

PRINCIPIUM

The Newsletter of the Initiative for Interstellar Studies

Issue 23 | November 2018

ISSN 2397-9127

www.i4is.org

The MEMBERSHIP Edition

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Scientia ad sidera
Knowledge to the stars

Editorial

Welcome to the 23rd issue of Principium, the quarterly newsletter about all things interstellar from i4is, the Initiative for Interstellar Studies - and our US-based Institute for Interstellar Studies. And a special welcome if you are a new reader. Please tell us if we have your details wrong (info@i4is.org).

Our Introduction feature for Principium 23 is *Implications of the Gaia Mission for Future Interstellar Travel* by Dr Phil Sutton of Lincoln University, UK. Gaia is mapping our neighbourhood in unprecedented detail - one day we will go!

The nature of the interstellar object Oumuamua remains a mystery and its trajectory and tumbling motion seem to be in

contradiction. John Davies contributes a survey of knowledge and a personal call to action, *What is Oumuamua?*, which has been prompted by a conjecture of Professor Abraham Loeb and Dr Shmuel Bialy of Harvard University. Our front cover is a visualisation of a possible explanation *Wrecked Solar Sail* by artist Alex Storer.

Our back cover reminds us that most of humanity has regular sight of our first long-term outpost in space, the International Space Station, in a photo tracking the ISS from the back garden of Dr Leslie Wood of Glasgow Caledonian University.

A major item this time is the report on the big event of the astronautical year, the Congress of the International Astronautical Federation, IAC 2018 in Bremen. John Davies and Patrick Mahon report on interstellar and related presentations. Interstellar is a growing area in space technology and science - this year's congress reflected this.

Our Interstellar News this quarter reports -

» i4is team John Davies and Satinder Shergill at the Royal Institution (Faraday's place!) to inspire school students from Skateboards to Starships.

» Deputy Director, Rob Swinney, and team member Marc Casson at events at BIS UK, West Midlands.

» Kelvin Long, i4is researcher, spoke at two conferences in the USