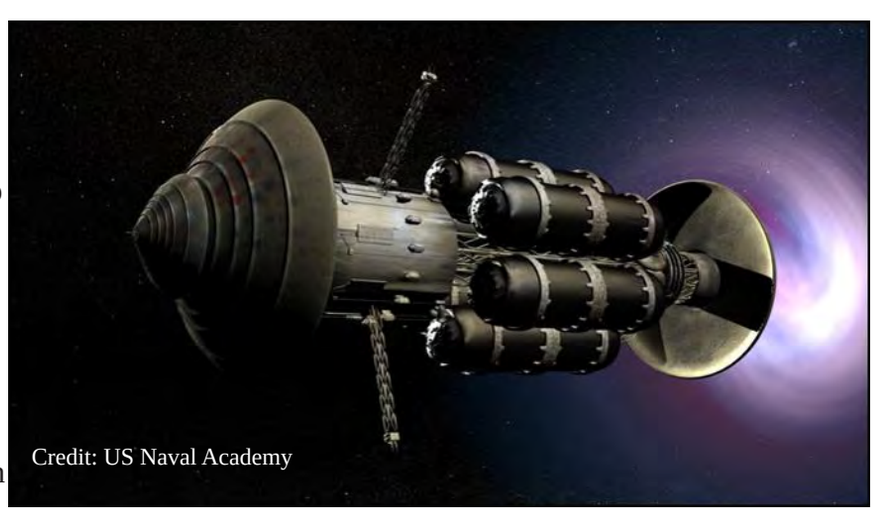
Videos

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

- *Starship Engineer,* 6 videos of the 2016 event at the British Interplanetary Society, London (i4is.org/videos/starship-engineer)
- *Sending Ourselves to the Stars* - a digital human tells us about her sister, just returned from Epsilon Eridani, based on Principium 12 page 14, *Overture from the 2500s* (i4is.org/videos/sending-ourselves-to-the-stars/)
- Project Dragonfly, 5 videos of the 2015 event (i4is.org/videos/project-dragonfly/) including presentations by the 6 finalist teams - **Cairo University,** Egypt, **University of California Santa Barbara**, USA, **Technical University of Munich**, Germany, **CranSEDS** (Cranfield University-UK, Skoltech-Russia, UPS-France)

Space Gallery

Explore our collection of images of spacecraft and interstellar destinations - Interplanetary Exploration, Interstellar Destinations, Starship Designs, Starship Concepts and Starship Science Fiction (i4is.org/members/space-gallery).


Credit: US Naval Academy

We will also be sending out a regular and exclusive email to members with the latest news of i4is and the whole interstellar endeavour.

And help us to grow! Print the poster on page 20 and student poster on page 3.

Foundations of Interstellar Studies II

A Workshop on Interstellar Flight

27 – 30 June 2019
Gloucestershire, United Kingdom

AT THE START OF THIS NEW MILLENNIUM we face one of the greatest challenges of our age – can we cross the vast distances of space to visit 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 more interest, particularly since the discovery of many planets outside our Solar System around other stars. In addition, national space agencies and private commercial industry are beginning to turn their attention to the outer planets and beyond. It is time to consider the bold interstellar journey and how we might accomplish it. This challenge presents many difficult technical problems to solve and who better to address them than the global physics community.

www.fisw.space

The First Foundations of Interstellar Studies workshop took place in New York City in June 2017. The Second Foundations of Interstellar Studies workshop will take place in the county of Gloucestershire, United Kingdom, at the Headquarters of the Initiative for Interstellar Studies (i4is), who are the host organisation along with the partners, the British Interplanetary Society. Previous speakers at this venue have included NASA Apollo 15 astronaut Al Worden, former NASA Ames director Pete Worden, Spaceplanes pioneer David Ashford, Saturn expert Professor Carl Murray, interstellar pioneer Greg Matloff, planetary scientist Professor Ian Crawford, former BIS President Mark Hempsell, artists C Bangs and David A. Hardy and others from the i4is team.

The 2019 workshop will take place in the village of Charfield, near Wootton-under-Edge, GL12 8ES, in the English county of Gloucestershire, on the edge of the historic Cotswolds an area that was also a key part of the first industrial revolution. The Cotswolds are designated an Area of Outstanding Natural Beauty.

The technical component of the workshop will be three days of scientific discussions on interstellar flight, focussed on the themes described below. Submissions are invited for presentations at this workshop. See the website for further details on how to submit your abstract and also on how to register **www.fisw.space**.
In addition to the formal scientific proceedings, there will also be an opening social event on the evening of **Thursday 27th June**, starting at 18:00 hours taking place at the i4is HQ. There will also be a workshop dinner on **Saturday 29th June** starting at 19:00 hours at a venue to be announced.

The three themes for the workshop for each day includes:

LIVING IN DEEP SPACE

This theme includes space habitats on moons or planets. It may also include existing on small exploration vessels, living within medium sized slow boats or large world ships that travel over interstellar distances. The assumption is that for vessels that require human occupation for travel times which are equivalent to or exceed a human lifetime.

ADVANCED PROPULSION TECHNOLOGY & MISSIONS

This includes technologies that will take our probes outside of the Solar System, beyond the Voyagers and to interstellar or intergalactic distances. This may include beaming systems and energetic reactions engines such as fusion and also exotic systems such as antimatter. Propulsion concepts which include an application of known physics will be considered. Not considered here would be concepts which only enable orbital or interplanetary travel.

BUILDING ARCHITECTURAL MEGASTRUCTURES

This includes a consideration for constructions that are the size of moons or planets, such as planetary/stellar engineering initiatives like Dyson-Stapledon spheres, Stellar Engines, Matrioska brains, Ring Worlds and other innovative inventions. This may also include the possibility of constructing gravity-based engines from space-time geometry such as wormholes.

The event is organised by the Co-Chairmen for the meeting which includes:

Kelvin F Long, Initiative for Interstellar Studies, Stellar Engines, UK

Rob Swinney, Initiative for Interstellar Studies, UK

Harold 'Sonny' White, NASA Lyndon B Johnson Space Center, USA

An invitation will be made to submit papers from selected authors post-conference, to the Journal of the British Interplanetary Society (JBIS) and/or publication in the official conference proceedings.

Speakers Selected to Date:

Philip Lubin, *Directed Energy - The Path to Interstellar Flight*

Mark Hempsell, *Colonies and World Ships*

Kelvin F Long, *Microwave Beam Driven Worldship*

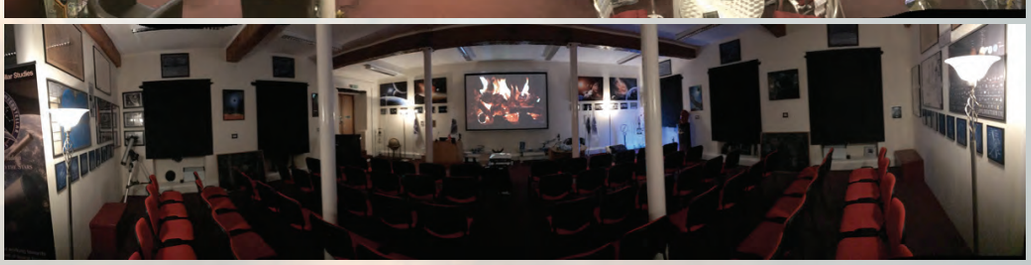
Harold 'Sonny' White, *Dynamic Vacuum Model and Casimir Cavity Experiments*

Remo Garattini, *Traversable Wormholes and the Casimir Effect*

Charles Swanson, *Direct Fusion Drive for the Gravitational Lens Mission*

Al Jackson, *A Neutrino Beacon*

Gregory Matloff, *Is the Kuiper Belt Inhabited?*



For Further information, please contact the workshop Secretary:

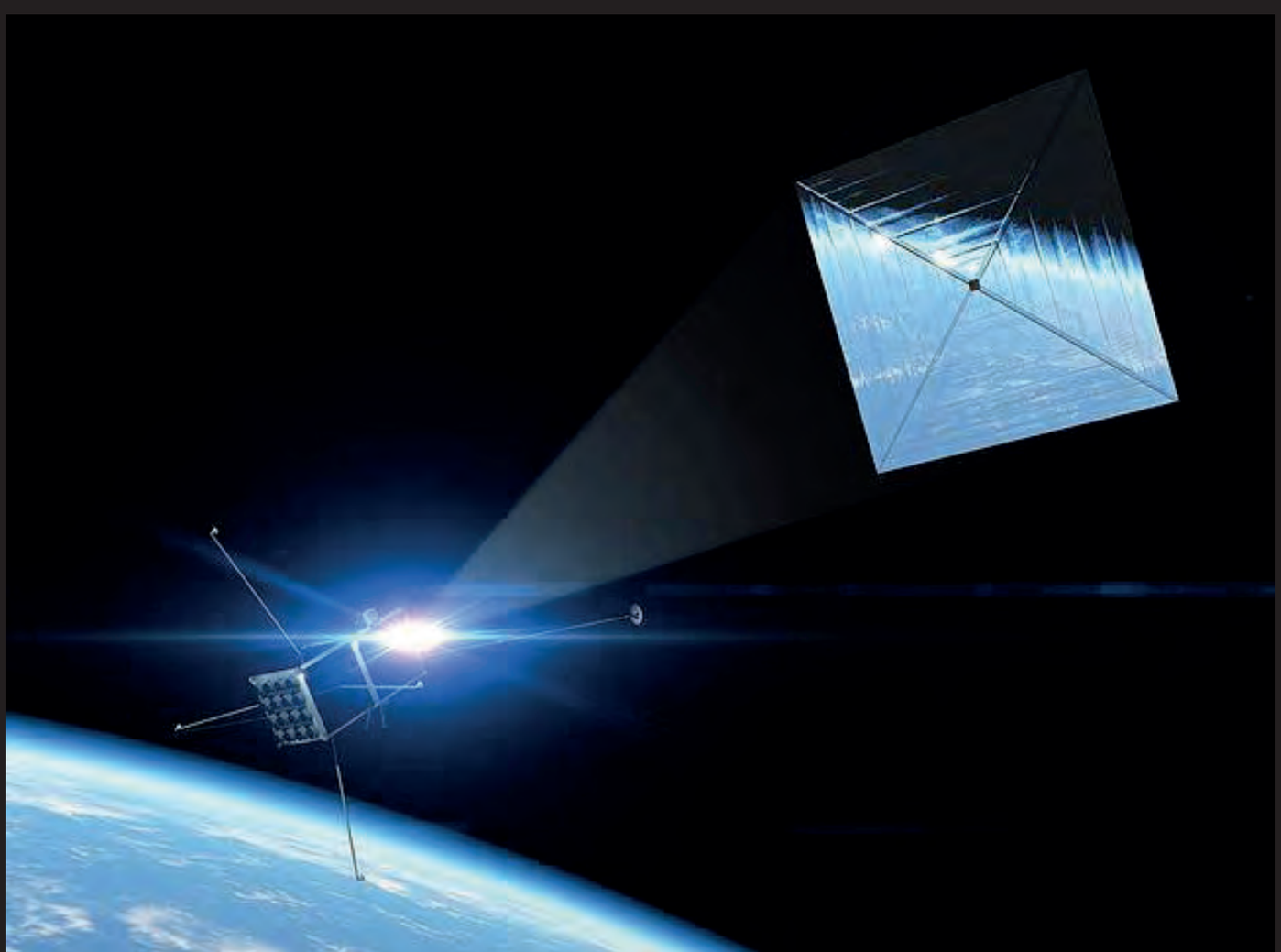
Samar AbdelFattah, University of Cairo Aerospace Department, Egypt – Email: **fiswinfo@gmail.com**

This event has been sponsored by Stellar Engines Ltd, Interstellar Research Centre

JOIN I4IS ON A JOURNEY TO THE STARS!

Do you think humanity should aim for the stars?

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



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

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

Join us and get:

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

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

News Feature: Indian Anti-Satellite test - Time for an international agreement to ban Anti-Satellite Tests?

Gurbir Singh

The public perception of the worst effects of space debris will be the film *Gravity* and the Kessler syndrome (en.wikipedia.org/wiki/Kessler_syndrome). Anti-Satellite (ASAT) weapons are inevitably producers of space debris. Here Gurbir Singh reports both methods and motivation for the recent Indian Anti-Satellite test.

At 11:08 on Wednesday 27 March 2019, a missile was launched from the tiny island off the coast of India about 400 km south-west of Kolkata. Three minutes later it intercepted and destroyed a satellite orbiting the Earth at an altitude of 280 km. India had launched this satellite two months earlier. With it, India joined three countries USA, Russia and China that have demonstrated this capability. The official press release (pib.nic.in/PressReleseDetail.aspx?PRID=1569563) stated that "interceptor missile was a three-stage missile with two solid rocket boosters". The Ministry of External Affairs followed this up with an official release of an FAQ for the ASAT test[1]. A few days after the test, a report in the Indian press revealed that the successful test was not the first but the second attempt [2].

The number of detectable fragments is not high given the impact took place at an altitude of 283 km. Most of the fragments will burn up in the Earth atmosphere in the coming weeks but a few fragments were accelerated to a higher orbit where they will remain longer, potentially endangering the ISS. This unnecessary risk to the ISS lead NASA to temporarily suspend its cooperation with ISRO on human spaceflight [3]. In response, the Defence Research and Development Organisation (DRDO) chief dismissed the risk saying "there was no possibility of it posing any threat to the ISS".

A Youtube video released on 6 April 2019 by the DRDO placed in to the public domain a surprising amount of data that would normally be considered too sensitive.

• Space important for the national economy and military superiority.

• The missile used was a variant of the Prithvi ballistic missile – here named as the Prithvi Defence Vehicle Mk II.

• Seeds for the ASAT test sown in 2014 by the current PM – final go-ahead from the Prime Minister in 2016. [Other reports indicate that the mission had been initiated by the previous administration now in opposition.]

The Defence Research and Development Organisation (DRDO) successfully launched the Ballistic Missile Defence (BMD) Interceptor missile, in an Anti-Satellite (ASAT) missile test 'Mission Shakti' engaging an Indian orbiting target satellite in Low Earth Orbit (LEO) in a 'Hit to Kill' mode from the Dr. A P J Abdul Kalam Island, in Odisha on 27 March 2019.

Caption and Image Credit: Wikipedia//DRDO

• The impact took place at an altitude of 283 km at a closing speed of more than 10 km/s.

• New technologies used for this mission included long-range strap down Imaging Infrared Seeker for guidance control, ring laser gyro-based navigation and precision attitude control system,

• 150 Scientist working around the clock to realise the mission in two years.

• Many external companies involved but only a limited number of personnel aware of the intended goal, an ASAT test.

• Microsat-R launched in January 2019 with an orbit of 300 km designed at the outset to serve as a target.

• ASAT test support by several ground-based systems including radar, data and communication links.

• The exact launch time point in space of impact so that it could be monitored from India which determined the time of launch of 11:09 IST 27/3/19.

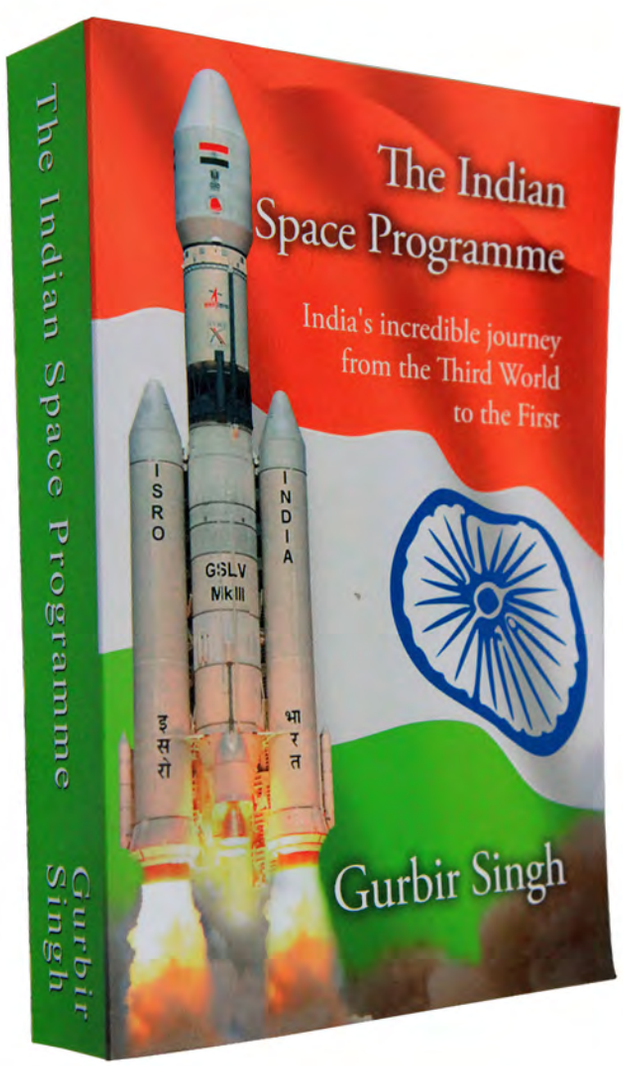
• The kill vehicle impacted with an accuracy of 10 cm of the aim point.

Why did India conduct this test now? There were two primary motives (a) to respond to China's ASAT test conducted in 2007 and (b) to avoid being "left out" should an international ban on ASAT testing be agreed. India did not want to repeat being sidelined as it was with the Non-Proliferation Treaty (NPT).

[1] Frequently Asked Questions on Mission Shakti, India's Anti-Satellite Missile test conducted on 27 March, 2019 www.mea.gov.in/press-releases.htm?dtl/31179/Frequently_Asked_Questions_on_Mission_Shakti_Indias_AntiSatellite_Missile_test_conducted_on_27_March_2019

[2] Exclusive: India Conducted a Failed Anti-Satellite Test in February 2019 thediplomat.com/2019/04/exclusive-india-conducted-a-failed-anti-satellite-test-in-february-2019/

[3] NASA resumes cooperation with ISRO after ASAT test spacenews.com/nasa-resumes-cooperation-with-isro-after-asat-test/



About Gurbir Singh

Gurbir is the author of *The Indian Space Programme - India's Incredible Journey from the Third World To the First* (astrotalkuk.org/product/indian-space-programme-paperback). He presented this at the British Interplanetary Society (BIS) 29 November 2018 www.bis-space.com/2018/08/06/20927/the-indian-space-programme-by-gurbir-singh-29-november-2018

He writes on Space and Astronomy on www.astrotalkuk.org. He is an independent Cyber Security Consultant and has worked for Thales and Fujitsu. Gurbir has degrees in computing from Manchester Polytechnic and the UK Open University.

Become an i4is member

Patrick J Mahon

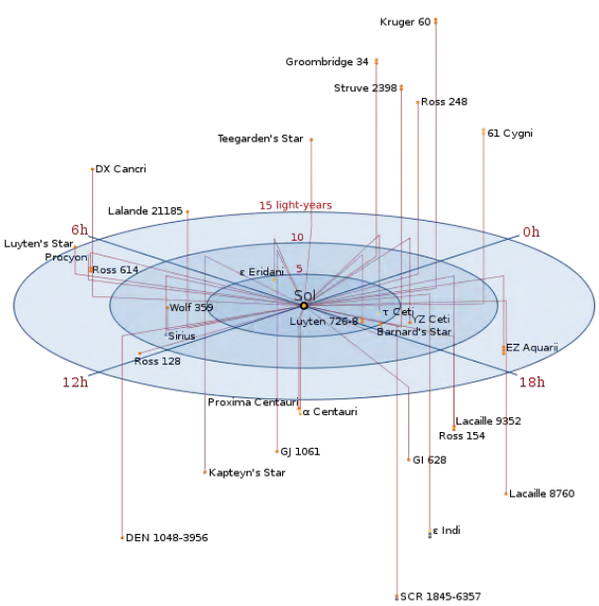
How becoming a member of i4is helps our work and delivers exclusive benefits to you

We are a growing community of enthusiasts who are passionate about taking the first steps on the path toward interstellar travel now.

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

In addition to supporting the programme, members have access to privileged content. This includes videos such as the complete Starship Engineer course we delivered at the BIS in 2016 (SSeng2016), the Project Dragonfly presentations and a short piece of fiction *Overture from the 2500s*.

i4is Deputy Director Rob Swinney listens to a question at SSEng2016



Nearby Stars out to 14 light-year radius
Credit: ESO/R.-D Scholz et al (AIP)

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

More in the i4is Members' Page, also in this issue of Principium and, of course, access to all the content when you join.

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

The first Annual Report to members is in preparation. This gives details of our achievements in the preceding year, a survey of the broader interstellar endeavour and a summary of our finances. And it will, year on year, show how your subscription has supported our work.

We are also developing a regular newsletter exclusively for members with the latest news on matters interstellar and our own activities. For all benefits of membership and to join, go to i4is.org/membership.

And the i4is Members Page, page 17 in this issue.

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

Extreme Deep Space Exploration:

A Personal Perspective

Robert W Swinney

As regular Principium readers will know, people are working on how we might really travel to the stars in the near future. In the essay, Rob Swinney, i4is, Fellow of the BIS, Project Leader of Project Icarus and former RAF Squadron Leader discusses the likely methods of doing so. In the near future will it be giant nuclear rockets or miniature beamed sails; will it be some private adventurer or nation state – or will it take some unified world organisation; and will the driving force be peace or war? It's based on a talk Rob gave in July 2018 at i4is HQ, The Bone Mill, in Gloucestershire. The illustrations are based on his presentation.

I was inspired by the prolific SF writer Isaac Asimov as a young teenager, but it was that author's great non-fiction science writings that first led me to an interest in space. After gaining degrees in Astronomy and Astrophysics 'real life' got in the way; mortgage, job etc. So, after some time teaching and a career as an engineering officer in the RAF, I finished my service commission in the rank of Squadron Leader in 2006. After nearly 20 years I left to start work 'in space'.

A further 10 years on I've been involved with different space adventures (from spaceplanes, nuclear fusion rockets concepts and miniature spacecraft), often with members of the British Interplanetary Society (BIS), and it has been impossible not to wonder what the longer-term future might hold. Not just technical stuff but also what sort of organisations, political situations and funding options that might be required for real extreme deep space exploration.

Although considering extreme missions I didn't intend to stray from 'near term' so I've no intention to discuss warp drives or FTL nor SF magic or the hopeless options ('You canna break the laws of physics, Captain'). In thinking of how to travel to the stars then arguably the most likely and credible and near-term options seem to be nuclear rockets or beamed sails, possibly in the coming decades. Certainly, as I like to point out it was only 100 years from some guys working in their bicycle shop with tubes, cloth and chains to build a heavier-than-air flying machine to satellites, moon landings and to a 500-tonne space station in orbit! Or a few hundred years from Kon-Tiki to supertankers and 14-storey high luxury cruise ships sailing our great oceans.

If we recognise that the first interstellar probes (eg Pioneer 10/11, Voyage1/2 and New Horizons) then spacecraft speed has barely progressed – mainly due to the fact we are using basically the same chemical propulsion technology. And interstellar distances mean it would literally take tens of thousands of years to get anywhere, even the nearest stars. Shorter trip times mean higher speeds and that leads to greater energies than available in chemical reactions. 'Reasonable' journey times (assuming travelling less than the speed of light 'c') might mean speeds of 10% c resulting in a trip to the Alpha Centauri system taking about 40 years.

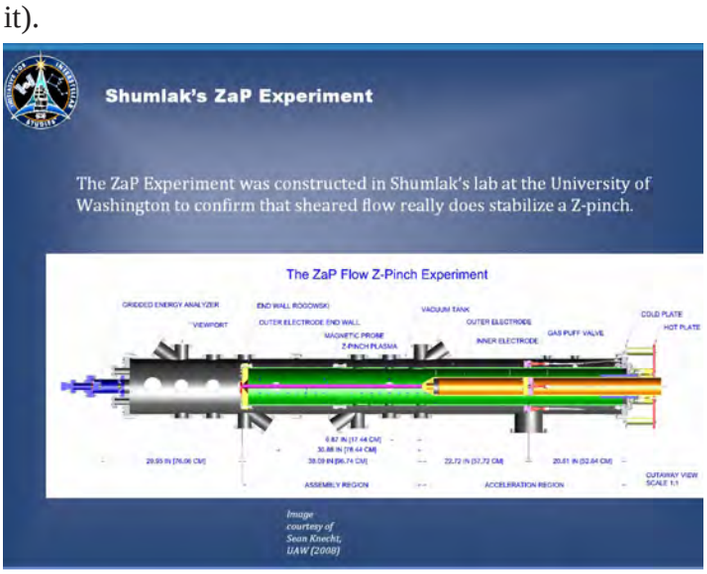
Nuclear rockets – more energy.

Rocket options using ion drives or plasma drives might help around the solar system but the key parameter of the rocket exhaust velocity, although better than chemical, are still too low for interstellar trips. There had been some interesting thinking of a potential alternative in the past eg the atomic rocket of Project Orion in the 1950s and 60s and described elsewhere in this issue (*The State of the Art in Fusion Propulsion*, Kevin Schillo). Quite simply the energy of the nuclear explosion gave hope of achieving higher cruise speeds and the Orion was to be an external pulse rocket using a pusher-plate to transfer momentum to the vehicle – the formal design work was for an interplanetary craft reaching speeds that might cut the travel time to somewhere like Saturn from years to months. The craft was designed and literally engineered like a battleship but was, in essence, something we could only have built then if we really had to. Some further design work was done to conceive of an interstellar craft using the same Orion-type principles and it was thought that, given enough nuclear 'units', it might be possible to reach 3% c.

Another classic nuclear design was undertaken in the 1970s by some members of the British Interplanetary Society and called Project Daedalus. The study team were able to conceive of a fusion design that could reach 12% c. This time small pellets of fusionable material would be 'internally' fused in an engine bell using relativistic electrons in an Inertial Confinement Fusion (ICF) design. The result was a HUGE vehicle of some 54,000 tonnes. With their work it seemed it was at least feasible to build an interstellar vehicle.

In 2009 a follow up team of individuals from the BIS and the Tau Zero Foundation collaborated on Project Icarus to redo the fusion design after 3 decades of nuclear development. They used various fusion concepts/solutions and designed various precursor designs.

The most advanced design was known as Project Icarus Firefly and used a Z-pinch drive (featured in Principium issue 22, August 2018). This required a very large current to pass through a plasma jet which would create a large inward Lorentz force great enough to fuse isotopes of hydrogen (en.wikipedia.org/wiki/Lorentz_force). This was a development along the same lines of University of Washington (see Shumlak's ZaP Experiment below) and NASA propulsion concepts but with a largely engineered vehicle to carry the ignition system (see Z-Pinch Thruster Design opposite). As with all the designs, they were still BIG, just like Daedalus, but bring forward the potential of a credible fusion craft that could achieve 5% c (more in P22 *To the Stars in a Century: Z-Pinch fusion & Firefly Icarus*). And, like all the Project Icarus designs, this vehicle is designed to decelerate at the target star, unlike Daedalus, which would fly through at 12% c (see sidebar - Blink and you miss it).



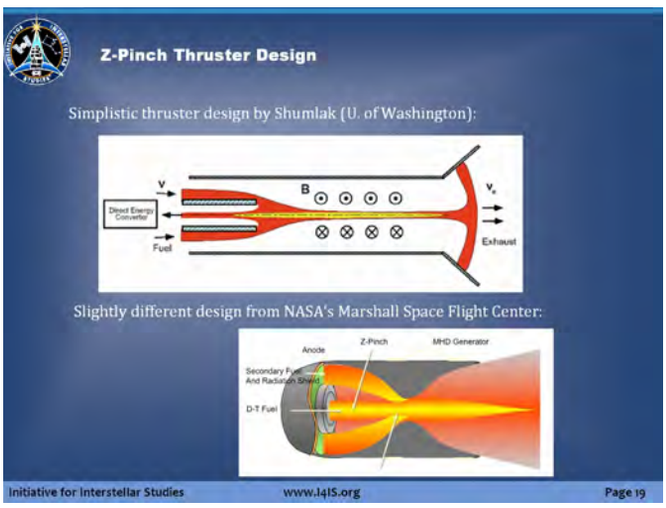
Shumlak's ZaP Experiment - Image courtesy of Sean Knecht, UAW (2008)

What about true Magnetic Confinement Fusion like that used in tokamaks? Tokamaks feature in development work in trying to produce power for the electrical grids but could be repurposed for spacecraft flight? Considering something like the International Thermonuclear Experimental Reactor, any spacecraft would be even larger than Icarus or Daedalus as can be suggested by the ITER plant building that spreads over many sports fields in France! Nevertheless, a number of smaller versions of magnetic confinement are being pursued although many of the details are being quite closely guarded. They are often based on rotating magnetically confined 'slugs' of material crashing together or in to targets.

Whether it's inertial confinement, magnetic confinement or something in between, even with many engineering difficulties to solve, it seems that if you need large payloads a version of fusion will likely form some solution to future deep space travel, with just a few engineering challenges to resolve.

Z-Pinch Thruster Design

Simplistic thruster design by Shumlak (University. of Washington):and slightly different design from NASA's Marshall Space Flight Center

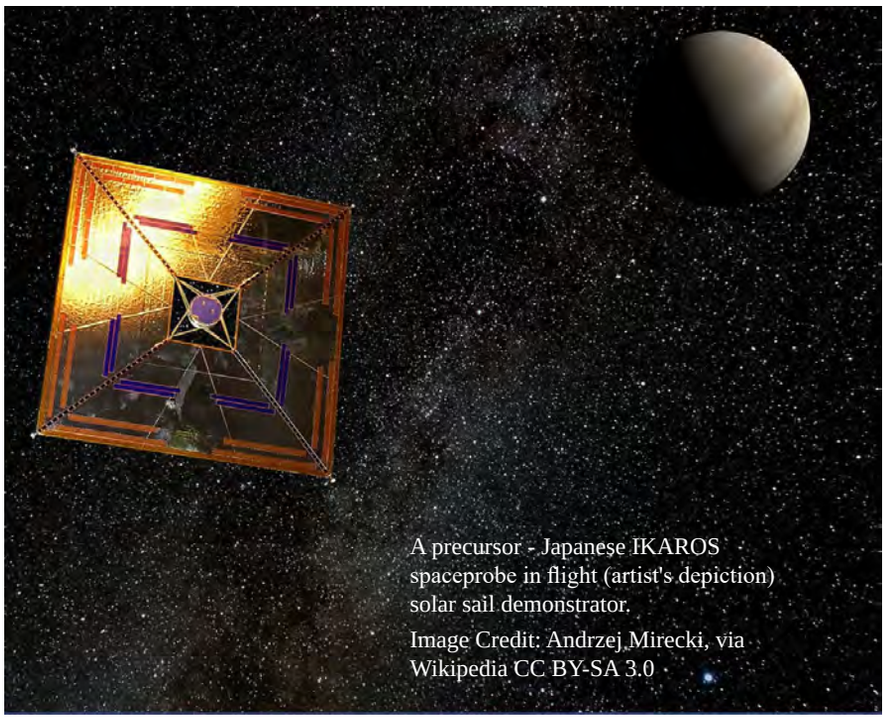


Blink and you miss it!

The speed of light is 300k km per second so Daedalus, travelling at 12% of 300k=36k km per second. Remember that light takes just over 8 minutes, 480 seconds from the Sun to the Earth. Daedalus would cover the same distance in 480/0.12 = 4000 seconds or just over an hour. Not much time to do your exploring!

Beamed Sails

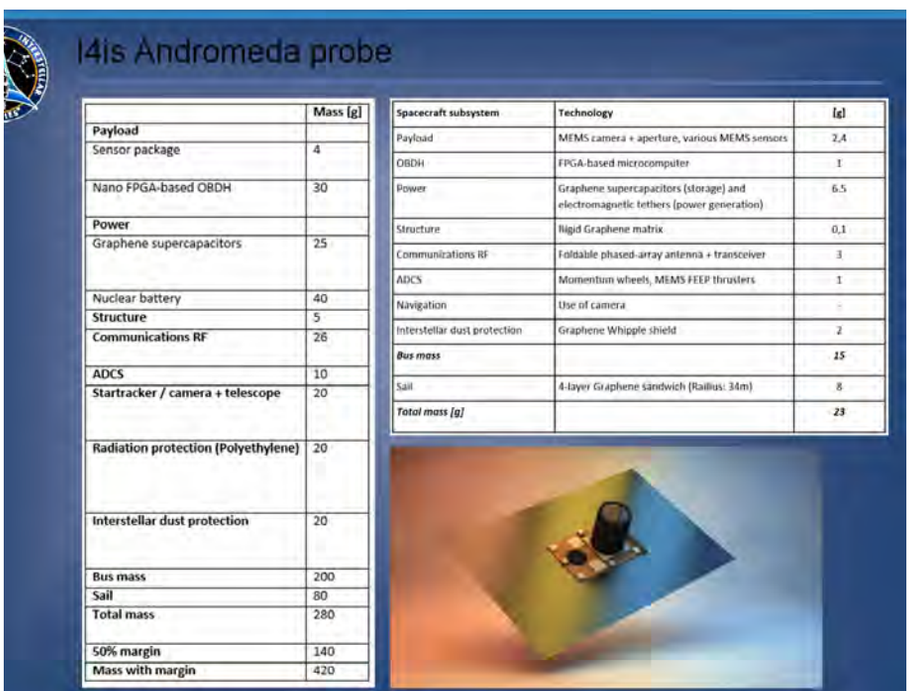
An alternative being considered strongly is beamed sailing. A popular and credible alternative, if you only need a small payload (for now), it appears beam driven sails could really be an option. In 2014 i4is team members were thinking about this issue and came up with a design competition that was tackled by several university teams – Project Dragonfly. This was to design a concept mission to use a laser driven sail craft to journey to the nearest stars. The innovative designs were built around miniaturization of electronics and components and increasing availability of powerful lasers. Still, the Dragonfly designs were still a few tonnes in mass.



A precursor - Japanese IKAROS spaceprobe in flight (artist's depiction) solar sail demonstrator.

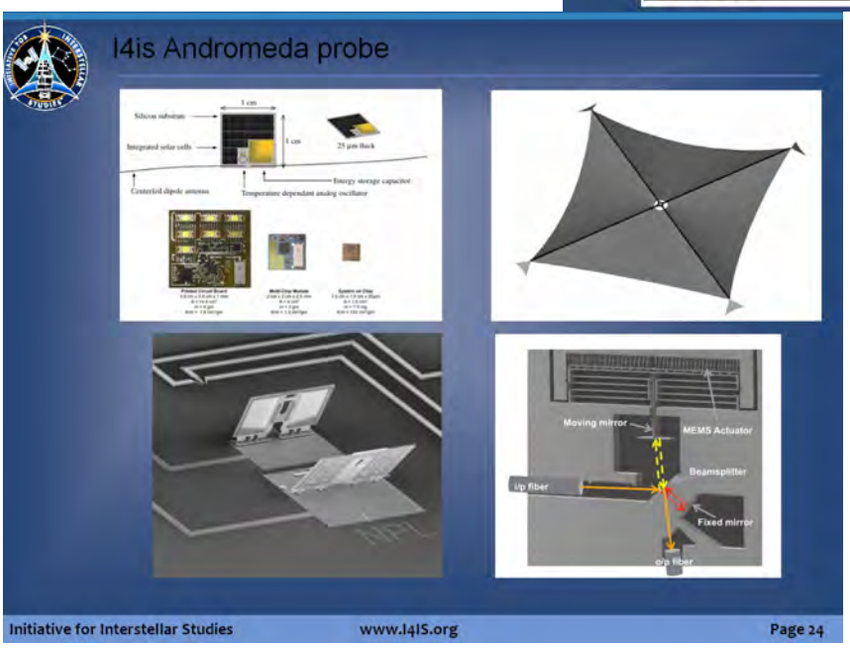
Image Credit: Andrzej Mirecki, via Wikipedia CC BY-SA 3.0

Following Dragonfly in early 2016 the i4is team were challenged by an organisation to come up with a much smaller design - just several grams - and the i4is Andromeda Probe concept was drawn up, for a probe of some hundreds of grams powered by a powerful in-space laser. No, was the response, make it smaller; so, Andromeda was redesigned to only 10s of grams but the in-space laser beamer option was retained.



	Mass [g]
Payload	
Sensor package	4
Nano FPGA-based OBDH	30
Power	
Graphene supercapacitors	25
Nuclear battery	40
Structure	5
Communications RF	26
ADCS	10
Startracker / camera + telescope	20
Radiation protection (Polyethylene)	20
Interstellar dust protection	20
Bus mass	200
Sail	80
Total mass	280
50% margin	140
Mass with margin	420

Spacecraft subsystem	Technology	[g]
Payload	MEMS camera + aperture, various MEMS sensors	2,4
OBDH	FPGA-based microcomputer	1
Power	Graphene supercapacitors (storage) and electromagnetic tethers (power generation)	6.5
Structure	Rigid Graphene matrix	0,1
Communications RF	Foldable phased-array antenna + transceiver	3
ADCS	Momentum wheels, MEMS FEEP thrusters	1
Navigation	Use of camera	-
Interstellar dust protection	Graphene Whipple shield	2
Bus mass		***15***
Sail	4-layer Graphene sandwich (Radius: 34m)	8
Total mass [g]		***23***



i4is Andromeda Probe
Components and masses
Credit: i4is

i4is Andromeda Probe
Visualisation
Credit: i4is

The organisation which challenged us turned out to be Breakthrough Initiatives (see Starshot launch event below) who were soliciting ideas for their plan for an interstellar beamed sail craft – around 1 g in mass and accelerated to 20% c – to be known as 'Starshot'.

Backed by billionaire money, Breakthrough planned to invest $100 million in developing their ideas over a period of about 10 years. With the ongoing revolution in miniaturisation and other technologies the potential for this solution seems realisable and, for the first time, with some real funding. Starshot plans to use an Earth-based laser, improving its near-term chances due to the ease of manufacture and build but complicates the mission profile compared to Andromeda. Indeed, in a spirit of openness Breakthrough listed online 19 major challenges to their programme from the light beamer, to communications, to policy issues.

They are working on them now -

1. Light beamer: cost, combining beams & atmospheric effects
2. Light beamer cooling
3. Precision pointing of light beamer
4. Pointing during acceleration of nanocraft
5. Aiming trajectory at exoplanet
6. Sail integrity under thrust
7. Sail stability on the beam
8. Interstellar dust
9. Interplanetary dust
10. Interstellar medium & cosmic rays
11. Maintaining functionality over decades in space
12. Pointing camera at planet
13. Pointing transmitter at Earth
14. Sending images using laser as transmitter & sail as antenna
15. Receiving images with light beamer
16. Power generation & storage
17. StarChip components at gram scale
18. Launch safety & space debris
19. Policy issues

With the rise of Breakthrough you get to wondering how it will really happen or who will organise it? It seems highly unlikely that national governments or agencies would support it, eg, NASA, ESA, etc. Constrained budgets and the need to keep their feet on the ground is mandatory. It seems even less likely that a transnational or world government would be successful in this area.

So how about non-profits such as i4is, Icarus Interstellar and Tennessee Valley Interstellar Workshop? They certainly keep the interest and 'fires burning'. I see that option as huge untapped potential in modern societies.

Or would it be wealthy entrepreneurs or philanthropists such as those funding Breakthrough? That funding has not been 'interstellar' (yet) but clearly seems to be having an exciting influence on suborbital, orbital, Earth to Moon, Mars etc. Incentives like the Ansari X-prize. Or in a related way companies like SpaceX where NASA is helping leverage this activity through industry to support its own programmes.

It seems very likely that once the cheap access to space is provided by any of the above we're more than half way to the future in local space and interplanetary space- and then interstellar space indeed as a civilisation and not just robotic probes.

But then will it even be 'western' or US led? What about other players like Russia and China? Currently (but not for too much longer) Russia is the only country that regularly send humans into space. But that budget and programme are suffering due to the economy and sanctions; you always get the feeling they are basically in a pickle. But you can't count them out from almost anything given their record in space and following national motivations.

China is spending more than Russia and their space programme is growing fast with their technology related ambition. This is illustrated by developments like the 500 m aperture telescope FAST and landing a probe on the so-called dark side of the moon. China has further plans for the Moon, asteroids and Mars. They are building up their own space station technology as they are locked out of the ISS as a security risk. The Chinese national space programme is probably indistinguishable from the military plans. They should be counted in as driving a future in space.

Then again there might be others to consider such as Japan, India or even the UK to make a crowded field but does that equate to a new space race? Either way we can be encouraged that a definite momentum is being created.

There is one area that might be more covert. Military needs drive offensive and defensive technology - and even more so in times of major conflict. But some argue that the mass commercial markets are in charge now. Nevertheless, some of the high technology has obvious cross-over to military use eg high power lasers or high energy propulsion systems. Recently the US announced ambitions for a national space force, combining assets from the other forces and significantly from the USAF Space Command. But other than near

Earth or even just orbital there doesn't seem much likelihood for military driving expansion into the solar system and further frontiers; only commercial/economic activity seems likely to create a solar system wide society and economy. A small exception to that might be planetary defence such as from wandering asteroids or even interstellar visitors such as 'Oumuamua? The military might have had interest if there had been more indication that 'Oumuamua was not just a rock. Who knows what might happen if some other extra-terrestrial visitors came our way?

One final thought on the military; we know that NASA in the US, for example, has a budget for space and their military has a similar, known budget spent on space – there are some indications that the same amount of money again of both combined is being spent on space black projects. One might wonder where that research may lead but hopefully crossing over to peaceful activities?

So, what might it cost to send something 'interstellar'? One estimate for Project Icarus was for a single Firefly probe to cost $780 billion which suggests that the only solution, if they could be persuaded, would be for multiple nations to tackle it together. The beamed sail craft envisaged by Breakthrough would be much cheaper but likely still in the billions. Perhaps a world organisation might be in control and drive this but might lack the competition incentive to make much progress. It might be easiest to imagine just waiting for the technology to come along perhaps at a much-reduced cost due to normal economic and technological development. Or we could wait for the world's GDP to increase to such a level that the probe costs seem to shrink to something sensible in comparison. A worrying challenge to all these suggestions might be that there may be a window of opportunity to meet but without anyone knowing how long that is.

Starshot Launch Event

Top: Mark Zuckerberg, Facebook; Yuri Milner. Breakthrough Initiatives.

Below:Stephen Hawking, FRS.

Table: Freeman Dyson, FRS; Ann Druyan, Cosmos Studios; Avi Loeb, Harvard; Mae Jamieson, 100YSS; Pete Worden, Breakthrough Initiatives.

Image Credits: Breakthrough Initiatives

If it isn't obvious, I'm really quite optimistic about our future on Earth and in space. To me the inner solar system is a done deal and will fall out of current, mostly private and industry activities (or perhaps military?) funded in different ways. Advancing technology will be developed to support much of the above, particularly including beamed sails or fusion options and interstellar will just be another challenge for humanity and will likely be solved in the lifetime of youngsters today.

Competition

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

With July 2019 marking the 50th anniversary of the Apollo 11 moon landing, i4is would like to recapture the spirit of exploration that inspired the world in 1969, and focus it onto the new interstellar frontier.

So we are challenging our members, supporters and anyone else with a passion for space to write a poem that shows why interstellar exploration can and should generate almost the same level of excitement as the Apollo programme did half a century ago.

Poems should be no less than ten and no more than twenty five lines long, must include the words ‘Apollo’ and ‘interstellar’ and should aim for inspiration of the interstellar endeavour.

Entries should be emailed to info@i4is.org. The deadline for entries is 23:59 on Thursday 20 June.

Entries will be judged by a panel appointed by the i4is Board, on the basis of their impact, creativity and artistic merit, and the winner will be announced on i4is’s social media channels on 20 July 2019, the 50th anniversary of the first Moon landing. The winning poem will be published in issue 26 of Principium, and the winning author will receive a year’s free membership of i4is.

Full terms and conditions can be found on the i4is website at i4is.org/apollo-competition

Apollo 11, Buzz Aldrin on the Moon, NASA photo

News Feature:

Latest on Oumuamua, Project Lyra and Interstellar Objects

Patrick J Mahon & John I Davies

The interstellar object Oumuamua continues to stimulate research, debate, speculation and controversy. Principium and i4is in general have no "official" view on any of this intellectual turmoil. But we do have a very clear intention of both following all the latest thinking and results and, via the i4is Project Lyra team, researching how we might find more about Oumuamua and other interstellar objects.

This News Feature may prove to be the first of a series. Interstellar objects are messengers from the rest of the universe, whatever their nature, so i4is will have a continuing interest in them.

This time we bring you news of our own Project Lyra work and the latest on Oumuamua including the latest work of Laughlin and Seligman of Yale University.

Project Lyra – Mission Opportunities after 2024

The original i4is Project Lyra report, *Project Lyra: Sending a spacecraft to 1I/'Oumuamua (former A/2017 U1), the interstellar asteroid* [1], was the first serious study to show that sending a spacecraft to our Solar System's first interstellar visitor was technically feasible. The report received world-wide attention.

The main limitation of this first study was that it required the spacecraft to be launched between 2020 and 2021. This is too soon to allow the development of a suitable spacecraft – a process that typically takes at least five to ten years.

A new paper from the Project Lyra team, entitled *Project Lyra: Catching 1I/'Oumuamua – Mission Opportunities after 2024* [2], demonstrates that a later launch date, of 2030 or 2033, is also feasible, enabling the spacecraft to arrive at its target in 2047 or 2049 respectively. This provides sufficient time, over a decade, for the development of a spacecraft, indicating that this is a realistic objective.

The obvious problem that needs to be solved for any mission to Oumuamua is that this interstellar object is on a hyperbolic trajectory and thus – by definition – travelling fast enough to escape the solar system. This makes it faster than any spacecraft yet launched by humanity can achieve unaided. Worse, if we want to see it close up, then the spacecraft is going to have to go even faster in order to catch up, given that Oumuamua is already past Saturn's orbit, some ten times as far from the Sun as we are here on Earth. And the longer we wait to send our probe, the faster it will need to go to catch up with Oumuamua.

Is there a solution to this problem that allows enough time for spacecraft development? The Project Lyra team think so, and the answer is to be found through multiple gravity assists. Older readers of Principium may remember that the concept of a gravity assist first came to prominence in the late 1970s, when NASA's Voyager 1 and 2 missions were deliberately planned so as to use the 'free' energy that can be gained as they travel close to a planet to change their direction and speed multiple times, enabling Voyager 2 in particular to fly by Jupiter, Saturn, Uranus *and* Neptune – something it simply could not have done on its own.

However, gravity assists are not some magic wand that can be waved over any mission, enabling you to go where you want, when you want. The value of a gravity assist depends crucially on the precise geometry of the solar system at the time that your spacecraft passes the planet which is being used for the assist. And that geometry changes over time, of course, as the planets in the solar system all orbit the Sun at different rates.

What Hibberd, Hein and Eubanks have done this year, therefore, is a huge amount of number-crunching. Using Hibberd's Optimum Interplanetary Trajectory Software (OITS), they have modelled nine different sets of trajectories that would potentially enable a spacecraft to increase its speed sufficiently to be able to catch up with Oumuamua. The two that come out as frontrunners are:

- A launch from Earth in May 2033, followed by a gravity assist at Jupiter and a Solar Oberth manoeuvre [3] at 3 solar radii, before heading for Oumuamua, arriving there in April 2049.
- A more complicated trajectory, involving a launch from Earth in April 2030, followed by a Deep Space Manoeuvre at 3.2 AU, gravity assists at Earth and then Jupiter, and finally a Solar Oberth manoeuvre at 3 solar radii, before again heading for Oumuamua, arriving in September 2047. This mission takes slightly longer than the first one, but launches and arrives earlier.

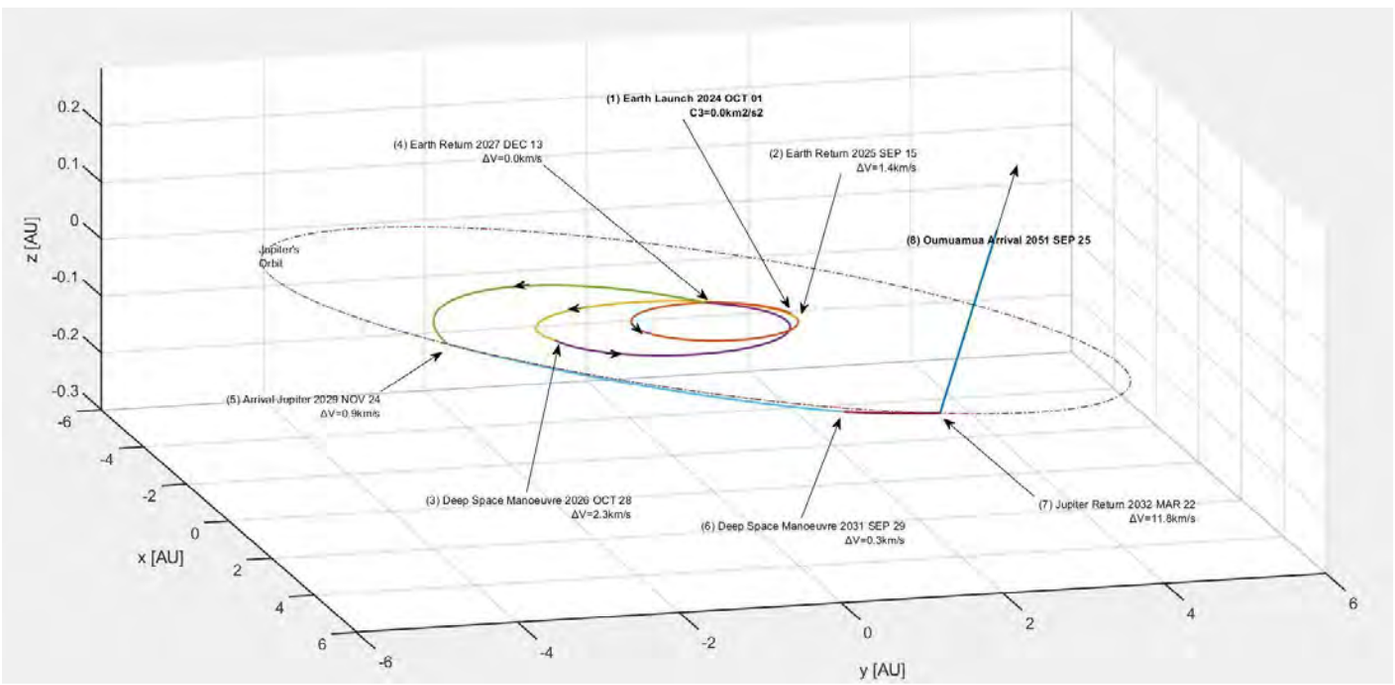
Having now established that a mission is not only technically feasible but on a timescale that allows for the development of a suitable spacecraft, the Project Lyra team's next objective is to produce a conceptual design for the spacecraft and the scientific instruments it might carry to Oumuamua.

References:

[1] A M Hein, N Perakis, T M Eubanks, A Hibberd, A Crowl, K Hayward, R G Kennedy III, R Osborne, *Project Lyra: Sending a spacecraft to 1I/'Oumuamua (former A/2017 U1), the interstellar asteroid*, Acta Astronautica (2019, in press).

[2] A Hibberd, A M Hein, T M Eubanks, *Project Lyra: Catching 1I/'Oumuamua – Mission Opportunities after 2024*, (2019). arxiv.org/abs/1902.04935 (accessed 14 April 2019).

[3] For a basic explanation of the Solar Oberth manoeuvre, see en.wikipedia.org/wiki/Oberth_effect (accessed 14 April 2019).



An example early mission trajectory (ref EEIPEJIPJO) derived by Hibberd's Optimum Interplanetary Trajectory Software (OITS). Credit: Adam Hibberd and the i4is Project Lyra team.

Oumuamua - the latest

Oumuamua has continued to be the object of research and conjecture. Here are some of the most interesting since our last issue.

On the Anomalous Acceleration of 1I/2017 U1 `Oumuamua

Gregory Laughlin and Darryl Seligman of Yale University have already contributed to the Oumuamua literature, including thinking about intercepts of subsequent similar objects (see *The Feasibility and Benefits of In Situ Exploration of 'Oumuamua-like Objects* iopscience.iop.org/article/10.3847/1538-3881/aabd37/meta) also reported in a Principium News Feature *What is Oumuamua? The Loeb/Bialy Conjecture and i4is Project Lyra* in P23, November 2018. This work has been followed up by both a paper and a presentation at the January meeting of the American Astronomical Society - "the Superbowl of Astronomy".

On the Anomalous Acceleration of 1I/2017 U1 `Oumuamua (arxiv.org/abs/1903.04723) by Darryl Seligman and Gregory Laughlin (Yale University) and Konstantin Batygin (Caltech) suggests that the consistent photometric period (the regular variation of its brightness as seen by telescopes) and the astrometrically measured non-gravitational acceleration (in other words, something is pushing it out of the Solar System - it is decelerating too little as it heads out from the Sun) can be explained by a nozzle-like venting of volatiles whose activity migrated to track the sub-solar location on the object's surface.

These two behaviours appear to conflict since a naturally occurring "thruster" as with normal comet outgassing would be virtually certain to act "off axis" and thus change the period of rotation and/or tumbling of the object. Seligman et al use ray tracing to model sunlight reflected from an ellipsoid to show that the "thruster" must migrate across the object so that it is always pointing towards the Sun. Think of a spinning rugby ball with a leak! If the leak in the rugby ball keeps moving across its surface so that it always points back toward the kickers boot then the ball will keep spinning and tumbling in the same way as when it was kicked.

There has been some press attention to this paper including -

- Salon *'Oumuamua sped up as it left the inner solar system. This might be why*. www.salon.com/2019/03/12/oumuamua-sped-up-as-it-left-the-inner-solar-system-this-might-be-why_partner/
- dailygalaxy.com *"Provocateur" –Oumuamua Past Saturn on Its 10,000-Year Journey Through Solar System* dailygalaxy-com.cdn.ampproject.org/v/s/dailygalaxy.com/2019/03/provocateur-oumuamua-passes-saturn-on-its-10000-year-journey-through-solar-system/amp/?amp_js_v=0.1&amp_lite

At the January 2019 meeting of the American Astronomical Society Seligman et al presented further work, with co-author Konstantin Batygin of Caltech, *A Color Out of Space: 'Oumuamua's Brief and Mysterious Visit to the Solar System* (slides at -]oklo.org/wp-content/uploads/2019/01/LaughlinOumuamua.pdf). The paper (as yet unpublished, -aas.org/files/aas233_abstracts.pdf) will aim to summarise what is known and postulated about Oumuamua, outline the implied consequences of this first detection of an interstellar object (ISO) for the planet-forming process and assess the near-term prospects for detecting and observing similar objects, both remotely and via probes, in future. As in their earlier paper, Oumuamua is used as a proof-of-concept for missions that intercept ISOs using conventional chemical propulsion.

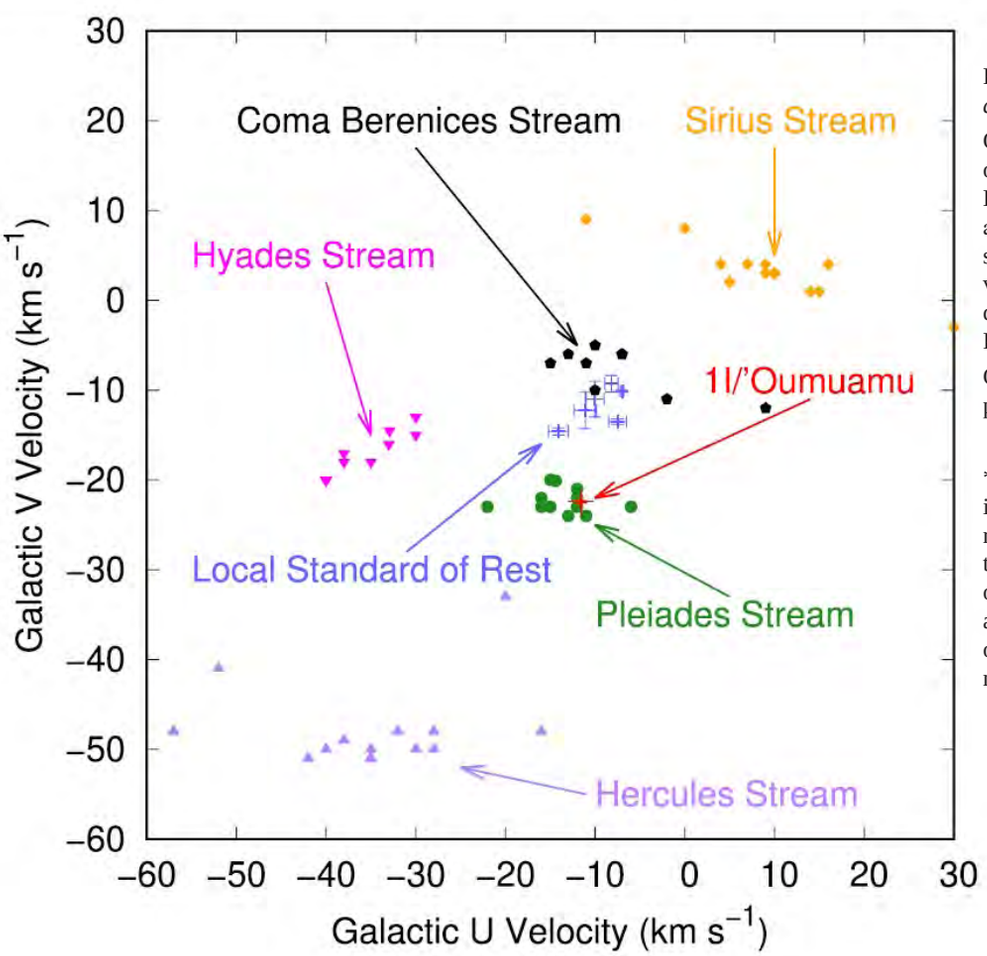
This work complements i4is Project Lyra which has, so far, concentrated efforts on interception of Oumuamua itself. Clearly the latter remains vital if we do not find similar objects in the near future.

Is Oumuamua a fragment of a larger object which disintegrated around perihelion?

Zdenek Sekanina of NASA JPL suggests, in *1I/'OUMUAMUA as debris of Dwarf Interstellar Comet that disintegrated before Perihelion* (arxiv.org/pdf/1901.08704.pdf) that faint comets have a strong propensity for suddenly disintegrating at a time not long before perihelion and that "a sizable fragment, resembling a devolatilised aggregate of loosely-bound dust grains that may have exotic shape, peculiar rotational properties, and extremely high porosity, all acquired in the course of the disintegration event". Could this account for Oumuamua's curious form? Perhaps "a monstrous fluffy dust aggregate released in the recent explosive event, 'Oumuamua should be of strongly irregular shape, tumbling, not outgassing, and subjected to effects of solar radiation pressure, consistent with observation". So, maybe no solar sail required!

High-Drag Interstellar Objects And Galactic Dynamical Streams

T Marshall Eubanks of Space Initiatives Inc and i4is has a paper, *High-Drag Interstellar Objects And Galactic Dynamical Streams* published in Astrophysical Journal Letters, iopscience.iop.org/article/10.3847/2041-8213/ab0f29 , pointing out that the incoming velocity vector of 1I/'Oumuamua is close to the motion of the Pleiades dynamical stream (more about stellar streams in the galaxy in *Kinematically Detected Halo Streams* Martin C Smith, ned.ipac.caltech.edu/level5/Sept16/Smith/Smith_contents.html). The fact that Oumuamua accelerated as it headed back out of the solar system is perhaps the biggest mystery about our recent visitor. It showed no outgassing and no change in rotation so how can we explain the acceleration? Marshall recalls the theory that this was due to solar radiation pressure by Professor Avi Loeb (Harvard) and his colleague, Shmuel Bialy. This Loeb/Bialy conjecture (see the news feature *What is Oumuamua?* in Principium 23), that solar radiation pressure is the explanation, requires an extremely low mass-to-area ratio (or area density) for the object. Loeb suggests a thin sheet, like a solar sail. Marshall suggests an extended, light, structure. He hypothesises that a low area density can also explain the very close kinematic association of Oumuamua and the Pleiades stream, rendering it subject to drag capture by interstellar gas. Such an object would be easily captured by interstellar gas clouds and make it likely that there is a significant population of low area density Interstellar Objects (ISOs) in the Galaxy. Marshall's abstract concludes "Any interstellar object entrained in a dynamical stream will have a predictable incoming velocity vector (known as v ∞ - velocity at infinity); Targeted deep surveys using this information should be able to find dynamical stream objects months to as much as a year before their perihelion, providing the lead time needed for fast-response missions for the future in situ exploration of such objects". If Oumuamua has numerous cousins then Marshall's conjecture may be testable very soon.



From *High drag Interstellar Objects and Galactic Dynamical Streams*

Galactocentric U and V components of velocity for Oumuamua, the Local Standard of Rest (LSR)*, and the five largest local dynamical streams. The Oumuamua incoming velocity is near the centroid of the determinations of the velocity of the Pleiades stream.

Credit: T Marshall Eubanks - see the paper for detail sources

* The average of the motions of stars in the Sun's neighbourhood. With respect to the local standard of rest, the velocities of nearby stars average out to zero. The LSR is moving around the centre of the Galaxy, orbiting the Galaxy in about 200 million years.

Oumuamua elsewhere

- **Physics World: Visitor from another star.** The February 2019 issue of Physics World, membership magazine of the Institute of Physics, reported that astronomers are still unsure about the true nature of ‘Oumuamua. This is almost a year since it ceased to be detectable. Reporting that "Aerospace engineer Andreas Hein is currently exploring the possibility of sending a space mission to reach ‘Oumuamua", i4is Project Lyra. A correction and a clarification for Physics World readers, they name i4is as the "Institute for Interstellar Studies — a UK-based not-for profit company". We are the Initiative for IS in the UK. Our US-based organisation is the Institute for IS. They also write "Their research is still to be published in a peer-reviewed journal". Acta Astronautica accepted *Project Lyra: Sending a spacecraft to 1I/’Oumuamua (former A/2017 U1), the interstellar asteroid* Hein et al, for publication in January 2019 (www.sciencedirect.com/science/article/pii/S0094576518317004). The planned interception by the Lyra probe would be well beyond telescope range and Andreas discussed the necessity for onboard terminal guidance - you might like Andreas' joke about this!
- **Rapid planet formation Interstellar Asteroids as seeds.**
  A recent paper, *A hypothesis for the rapid formation of planets*, by Susanne Pfalzner and Michele T Bannister, of Jülich Supercomputing Center (JSC) Germany, Max-Planck-Institut für Radioastronomie, Bonn, Germany and Queen’s University Belfast, UK, arxiv.org/pdf/1903.04451.pdf suggests that seed planetesimals, Oumuamua-sized and larger objects, could provide enriched seeding thus accelerating and enhancing planetary formation.
- **Migration of Life in the Universe - Breakthrough Discuss.**
  It even got into discussion of *Migration of Life in the Universe* in the 2019 Breakthrough Discuss Conference (April 12-13) "...the possibility of life as a communicable microbial infection between planets. But the exchange of life between planets could be galactic in scope" [by] "ejection of other planets from stellar systems. Such interstellar rogue planets are an ideal vehicle for the transfer of life across the galaxy. The interstellar object ‘Oumuamua’ may be an example of such an ejection." (breakthroughinitiatives.org/initiative/5/discuss2019)

Three explanations for Oumuamua that aren't alien spaceships

Finally, Lisa Grossman in Science News, February 2019, (www.sciencenews.org/article/explanations-oumuamua-not-alien-spaceships) summarises three less exotic ideas, including Zdenek Sekanina's fluffy fragment of something which disintegrated at perihelion, reported above.

More in Principium 25 about Oumuamua, Project Lyra and Interstellar Objects

Elsewhere in this issue of Principium you will find related reports in -

Interstellar News -

News Features -

News Feature: All Comets Great and Small

John I Davies

Principium editor John Davies attended the Inaugural Lecture of Professor Geraint Jones, University College London, 20 February 2019. The specific i4is interest in Professor Jones is his role in the Comet Interceptor proposal mentioned in the P23 News Feature: Oumuamua, Project Lyra and Interstellar Objects. This proved an interesting and thought provoking inaugural.

Professor Jones is Professor of Planetary Science at UCL, based at their Mullard Space Science Laboratory (www.mssl.ucl.ac.uk) where he is Head of the Planetary Science Group. His research topics are - Planetary magnetospheres (interactions with rings and moons), Comet- and dust-solar wind interactions and Interaction of unmagnetised planets with the solar wind and heliospheric physics. Like Professor Carl Murray of Queen Mary University of London, reported in P23, he was part of the Cassini mission team and has had much to do with mission planning for several beyond Earth orbit missions.

Comets

His theme, All Comets Great and Small, began with the long history of recorded comet observation. This is very long since comets are the only solar system objects apart from the Sun, Moon and the planets which are visible to unaided human vision. Here's an example from a terrestrial observatory - see below.

Professor Jones explained that these visible dust tails are differentiated by their size and mass and thus their acceleration by the solar wind, with the smallest being accelerated to hyperbolic velocities, so that they will disperse throughout the galaxy. Comets also have ion tails and flybys through them suggest that the solar wind extended them to the edge of the heliosphere (nearly 100 AU from the Sun - out where the Voyagers are!).

The composition of comets, and thus their tails, has become much better understood in recent times, largely through spacecraft activity. The initial missions were "fly bys", not staying with the comet, and there have also been missions which have flown through the tails of distant comets. Other missions have observed comet tails from afar.

Comet tails blowing in the solar wind. Comet McNaught over the Pacific Ocean. Image taken from Paranal Observatory in January 2007. Credit: ESO/Sebastian Deiries

The first probe sent to a comet was the International Cometary Explorer (en.wikipedia.org/wiki/International_Cometary_Explorer), which passed through the tail of Comet 21P/Giacobini–Zinner in 1985. Professor Jones' mentor, the late Professor Alan Johnstone (www.theguardian.com/news/1999/jun/11/guardianobituaries2), worked on the Giotto mission to Halley's comet (the first to be recognised as a regular visitor - by Sir Edmund Halley). Giotto was part of a swarm which were sent to greet the 1986 appearance of Halley (younger readers may care to mark their diaries for 28 July 2061. I'll be the unlikely age of 115 by then!). Prof Jones showed a slightly scary video of Giotto's close encounter (sci.esa.int/giotto/14610-giotto-encounters-comet-halley). The probe survived with sufficient resources to visit a second comet, Grigg-Skjellerup, in 1992.

In 2005 Comet Tempel 1 (9P/Tempel) was visited by the NASA Deep Impact mission. Sadly the eponymous projectile ejected from the probe produced such a monster debris cloud that it frustrated the mission objective of examining the inner structure of the comet. However the 2011 Stardust mission was able to observe the crater produced by the Deep Impact projectile.

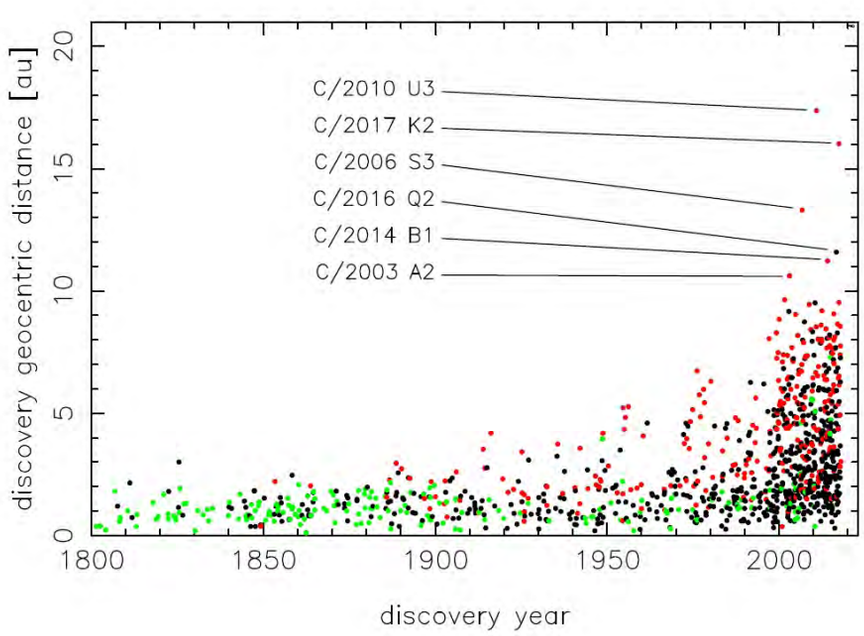
Everyone remembers the ESA Rosetta/Philae mission to comet 67P/Churyumov-Gerasimenko in 2014, and the sadly short life of the Philae lander. Prof Jones explained how the combination of the failure of its thruster (to push it down) and its anchors (to lock it down) meant Philae ended up in shadow and its limited battery capacity meant that it delivered information for only a short time. But it did yield some striking chemistry, including organic compounds revealed by its COSAC mass spectrometry(science.sciencemag.org/content/349/6247/aab0689). Compounds found included methyl isocyanate, acetone, propionaldehyde, and acetamide - none previously reported on comets. Rosetta also confirmed that this comet, at least, did not have the right sort of ice to have formed our oceans, as has been theorised; the deuterium (heavy water) to hydrogen (normal water) ratio was wrong.

Prof Jones ended by showing a visualisation of the object Oumuamua as an example of the ability of comets to continue to surprise us. There was far more fascinating stuff in this lecture which I have not captured but I was of course most interested in -

Comet Interceptor

The Comet Interceptor proposal (www.cometinterceptor.space) is led by Professor Jones. It's a proposed ESA mission to be launched with the exoplanet hunting ESA Atmospheric Remote-sensing Infrared Exoplanet Large-survey (ARIEL) spacecraft in 2028. It will enter a closed orbit around Earth Sun Lagrange point L2 (behind the Earth as seen from the Sun). This will be relatively crowded by then. The Gaia astrometry vehicle may have gone to the great heliocentric graveyard (mission end expected 2022) but the James Webb Space Telescope should finally have been launched and even be in early middle age - and many others will likely have joined it, including its travelling companion, ARIEL.

Comet Interceptor will wait for the "Scramble" order when its controllers are alerted by instruments like the existing Pan-STARRS (which spotted Oumuamua) and ATLAS surveys, and the Large Synoptic Survey Telescope under construction. It will fire off sub-probes to intercept incoming comets. Prof Jones explained that comet detection has already become much more prolific (see the distribution, left).



Geocentric discovery distances for all 1065 long-period comets (LPCs) versus discovery date [reference: Discovery statistics and the 1/a-distribution of long-period comets detected over the 1801–2017 period. Małgorzata Królikowska , Piotr A Dybczynski, Monthly Notices of the Royal Astronomical Society, Volume 484, Issue 3, 11 April 2019, Pages 3463–3475, open publication: arxiv.org/abs/1901.01722].

Credit: Królikowska and Dybczynski

The Comet Interceptor proposal (www.cometinterceptor.space) is due to be submitted to ESA in March and evaluated by July of this year (reference: *Call for a Fast (F) mission opportunity in ESA's Science Programme*, sci.esa.int/cosmic-vision/60498-call-for-a-fast-f-mission-opportunity-in-esa-s-science-programme/).

Prof Jones outlined the proposal (see Comet Interceptor, A proposed ESA mission to an ancient world, Geraint Jones, UCL Mullard Space Science Laboratory, Colin Snodgrass, University of Edinburgh, and the Comet Interceptor Team -www.lpi.usra.edu/sbag/meetings/jan2019/presentations/Tuesday-PM/Jones.pdf).

He told us that previous comet missions have been to objects that have passed the Sun many times and thus had been changed by past close encounters. The Interceptor vehicles would examine comets which are probably nearing the Sun for the first time and would thus be pristine, with surface ices as first laid down at the Solar System's formation.

Astrojots

Prof Jones also writes and draws for www.astrojots.com, a webcomic that concentrates on planetary science and astronomy. His strips have different levels of complexity, aimed at under 10s, those with a secondary school science background, and a few more advanced topics. Astrojots strips are free to use for educational and personal use and he says "Teachers, please feel free to download strips and print them out for your class".

Here's an example on Planetary Landers

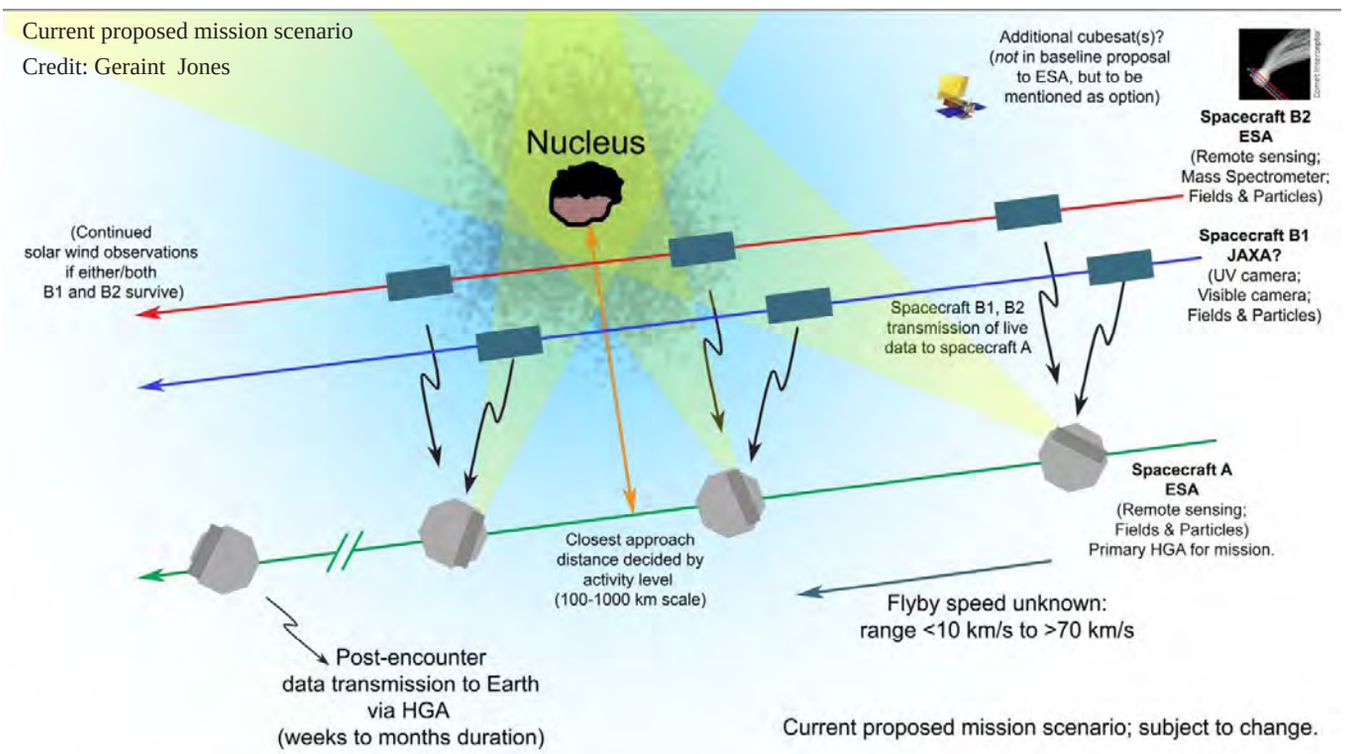
Credit: astrojots.com

Under the current proposed mission scenario each interceptor would consist of three sub-probes, two flying as close as possible to the comet to gather spectra, dust and images and the third gathering information at a longer, safer, range and acting as relay for the close-in probes, which would not necessarily survive the encounter.

After the lecture I suggested to Prof Jones that interstellar objects had similar trajectories to comets on highly eccentric orbits. He agreed that this was so and that a new Oumuamua-like object would be a good target for the interceptor. I did not press him for a view on the Loeb/Bialy conjecture (see Principium 23 and 24) since he told me that his interests lay primarily in cometary composition rather than orbital dynamics.

I hope the proposal is accepted by ESA so that both new comets and interstellar objects like Oumuamua can be studied at close range. In particular, if we can detect cousins of Oumuamua and investigate them at very close range then our knowledge of the universe beyond our Solar System will be immensely enhanced.

Current proposed mission scenario
Credit: Geraint Jones



Précis of progress & activity by i4is-US 2017, 2018 and early 2019

Robert G Kennedy III

Robert Kennedy is president of the Institute for Interstellar Studies, the United States part of i4is.org. Both parts of our organisations were incorporated in 2014 (The European part is aiming for Institute status under the more rigorous regulation of Companies House in the UK). Here Robert presents a summary, in the form of a timeline, of the activity and accomplishments of i4is-US in 2017 and 2018.

i4is-US, Inc a not-for-profit public-benefit corporation in the State of Tennessee USA, was founded by me in April 2014 as a professional courtesy to the i4is-UK*, in order that their intellectual property, especially their good name, be protected here in the US. For almost 2 years, it lay dormant, kept in existence by modest fees and minor paperwork.

i4is-US formally announced at Asilomar Microcomputer Workshop #42, Pacific Grove, California (www.amw.org) in April 2017. You can read more about AMW in Principium P22.

In June 2017, i4is-US participated in i4is-UK-led *Foundations of Interstellar Studies* workshop for 40 participants at Brooklyn Tech, part of the City University of New York (www.citytech.cuny.edu/physicsworkshop/). Apart from making a presentation, i4is-US sponsored awards to Professor Greg Matloff & C Bangs at the Harvard Club, NYC. I presented the second opening paper "Interstellar Fusion Fuel Resource Base of Our Solar System" (eventually published in JBIS 71, no 08, pp 298-305; see also the JBIS news item in the last issue of Principium, P24).

In August 2017, i4is-US took the administrative lead of the i4is proposal #17-NIAC18A-0173 to NASA. I also contributed news reports from *Foundations* workshop to Principium P18.

In September 2017, i4is-US registered in US federal System for Award Management. (SAM) and in NASA NSPIRES and submitted the Step A proposal #17-NIAC18A-0173, titled "Low-cost laser-based asteroid water mining using CubeSat class-spacecraft".

In October 2017, the interstellar object **1I/'Oumuamua made itself known to science** and i4is-US contributed to the first Project LYRA paper showing how interception was feasible using existing technologies.

On 8 November 2017 the "Project LYRA" preprint by Hein *et al*, was posted on arXiv.org. I have the honour of being 6th co-author, with others from i4is-UK. A few days later this paper was picked up by MIT Technology review "Best of the Physics arXiv". Later it was cited by the Paris Observatory and numerous major science and news sources including *Scientific American, The Times* and the *London Review of Books.*

From a Distant Solar System

I PRAY every day that super-intelligent aliens will come to earth and save us from self-destruction, so when an 800-metre-long cigar-shaped object was found to have hurtled into our solar system I felt a stirring of hope. It was picked up on 19 October by the Pan-STARRS (Panoramic Survey Telescope and Rapid Response System) at the University of Hawaii's Astronomical Institute. Its speed and the direction of its orbit indicated that it had come from outside our solar system – making it the first object we've ever identified as an arrival from interstellar space – and that it would eventually leave on its way towards the constellation of Pegasus. It was initially thought to be a comet, but soon reclassified as an asteroid: comets are icy rocks formed on the outskirts of solar systems and produce a tail of gas and dust when they fly close to the sun, but the cigar had no tail. It is also deep red in colour, the result of its irradiation by cosmic rays over millions of years. The astronomers at the University of Hawaii gave it the name 'Oumuamua', which reportedly means 'scout', but which, according to the one Hawaiian dictionary I could access online, refers specifically to 'the foremost soldier or the front line in battle', giving the cigar a more sinister complexion.

Oumuamua is ten times longer than it is wide. Nothing else we've observed in our solar system has this shape. Asteroids aren't cigar-shaped, spaceships are. There have been several UFO sightings of cigar-shaped vessels, including one seen over Paris in May. Many Oumuamua-watchers have also noticed the similarity between Oumuamua and the alien spaceship in Arthur C. Clarke's *Rendezvous with Rama*, a cylindrical vehicle that turns out to be hollow and filled with strange machinery, including hybrid mechanico-biological robots. Rama creates an artificial gravitational field by spinning along its axis; Wired published a piece a few days ago showing how Oumuamua, which is also spinning, is doing the same thing (though its gravitational field is much weaker than Earth's, and isn't really a gravitational field at all but 'apparent weight'). Someone joked on Twitter that Oumuamua was piloted by aliens who had intended to make contact, but that having noticed that the Flat Earth International Conference was taking place on 9-10 November decided to give us a miss. Flat Earthers believe the Earth is flat and that scientists and governments have conspired to keep this truth from us. Apparently some of them also believe that the 'spherical Earth theory' was seeded by aliens who want to stop us from developing actual space travel technology, which is ironic, if that's the word.

In *Rendezvous with Rama*, a survey vehicle called 'Endeavour' is sent to explore the alien ship. Members of its crew touch down on one end of the cylinder and find an entry hatch, then cautiously begin looking around the cylinder's vast interior, a highly organised patchwork landscape of mosaics, artificial waterways and giant electrical components. The novel contains some of the most hallucinatory descriptions in science fiction of an encounter between humans and a technology they find incomprehensible: there are fields of wire wool and beds of crystal-studded sand, crackling metal columns and curious robotic crabs that pick up detritus and carry it into Rama's canals. I'm not saying Oumuamua will definitely look like that close-up, but even if it turns out not to be an alien spaceship, surely we should explore it if possible: it's the first piece of macroscopic interstellar material we've been aware of, and it's still relatively close by. Happily, scientists are trying to work out how we might go about it. Some of them even think it could be managed. Members of the Initiative for Interstellar Studies, a proto-institute whose goal is 'to enable both robotic and human exploration and colonisation of the nearby stars', have published a paper of recommendations for how we might catch up with Oumuamua – they call it Project Lyra.

One difficulty is that Oumuamua has an excess velocity of 26 km per second ('excess velocity' denotes speeds greater than the speed required to escape the sun's gravitational pull). The fastest object humanity has ever built is Voyager 1, a probe launched by Nasa in 1977 which is still sending information back from beyond Eris, and it had an excess velocity of 16.6 km per second. Another difficulty is that Oumuamua is getting further and further away. The longer it takes us to launch the probe, the more speed we'll need to intercept Oumuamua, and the longer the mission will take. One of the possibilities considered by Project Lyra is using SpaceX's Big Falcon Rocket, a launch vehicle powered by methane-fuelled engines whose design was unveiled in September, which should be operational by the early 2020s. The plan would be to have the rocket fly towards Jupiter, and use the planet's gravitational field to fling it in the direction of the sun for a close solar fly-by (or 'fry-by'), then on towards Oumuamua. The Project Lyra people calculate that an excess velocity of 70 km per second should be achievable with this technique, and that the ship would intercept Oumuamua in 2039 at a distance from Earth of 85 AU (Astronomical Units – the average distance between the Earth and the Sun, around 150 million km). The second option Project Lyra considers is a fleet of lightsail-powered probes. Lightsail-powered craft are currently under development by a company called Breakthrough Initiatives, and would fly using solar pressure, or multi-megawatt laser beams, directed at giant mirrors. Project Lyra envisages a 'swarm' of hundreds of thousands of lightweight sail-powered probes launched in Oumuamua's direction in five years' time.

There are so many signs that we're on the cusp of a new dark age. Religion is on the rise, as are the numbers of believers in astrology and conspiracy theories, and average IQ is falling: according to one psychology professor at the University of Amsterdam it has fallen among Westerners by as many as 14 points since the beginning of the 20th century. The pace of technological development is slowing. A Flat Earther called 'Mad' Mike Hughes had planned to launch himself into the atmosphere in a homemade rocket on 25 November in an effort to prove that the Earth is flat, but was prevented from doing so by the US's Bureau of Land Management, which of course only reinforced his theory that there's been a cover-up. This trend is discouraging. Whether or not we're capable of commanding swarms of laser-sail powered space probes in ten years' time will depend on what kind of people we've become. Play our cards right and the Flat Earthers will be able to send their own mini-probes up into the atmosphere, without putting their lives in danger, and resolve their doubts for good. Get it wrong and we'll forever be the dunces of the universe, pointed at and mocked by aliens as they pass through in their cigars on their way to somewhere more sophisticated.

Nick Richardson

36 LONDON REVIEW OF BOOKS 14 DECEMBER 2017

From a Distant Solar System, LRB 14 Dec 2017
Credit: Nick Richardson / London Review of Books

* "i4is-UK" is used in this report to refer explicitly to the UK-registered i4is.

In December 2017 I visited the i4is-UK HQ, the Bone Mill, Gloucestershire, and presented to members of the i4is-UK board of directors. All of us present were also interviewed by Joanna Durrant of the BBC Radio Gloucestershire (www.bbc.co.uk/programmes/p05wflrf & www.bbc.co.uk/programmes/p05wrqcc#play).

In April 2018 i4is-US jointly co-sponsored (with Ultimax Group Inc) SoCIA'18 socia.space. My paper "Estimating Optical & RF Signatures of Geoengineering at Interstellar Range" was presented by Dr Jim Schwartz, Wichita State University, Kansas.

April 24: met Drs Edw Goolish, Melissa Kirven & Jacob Cohen Chief Scientist @ NASA Astrobiology Inst @ NASA Ames Research Center.

I was the general chair of Asilomar Microcomputer Workshop #44, Pacific Grove, California. There was an interstellar session on the closing day led by myself, Dr T Marshall Eubanks and Dan Fries of i4is-US.

"Catching A Little Bit of Heaven--i4is-US at the Asilomar Microcomputer Workshop" was published in Principium P22.

In September 2018, our Step A proposal #18-NIAC19A-0090 "Swarming Proxima Centauri: Optical Communication over Interstellar Distances" was submitted by i4is-US to NIAC.

In September, i4is member Marshall Eubanks attended the NASA NIAC Symposium in Boston, Massachusetts. www.nasa.gov/content/niac-symposium.

Joanna Durrant BBC Radio Gloucester interview Rob Swinney and Robert Kennedy III
Credit: Kelvin Long

In December 2018, Ms Cassidy Cobbs, mycologist/evolutionary biologist, resident of New York, *JBIS* co-author (see JBIS 68, nos 3/4, pp.81-85) and formerly of the Tennessee Valley Interstellar Workshop (TVIW), joined i4is-US as Corporate Secretary.

I joined-in via Zoom with the team at IAC in Bremen, Germany, including the i4is-UK AGM.

October 17: host dinner in Reno, Nevada for JAXA astronaut-candidate Dr Kasumi Yasukawa, now Deputy Director of the Fukushima Renewable Energy Institute (yes, she works ***there***, Japan.)

October 18: host brekkie in Reno, Nevada with Dr Carlos Mariscal of University of Nevada-Reno & co-founder/co-chair of SoCIA'18 re continuing collaboration with i4is and participation in SoCIA'20,

October 31: lay groundwork for meeting in Mar 2019 in Addis Ababa with Ethiopian Space Science Society, www.ethiosss.org.et/index.php/en/home/about-esss in re: potential future collaboration with i4is.

On Dec 5, 2018 the Institute for Interstellar Studies submitted a Step B proposal #18-NIAC19A-0090 "Swarming Proxima Centauri: Optical Communication over Interstellar Distances" .

As reported elsewhere in this issue, Dan Fries and I of i4is-US attended the MIT "Beyond the Cradle" event in March 2019.

Upcoming Events

At the time of writing there are three more i4is-US activities upcoming -

- 10-12 Apr 19: Participation in Breakthrough Discuss in Berkeley CA from i4is - Robert Kennedy, Andreas Hein, T Marshall Eubanks, Nikolaos Perakis.
- 22 or 23 Apr 19: NASA Ames Research Center in Mountain View CA, including the NASA Astrobiology Institute.
- 24-26 Apr 19: AMW#45 at Pacific Grove CA, T Marshall Eubanks will present (off-the-record, per Chatham House rules, www.chathamhouse.org/chatham-house-rule) our approach in the NIAC Step B proposal: "Swarming Proxima Centauri".

And more to come later in the year, of course.

News Feature - IAC 2018
Special Session - Swarm Systems

Reported by John I Davies

Our main reports from the 69th IAC, Bremen 1-5 October were in P24 (February 2019) and P23 (November 2018). This final report is a partial account of a significant non-interstellar event, one of the Special Sessions - a set of five presentations, Swarm Systems for Future Space Exploration, Tuesday, 2 Oct 2018.

The presentations for this session have not been made available on the conference website but two of the presenters were able to provide slides or supporting material. However, some of this report is the fruit of research and serendipity.

This session is especially relevant to interstellar studies because we currently envisage just two early technically feasible means of interstellar propulsion, fusion rockets and laser propelled sails. The scale economies of laser propelled sails demand swarming approaches since the cost equation has two main inputs - probes, small and relatively cheap, and laser arrays, massive and very expensive. This means large numbers of spacecraft per mission. Cooperating swarms are therefore a natural architecture.

The session consisted of four presentations -

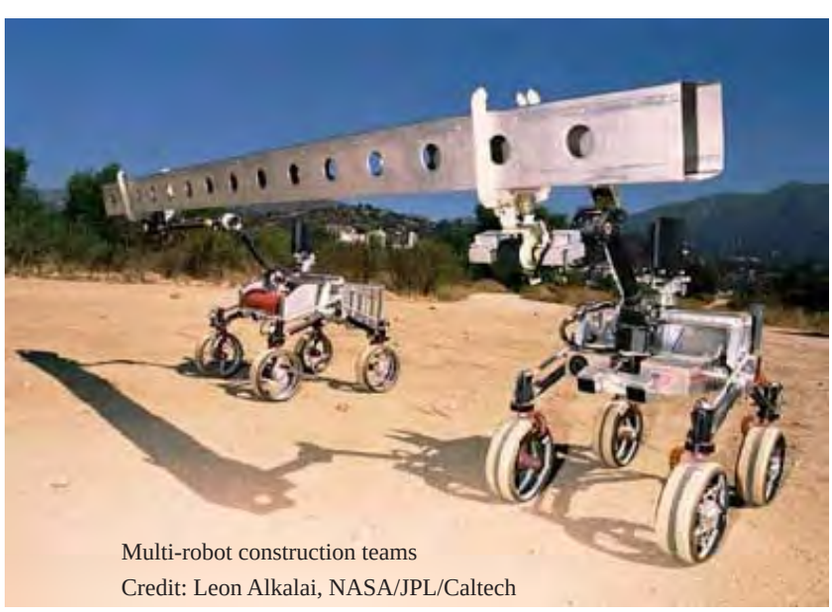
- *Autonomous Swarm Systems for Deep-Space Exploration,*
  Dr Leon Alkalai, NASA JPL, Pasadena, USA
- *Pico-Satellite Formations for Innovative Observation Approaches,*
  Prof Klaus Schilling, University of Würzburg, Germany
- *Swarms: An Enabling Capability in Responding to the Exigencies of Future Space Exploration,*
  Dr Fred Hadaegh, NASA JPL, Pasadena, USA
- *Swarm Solutions for Future Planetary Space Exploration Applications,*
  Dr Dmitriy Shutin, DLR, Oberpfaffenhofen, Germany

The flyer for the session *Special Session - Swarm Systems for Future Space Exploration* is publicly available at www.iafastro.org/wp-content/uploads/2018/09/IAC-Swarm-Systems-for-Future-Space-Exploration-Flyer-final.pdf. This includes short biographies of each of the speakers.

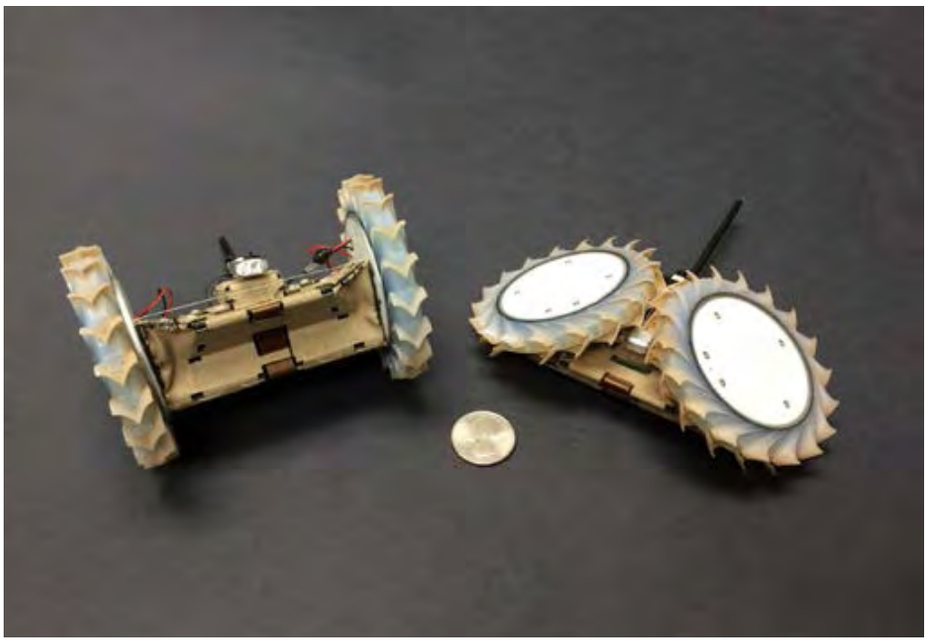
Taking the presentations in order of available detail -

Autonomous Swarm Systems for Deep-Space Exploration, Dr Leon Alkalai, NASA JPL

Dr Alkalai kindly provided Principium with a PDF of his presentation, *On Swarm Systems and a New Era of Space Exploration*. In his talk he explained why swarms are of increasing interest. For example, they provide the possibility of large effective apertures for astrophysics, multiple distributed sensors for Earth observation and distributed, load-balanced HPC (high performance computing) and data store capabilities for planetary exploration. Multi-robot construction teams are adaptable to a range of tasks. In wider terms swarms can provide enhanced risk tolerance for any mission through redundancy and cooperative networking.



Multi-robot construction teams
Credit: Leon Alkalai, NASA/JPL/Caltech



PUFFER robots [1]
Credit: Leon Alkalai, NASA/ JPL/Caltech

Risk can be modulated across a swarm, with a few "team members" undertaking high risk, high reward, missions while others take fewer risks. Examples of potential space-borne swarms could include ideas based on existing proposals such as -

- Planetary Rovers, for example PUFFER (Pop-Up Flat Folding Explorer Robot) [1]
- Planetary Flyers, for example the JPL Mars Helicopter [2] rotorcraft mission and Titan's Dragonfly - from Johns Hopkins University Applied Physics Laboratory (APL) dragonfly.jhuapl.edu
- Planetary underwater vehicles, including concepts for exploring ocean-worlds.

JPL has been a pioneer in swarm thinking and aims to remain a leader into the future.

JPL Mars Helicopter rotorcraft deployed from lander [2]
Credit: Leon Alkalai, NASA/ JPL/Caltech

1- *Origami-inspired Robot Can Hitch a Ride with a Rover* www.jpl.nasa.gov/news/news.php?feature=6782

2- *Mars Helicopter to Fly on NASA's Next Red Planet Rover Mission* www.jpl.nasa.gov/news/news.php?feature=7121

Pico-Satellite Formations for Innovative Observation Approaches, Professor Klaus Schilling, University of Würzburg

Prof Schilling kindly provided Principium with briefings on relevant aspects of his projects. His presentation mentioned the Netsat project over 2 years and the subsequent TOM (Telematics earth Observation Mission). Prof Schilling also shared *Small Satellites - Light weight, strong impact: small satellites for telecommunication and Earth observation* a Regional Leaders Summit (RLS) Project Description - Small Satellites update and *CT for Clouds: A Fleet of Micro-Satellites Will See into the Smallest Clouds*. In his talk he mentioned some intriguing applications including quantum key distribution and technologies including reaction wheels only 2 cm in diameter! (Reaction wheels are one of the two main angular momentum-based methods of attitude control - *en.wikipedia.org/wiki/Reaction_wheel*).

My subsequent research showed *Orbit design and control method for satellite clusters and its applications to NetSat project*, 2017, in the Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering, unfortunately not on open access. This is an RLS project. More about this small satellite project at the project website rls-smallsatellites.org. More about the TOM work in *Using picosatellites for 4-D imaging of volcanic clouds: proof of concept using ISS photography of the 2009 Sarychev Peak eruption* Klemen Zakšek et al (www.researchgate.net/publication/323822362_Using_picosatellites_for_4-D_imaging_of_volcanic_clouds_Proof_of_concept_using_ISS_photography_of_the_2009_Sarychev_Peak_eruption).

Dr Shutin amusing us with "Swarm Quo Vadis", envisaging exploration of Martian caves by swarms - and surprising us with very unexpected fossils!

Credit: Dr Dmitriy Shutin, German Aerospace Centre (DLR)

Photo: John I Davies

Swarms: An Enabling Capability in Responding to the Exigencies of Future Space Exploration, Dr Fred Hadaegh, NASA JPL

Dr Hadaegh, JPL Chief Technologist, invoked ant swarms and asked us to imagine a heterogeneous ant swarm investigating the interstellar object Oumuamua. NASA began swarm thinking with an exoplanet detection application using femto-satellites to form a distributed aperture telescope with perhaps 25,000 elements providing both a very large effective aperture and a high degree of resilience. (This probably refers to the work reported in 2011 - *Swarms of Femtosats for Synthetic Aperture Applications* available at the Core open access site - core.ac.uk/download/pdf/77930058.pdf).

As in the case of Dr Alkalai's presentation, my subsequent research showed a strong JPL commitment to swarm technology. Their 2018 *Technology Highlights* - section "Flying Swarms" says -

> "JPL is developing swarming technologies that can revolutionize space exploration. Teams of spacecraft can cooperate to form virtual structures such as synthetic apertures, and can perform distributed measurements not possible with a single spacecraft".

More at scienceandtechnology.jpl.nasa.gov/sites/default/files/documents/JPL_2018_Technology_Highlights.pdf. And a Google Scholar search - Swarms Hadaegh - shows Dr Hadaegh has been continuously active in this sphere for many years.

Swarm Solutions for Future Planetary Space Exploration Applications, Dr Dmitriy Shutin, German Aerospace Centre (DLR), Oberpfaffenhofen

Dr Shutin suggested that the main technical challenges are communication, navigation and exploration. He has a specific interest in sophisticated radio technologies for aerospace including software defined radio (en.wikipedia.org/wiki/Software-defined_radio). Such swarms communicating in a mesh have better re-entry capabilities, more robustness, better uplink capability and perform better in target location. Dr Shutin also entertained us with "Swarm Quo Vadis", envisaging exploration of Martian caves by swarms surprising us with very unexpected fossils!

My subsequent research identified a recent paper discussing distributed communications architecture including software-defined radio, *Swarm Technologies for Future Space Exploration Missions*, Staudinger et al, from the German Aerospace Centre (DLR) Institute of Communications and Navigation (elib.dlr.de/120345/1/Staudinger_et_al_SwarmTechnologies.pdf).

i4is-US at the annual MIT Beyond the Cradle event

Robert G Kennedy III

The 2019 MIT Beyond the Cradle event took place at the MIT Media Lab on March 14, 2019. The title comes from the inspiring words of Konstantin E Tsiolkovsky (see many mentions in Principium, for example Tsiolkovsky - Interstellar Pioneer P20, February 2018).
Robert Kennedy and Dan Fries of i4is were invited (it's an annual invitation-only event) and Dan gave a short talk about our work. Here Robert gives us his inimitable take on this inspirational event including the plenaries and Track B. And Dan adds his experience of Track B of the event.

Getting thru Boston is just about like navigating across London. (Without having to pass "the Knowledge" – what would we ever do without satnav?) Once you get there, MIT is its own world. First you see "the Great Dome", then the tall tower wherein lies the Department of Earth, Atmospheric, and Planetary Sciences. (Someday, we'll get ourselves in that one, too.) They have their own argot at MIT. The taxonomy of courses is unique: think of the Dewey Decimal system, but with a much smaller namespace. So instead of asking "where's the Math Department?" you say "where's 'core 18'?" Classes within a core are simply numbered from "00" to "99". Anything starting with a zero everybody has to take, whereas I suspect only Nobel Laureates could understand what's being said in anything after "90".

Electrical Engineering is "core 6" and since computer science grew out of EE, MIT refer to CS as "core 6.3". MIT's notorious "Tech Model Railroad Club" is where the hacking subculture began in the 1940s (en.wikipedia.org/wiki/Tech_Model_Railroad_Club). It's where the word "hack" (in its non-pejorative sense) was coined. Then when the first computers started to appear in the 1950s, skills developed at the TMRC made for a perfect lateral migration to making cranky vacuum-tube mainframes do what you wanted.

Ariel Ekblaw and her crew (see picture below, Robert, Dan and Ariel) put on a first-class show, beginning with a scrumptious buffet breakfast and coffee on the top floor of the famous MIT

left to right: Robert Kennedy, Dan Fries and Ariel Ekblaw

Media Lab. It was a beautiful clear day. From the rooftop patio at #75 Amherst Street, you can see Cambridge, the Charles River, and all the way to the horizon.

The best talk all day was the morning keynote by Dr Samuel C C Ting, winner of the 1976 Nobel Prize for co-discovering in November 1974 (another group at Stanford did the same thing at the same time) the psion, a subatomic particle. This discovery ushered in the so-called "November Revolution" in high-energy physics. He is the principal investigator for the multi-billion-dollar Alpha Magnetic Spectrometer on the International Space Station. The AMS was the last big thing (a 7.5-metric-tonne instrument) to be launched on the Space Shuttle before the fleet's retirement, and literally required an Act of Congress to get up there. It counts cosmic rays of various origins and measures their energies--very high, up to a trillion electron-volts. About 130 billion cosmic rays have been counted, measured, and characterized so far. They are still waiting for several kinds of one-in-a-trillion events to show up, which will require at least fivw more years of exposure on the ISS (hopefully decades more). Some results so far conform to theoretical models but other results are peculiar, strange, and unexpected: instead of symmetries, asymmetries where they weren't expected, or vice versa; energy cutoffs for certain particles but no upper limit for others. People don't have the first clue why these things were observed, but there they are in black and white. This makes the AMS archive a rich treasure trove for theorists to mine for the foreseeable future. (Information theory tells us that the value of information is in perfect inverse proportion to its probability. Remember, many great discoveries eg, penicillin, begin with the words, "hmm, that's funny...") The AMS is telling us something profound about the universe we live in, so we're going to have to figure it out.

Lunch arrangements were interesting, an example that i4is might learn from. Lunches were boxed, but excellent. Limited choices (3), including something for vegans (which is an emerging lifestyle), but all very good. No chairs whatsoever. Rather, there were a score of tall narrow tables, about as high as your elbow, at which eight or so people could stand. Standing is no doubt a healthier way to eat, but I don't think this choice was about fitness. Eight is about the maximum size for intimate conversation. By not sitting, it takes almost no effort to move from one table to another, and there's less sense of offense created when one does that. Remember the event is being held at the world-famous MIT Media Lab, on one of the top engineering and architecture schools on the planet—I suspect the big room was engineered for the rapid formation and reconfiguration of conversation groups in order to facilitate and maximize the rapid exchange of ideas.

The rest of the event had two tracks. In order to have full coverage, Dan attended track B in the big room. He'll be reporting in P26 (August). The best and next-best talks of the afternoon track A were given by:

> Robbie Schingler, co-founder and chief strategy officer of Planet, an earth-remote-sensing company that operates a fleet of hundreds of tiny (3U form factor) reconnaissance satellites in sun-synchronous polar orbit. Robbie describes his system as "a once-a-day line scanner for planet Earth"--they are able to get sub-meter resolution, updated daily, a capability which was beyond the superpowers just a few decades ago. Fantastic. This capability is having real-world political and diplomatic consequences. (Someday I will tell you the story of my involvement at the birth of the commercial remote sensing industry.)

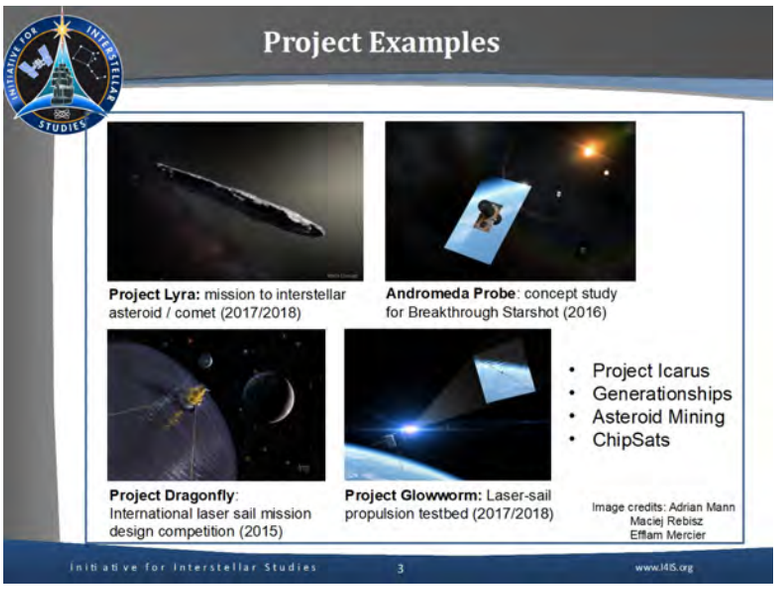
- and -

> Dr Natalya Bailey, CEO and founder of Accion Systems, which builds incredibly small but physically simple electric propulsion systems for nanosats. I note that the systems she is competing with in her corner of size/mass trade space are cold-gas thrusters (basically a balloon that you let the gas out of) with an anaemic specific impulse of 50-100 seconds. She has figured out a way to make small charged particles out of liquid droplets, which completely skips the expense, trouble, and non-scalability of ion-propulsion systems, AND managed to scale and fabricate a complete engine down to where it (actually a great many of them firing in parallel) fits on a chip, hence can be mass-produced like any other chip, AND wrings a fantastic I_{sp} (specific impulse) of 1800 seconds (!) out of it, with a theoretical upper limit near 4000 seconds!!! It is for this reason that I think Dr Bailey's innovation will be important to us (i4is) that comes out of "Beyond the Cradle", as we seek to realize practical near-term physical accomplishments in the interstellar field. Stay tuned.

Dan Fries did a great job presenting about i4is during the breakout workshops in the mid-afternoon (see just one slide Project Examples), and we made some very promising contacts in the citizen science/ open source space movement. See the picture (Dan is on the left).

The late afternoon was filled with more entertaining plenaries, and a panel of four astronauts and one cosmonaut with funny stories. See the picture below. I'm not sure an anecdote is worth the column space in a staid interstellar newsletter, but I'll relay one:

The space station might seem small to you and me, but weightlessness adds a third dimension which makes it quite roomy. Sound, however, carries far, plus white noise is ubiquitous. If you need some "alone time", sequestered nooks and crannies are not hard to find. The space station also has a big rubbish problem, so trash and stuff that's not needed anymore is packed in leftover containers and staged, also in out-of-the-way places, for eventual stuffing into the next departing resupply rocket (that burns up during reentry). One astronaut (Dominic Antonelli, far right in the picture below), seeking quiet, wrapped himself in his sleeping bag, zipped it up over his head, and bungeed himself amidst the boxes of trash so he wouldn't drift off.



Dan Fries and co presenters at his breakout workshop. Credit: Robert Kennedy


Four astronauts and one cosmonaut - seated left to right -

Nikolay Chub, cosmonaut; Nicole Stott, ret NASA astronaut; Cady Coleman, ret NASA astronaut (Moderator); Leland Melvin, ret NASA astronaut; Dominic Antonelli, ret NASA astronaut.

Credit: Robert Kennedy

Later, another crewman happened upon the bagged human form, misinterpreted what he was seeing, and screamed. The sleeper, having been abruptly woken out of his well-earned slumber, screamed back also. Then some more crew came along to investigate what all the screaming and hollerin' was about. Lesson learned: "when you go for some alone time, recommend you let others know first".

The day closed with a really excellent reception. I ran into Loretta Hidalgo Whitesides, who single-handedly created the worldwide "Yuri's Night" phenomenon. See the picture [Robert + Loretta Hidalgo Whitesides 20190314_180640] When I knew her 25 years ago, she was Loretta Y Hidalgo, a bright ambitious intern working with us at the US House Subcommittee on Space. I expect she'll be going into space one of these days. The bartenders would fix anything on demand, but they were handing out a pink-purplish concoction of gin, lemon juice, and prosecco. I don't know what it was called, but I know that a "French 75" is not purple. Also, it doesn't go super-well with wearing VR goggles. See picture below).

It was at this time that our young colleague Dan Fries deeply impressed me with his grasp of American culture, above- and below-ground. Suffice it to say we may have come up with a variant, an official drink for i4is, like the "Alpha Centauri Sunrise" was for TVIW. However its name might not be suitable for a Sunday supplement or the pages of aforementioned staid interstellar

Robert with Loretta Hidalgo Whitesides
Credit: Robert Kennedy

publication (Robert means Principium - are we staid? Ed). But if I do make it over to Merry Olde this June for the second Foundations Workshop, I'll tell you in person, and we'll see if we can "gin up" one. (You are on, Robert! Ed.)

More at -

www.media.mit.edu/events/beyond-the-cradle-2019

- and videos at -

www.youtube.com/playlist?list=PLj62-wQeg_DhbnRdvZPbM-RewSledYESr

Track A - Dan Fries

The four panels in Track A were focused more on social, artistic and conceptual issues and opportunities surrounding space exploration with at least four people on each panel discussing a given topic. An interesting commonality between most of the panels was that there appears to be a general consensus that humanity is ready and yet, not really ready to colonize and utilize space. Ready in the sense that technologies are maturing, investors are willing to spend money and the hope that bringing more people into space will bring about a shift in the human consciousness. The last point is often equated with the so-called "Overview Effect" but I will come back to that later. Now, this hoped-for and sometimes deemed necessary shift in human thinking and acting, or lack thereof, is also the reason for the why humans are not really ready to make the move towards a large-scale space-faring civilization. It becomes a sort of chicken and egg problem where a more responsible species is required to make the best out of the new space age while at the same time we need to make the new space age happen to become better. What we want to be better at that we need space for you ask? Good question and this is the point where the overview effect comes back in: a large number of returning astronauts have described how travelling to space has changed their perspective of what is going on on our planet. Harmful and short-sighted politics, pollution, social injustice as well as egoistic and narcissistic tendencies seem to become issues that should have no place in human society as we are all herded together on Spaceship Earth, hurtling through the uncaring and cold void at 514,000 miles per hour relative to our galactic centre.

The Overview Effect Illustrated - planet Earth seen on December 7, 1972, by the crew of the Apollo 17 (NASA designation AS17-148-22727) showing the Earth as seen by Apollo crew enroute the Moon. Recall this was the last time humans ventured beyond Earth orbit (www.nasa.gov/image-feature/apollo-17-blue-marble).

Credit: NASA and the Apollo 17 crew

Using space travel to inspire change and grand aspirations in humanity was lauded, exemplified and spear-headed by a number of panel members, such as Leland Melvin (retired NASA astronaut), Alex MacDonald (Emerging Space Program executive, NASA), Yonatan Winetraub (co-founder of the company SpaceIL that recently landed the first private mission on the moon), Erika Wagner (payload sales director, Blue Origin), and Frank White (author of "The Overview Effect" and space philosopher). However, what does humanity do with the growing power and resources it wields through these endeavours if the required transformation is not complete yet? I guess that question will be answered in hindsight, more importantly though, a lot of people have come to the conclusion that the next step for us as a species absolutely requires the expansion of our comfort zone into the space beyond our protective atmosphere. Maybe the best guideline is provided by a very simple question posed by Loretta Whiteside (Yuri's Night co-creator and founder astronaut, Virgin Galactic) during the event: "what is the kind of culture we would like to see in a human space settlement?" Take the answer and then act on it while we are growing, so that we don't have to look back one day in horror, the same way we already do often enough.

The panel compositions were very diverse and it was amazing to see how the ingenuity and input of every aspect of human ability contributes a small part towards achieving the monumental goal of regular space travel and utilization for a large part of human civilization. Several attendants emphasized the importance of rigor and excellence in pursuing this goal. Interestingly, the resulting challenge seems to bring out exactly these factors in people that accept it, together with a sense of meaning and belonging. Thus, the four sessions definitely did their job in bringing like-minded people together, stimulate important conversation, and motivate attendants to try even harder in realizing our future.

Fine Tuning our Lasers: Updates on Project Dragonfly and Glowworm

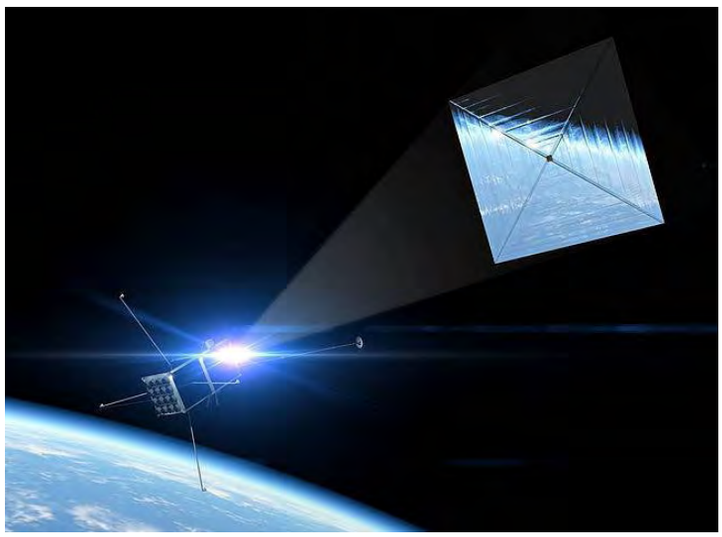
Dan Fries

In 2015 the Initiative for Interstellar Studies (i4is) successfully completed the Project Dragonfly competition and the accompanying KickStarter campaign, both related to concepts of full-scale laser sail missions. Subsequently, to actually make such a mission a reality, Project Glowworm was initiated in 2016 with the primary goals of responding to the technical challenges and the call for proposals by Breakthrough Starshot. Since then, participants of the Dragonfly competition and i4is members have refined the initial concepts and published them to make them available for review and scrutiny by the scientific community. In the following, we shine a spotlight on the most interesting developments in these publications, starting with the earliest one.

The paper simply titled "Project Dragonfly" appeared in Acta Astronautica in 2016 and was written by Nikolaos Perakis, Lukas Schrenk, Johannes Gutsmiedl, Artur Koop and Martin Losekamm from the Technical University of Munich[1]. The work is based on their winning entry into the Project Dragonfly competition and presents a system level approach with several scientific and technological foci to address the following mission requirements:

1. Design an unmanned interstellar mission that is capable of delivering useful scientific data about the Alpha Centauri system (4.35 light years), associated planetary bodies, its solar environment, and the interstellar medium.
2. The spacecraft shall use current or near-future technology.
3. The Alpha Centauri system shall be reached within a century of the probe's launch.
4. The spacecraft propulsion for acceleration shall be mainly light sail based.
5. The mission shall maximize encounter time at the destination.
6. The laser beam power shall not exceed 100 GW.
7. The laser infrastructure shall be based on existing concepts for solar power satellites.
8. The mission design should allow missions to a variety of target stars within a 10-light-year radius.

Credit: Adrian Mann



Glowworm illuminates chipsat sail.
Credit: David Hardy

Several technical and conceptual innovative solutions are presented in the paper. For example, situating the laser emitter on the moon would remove atmospheric interference while providing a solid position that does not have to be corrected with additional means of propulsion due to the reaction force of the laser. The paper also provides an approach to compute the effective reflectivity of an arbitrary number of layers of laser sail materials such as aluminised mylar, graphene monolayers and graphene sandwich. One of the major problems of interstellar missions is how to get rid of the massive amount of energy accrued during the acceleration phase. A requirement, if one wants to perform any significant surveying of the target star or even remain at the target of choice. The presented study proposes a combination of electric and magnetic sails and, together with other parameters (such as the number of laser sail lasers), performs a multi-variate optimization to find the combination of parameters that will best fulfil the mission requirements. One of the most interesting results of this optimization approach is that the pointing accuracy of the laser system is a major limiting factor with regard to total mission duration, ie pointing accuracies on the order of tens of picorads would be required to keep the mission duration within a 100 earth years for the given design space. Subsequent to Project Dragonfly, Project Glowworm was initiated to develop an in-orbit laser sail propulsion demonstrator for low-earth-orbit as a first step towards a full interstellar laser sail mission. The idea is to deploy a ChipSat (25x25 mm or smaller spacecraft) with a suitable sail from a CubeSat and have said CubeSat carry a laser system that is used to generate a reaction force on the ChipSat via the laser sail. In the paper "Project Glowworm: Testing Laser Sail Propulsion in LEO"[2], presented at the International Astronautical Congress 2018 by Zachary Burkhardt (International Space University – ISU), Nikolaos Perakis (i4is) and Chris Welch (ISU), two concepts to achieve this goal are analysed and their feasibility assessed. In one, the laser on the CubeSat is operated continuously to accelerate the ChipSat while the CubeSat maintains its position relative to the sail with an electric propulsion system. In the other, the laser is used impulsively to change the ChipSats orbit whenever the two spacecraft are aligned correctly. A system level design of the CubeSat, ChipSat and laser sail is also considered and discussed. For this study, the sail material is considered to be a multi-layer dielectric whose properties are computed with an in-house developed code. To predict the response of the CubeSat and ChipSat, the open source software GMAT was used for orbital simulations. Interestingly, the analysis shows that the second concept would not be feasible mostly due to atmospheric drag. On the other hand, the first concept in which the laser is operated continuously could deliver clear results over a 50 day mission, presenting a path towards space qualification of laser sail propulsion systems. Finally, the paper "Project Dragonfly: Sail to the Stars" by Tobias Häfner (Université Paul Sabatier), Manisha Kushwaha (Cranfield University), Onur Celik (Cranfield University) and Filippo Bellizzi (Cranfield University) was published recently in Acta Astronautica (2019)[3]. It is also based on the author's entry into the Dragonfly competition, but they have used the time since then to add a considerable amount of analysis and account for additional technological options. Specifically, they consider multi-layer dielectric materials for the laser sail and compute the deceleration towards the target star (Alpha-Centauri) caused by a magnetic

sail in detail. A comparison is made between three different magnetic sail models and the results indicate that an increase of current density in the superconducting materials for the sail are required to meet deceleration requirements, for the scenario considered. The results confirm the laser pointing requirements established by Perakis et al (2016) but come to a different conclusion about the placement and setup of the laser system itself, preferring a free flying setup in a stable orbit or Lagrange point and a focal point that makes it impossible to hit Earth with the full power of the laser. To achieve a more complete characterization of the target star system Alpha Centauri, the authors propose a multi-spacecraft scenario with multiple spacecraft in the three ton mass range launched in sequence with about 3.7 years delay between them. At i4is, we are very happy about this publication as it does not only provide additional technical insight, but it also shows that the original Dragonfly competition inspired the participants to pursue the topic further and with scientific rigour.

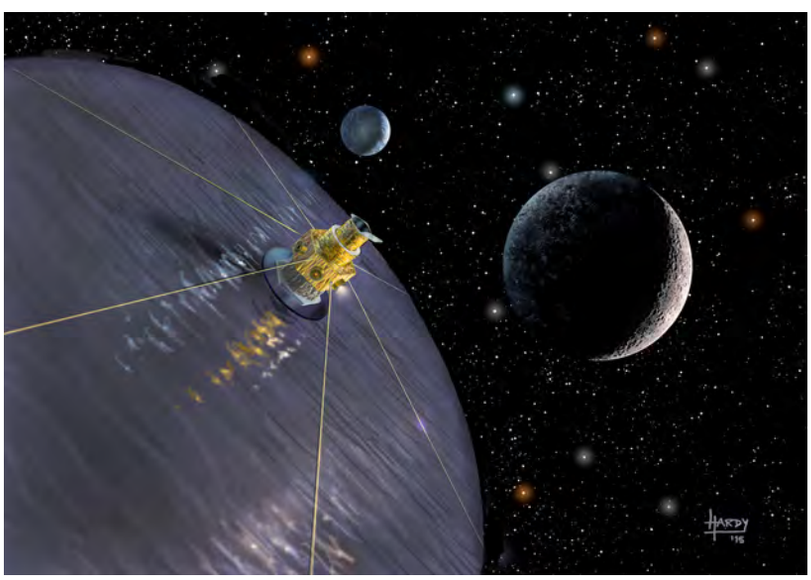
With this solid foundation, we plan to continue contributing to the conceptual and technological developments that will one day lead to the realization of humanity's first interstellar mission and the efforts outlined by the Breakthrough Starshot endeavour. In the short term, we prioritize the development of extremely small spacecraft (ChipSats, FemtoSats, AttoSats) and the characterization of dielectric sail material, including space qualification of the hardware. In the longer term, we are looking at concepts for long term system reliability, shielding from the interstellar medium and the construction of kilometre scale structures outside of Earth's atmosphere.

References

[1] "Project Dragonfly", Acta Astronautica Vol 129, December 2016, Nikolaos Perakis, Lukas Schrenk, Johannes Gutsmiedl, Artur Koop and Martin Losekamm (all Technical University of Munich). No open access available.

[2] "Project Glowworm: Testing Laser Sail Propulsion in LEO", Zachary Burkhardt (International Space University – ISU), Nikolaos Perakis (i4is) and Chris Welch (ISU) International Astronautical Congress 2018 www.researchgate.net/publication/328202365_Project_Glowworm_Testing_Laser_Sail_Propulsion_in_LEO.

[3] "Project Dragonfly: Sail to the Stars", Acta Astronautica Vol 154, January 2019, Tobias Häfner (Université Paul Sabatier), Manisha Kushwaha (Cranfield University), Onur Celik (Cranfield University) and Filippo Bellizzi (Cranfield University) was published recently in Acta Astronautica (2019) www.researchgate.net/publication/317491721_Dragonfly_Sail_to_the_Stars.



TUM laser-propelled interstellar probe concept,
Project Dragonfly
Credit: David Hardy

About Dan Fries

Dan is performing experimental research on combustion in incompressible and compressible turbulence for a PhD at Georgia Tech (www.gatech.edu). He has a degree in Aerospace Engineering from the University of Stuttgart and is interested in all things space exploration and propulsion. Within i4is, he is a member of the i4is Technical Committee and leads our work on Project Glowworm.

News Feature - The Membership Team

John Davies

The Initiative for Interstellar Studies membership scheme is now live - bringing people worldwide into a closer relationship with the i4is.
There is more about this including why and how everyone with an interest in taking our species to the stars can join in via our *Join* and *Members* pages, 20 & 17 in this issue.
The i4is membership scheme would not have been achieved without a strong team. This is the team.

Paul Campbell

Paul was in at the beginning of the i4is membership programme. Working with another volunteer, Michael Grant, he evaluated the ways in which the scheme might be implemented. Having selected the s2member plug-in for Wordpress, he installed it and got it working on our then-new website (which had been developed by our Wordpress consultant, Jason King). He interfaced it with Mailchimp to provide email conformation of memberships. He continues to be our lead technical expert. And he helped Terry Regan build our 2001 monolith!

Paul is originally from Newcastle. He has a first class degree in Computer Science from the University of Manchester. He was a volunteer with IT for Communities while completing his degree. On graduation he joined Bloomberg in the City of London as a Software Developer. He moved to charity Childreach International as their IT lead and later qualified in accountancy, taking over both financial and IT management. He added a Masters in Computer Science at Queen Mary University of London to his first degree and moved to Glasgow in another development role at Verint Systems, where he now works.

When not wrestling computer systems (and usually winning!) he relaxes by the seaside in Ayr with his wife, Laura, a medical researcher.

John Davies

John joined i4is a couple of months after formation in 2012. He found a natural role in education work given prior work as a STEM Ambassador to UK schools. He organised i4is presence at the 2014 SF Worldcon (with Gill Norman, now Executive Secretary, BIS) including the 4 metre high 2001 monolith (built by Terry Regan & Paul Campbell). He led the work on membership up to Tam O'Neill joining as Project Manager.

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

Patrick J Mahon

Patrick has been with i4is since attending a Starship Engineer course in November 2015; soon afterwards he became Deputy Editor of its quarterly, Principium. He joined the membership team in mid-2018, bringing his expertise in corporate policy and communications to the team. He was responsible for the launch marketing strategy and leads our thinking in this. Patrick has a first degree in Maths and Physics from Warwick University and a Masters in Environmental Decision Making from the UK Open University. He has previously worked as a civil servant and for a trade association, and he now works for WRAP (the Waste and Resources Action Programme), a national environmental charity, where he is responsible for policy development and political engagement. In his little spare time, Patrick runs a local writers' group and both reads and writes science fiction.

Conor MacBride

Conor joined the i4is team in early 2018 and has been editor of the i4is website since mid 2018. He worked with Paul on technical aspects of the membership system, especially the Members Area pages, certificate generation and integration with Mailchimp. Originally from Derry/ Londonderry, Conor is currently completing an MPhys in Mathematics and Theoretical Physics at the University of St Andrews and is due to start a PhD position at Queen's University Belfast in the area of solar physics later this year. While at St Andrews, Conor has taken an active role in the Physics Society, first being the publicity officer and then treasurer. He co-founded and co-produced a podcast, *insight*, interviewing scientists about their experiences in academia. Conor also enjoys reading science magazines, listening to podcasts and playing trombone in jazz bands.

Tam O'Neill

Tam joined the membership team in mid-2018 and rapidly took over as Project Manager. He has guided, coordinated and cajoled our volunteers to and through the launch of membership and beyond.

Tam is a Technical Consultant at HP Enterprise Services UK in Glasgow. He has worked as a database programmer for the Royal Air Force and was Information Manager – CVF Project, later named HMS Queen Elizabeth, while working with British Aerospace Defence Systems. Has also been an applications and systems software engineer before turning to consultancy during a long career spanning 30+ years in IT. Tam is a Fellow of the BIS and of the IAP (Institution of Analysts and Programmers).

When HP, i4is and family permit Tam likes to head for the gym to let off steam, then sit and relax with either a good SF book, or some loud rock music - and not forgetting the coffee.

Support

The membership scheme was strongly backed by consecutive executive directors, Kelvin F Long and Dr Andreas M Hein, and by deputy director Rob Swinney and our Board of Directors.

We learned a lot by studying other membership schemes, especially those of our older sibling, the British Interplanetary Society (BIS) and the Planetary Society. Gill Norman and Ralph Timberlake of the BIS were especially helpful, particularly in the early stages. Our former Wordpress consultant, Jason King, has been a reliably supportive contributor and two former members of the team, Dave Miller and Michael Grant, helped our first steps towards the system we have today.

Letter to the Editor: Interstellar Objects - A Warning from Oumuamua?

From: T Marshall Eubanks, Asteroid Initiatives, 24/2/2019

The object ‘Oumuamua (MPC: 1I/2017 U1) is the first known object on a hyperbolic trajectory around the Sun. As such it is almost certain to have entered the Solar System from interstellar space and is thus our first known interstellar visitor. It is unlikely to be unique. We have only recently acquired a minimal capability to detect them and since they do not have predictable orbits they are a new potential Earth-impact threat.

Is it worth setting up an early warning system for them?

The Cretaceous–Paleogene extinction event is thought to have been a 10 km asteroid. Let's say it was an impact at 20 km/sec - reasonable, for a near-earth object (NEO).

$(10\ km)^3 \times (20\ km/sec)^2$ is 4×10^5 (don't worry about the units just now).

Now, for ‘Oumuamua (hereinafter 1I) - $(0.1\ km)^3 \times (50\ km/sec)^2$ is 2.5

So, this has 10^{-5} the energy of the K-T/K-Pg impact.

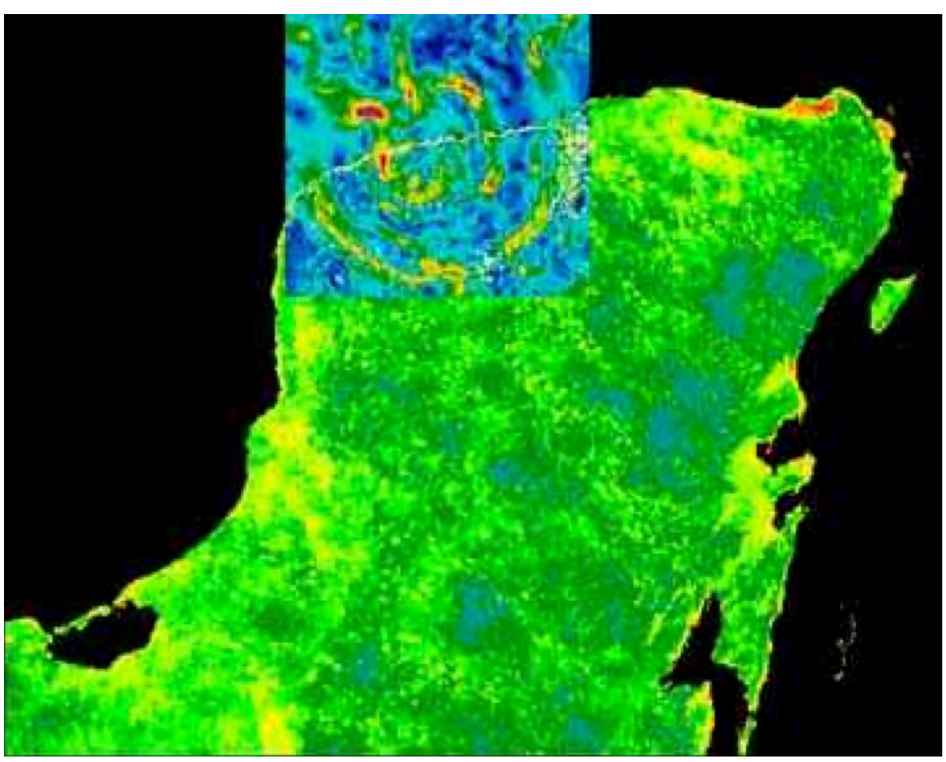
Going on - The Earth Impact Effects Program of Imperial College London and Purdue University impact.ese.ic.ac.uk/ImpactEarth/cgi-bin/crater.cgi?dist=1&diam=100&pdens=2000&pdens_select=0&vel=50&theta=45&tdens=2500&tdens_select=0

This is very similar to the Tunguska event. Of course, that would be a 1 in a million shot (100 years versus 2×10^8 years).

It will not be an extinction event, although it would take out any city it hit.

Note well: in the above I have been assuming a normal density, not the low mass-area ratio suggested for 1I to explain the anomalous acceleration.

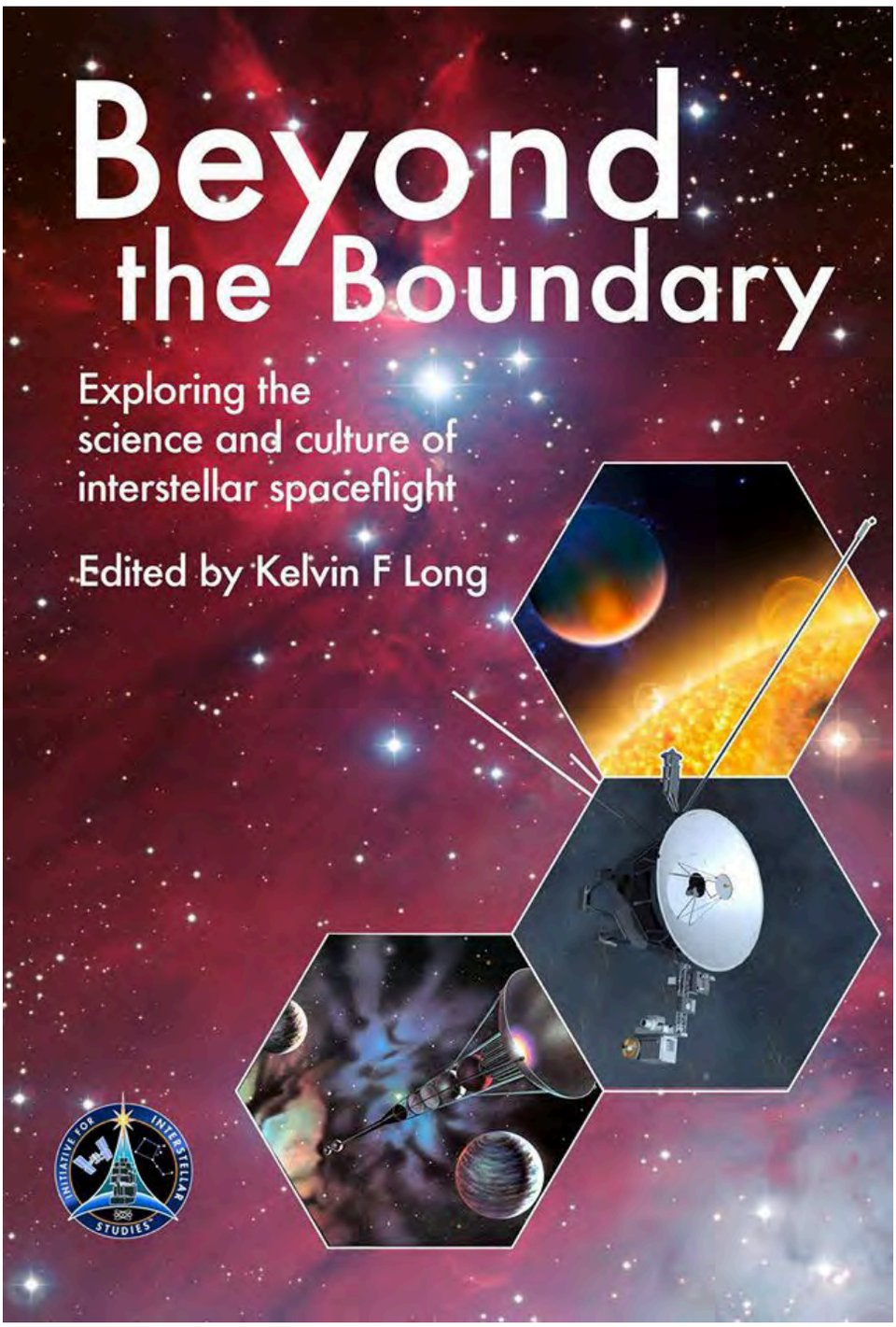
The paper - Earth Impact Effects Program: A Web-based computer program for calculating the regional environmental consequences of a meteoroid impact on Earth (spiral.imperial.ac.uk/bitstream/10044/1/11554/2/CollinsEtAl2005.pdf) explains the original program. The latest updated version of the program is the basis for the above calculation.



Asteroid anomaly map of Chicxulub crater

Credit: NASA

The NASA annotation says - A gravity anomaly map of the Chicxulub Crater area superimposed on the Yucatan Peninsula shows areas of mass concentrations (ie the yellow and red areas are ‘gravity highs’ whereas the green and blue areas are ‘gravity lows’). The aftermath of the impact led to the extinction of about 75% of all species on Earth.



Initiative for Interstellar Studies 2016 - 448 pages ISBN: 9780993510908
Price: GBP 30.00 plus local tax

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

http://www.lulu.com/shop/kelvin-long/beyond-the-boundary/hardcover/product-22522176.html

NEXT ISSUE

The State of the Art in Fusion Propulsion - Part 2
Nomadic Planets and Interstellar Exploration
News Feature: The Principium Team
Mariner 2 Spacecraft model - Part 1: The research phase

Mission

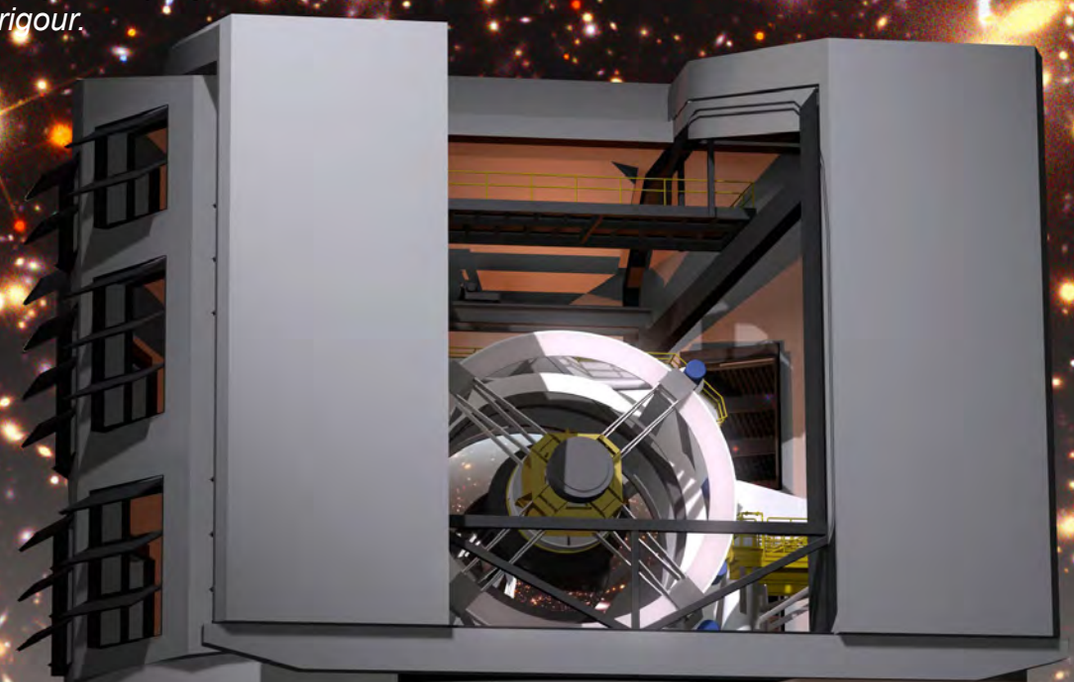
The mission of the Initiative for Interstellar Studies is to foster and promote education, knowledge and technical capabilities which lead to designs, technologies or enterprise that will enable the construction and launch of interstellar spacecraft.

Vision

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

Values

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



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

Front cover: Paths of photons in the vicinity of a black hole, Credit: Nicolle R Fuller/NSF (eso.org)
Back cover: visualisation of Large Synoptic Survey Telescope (LSST), Credit: LSST Project/NSF/AURA (lsst.org)

Editor: John I Davies
Deputy Editors : Andreas M Hein, Patrick J Mahon
Layout / Proofing: John I Davies, Carol Wright, Lindsay A Wakeman

i4is.org

Scientia ad sidera
Knowledge to the stars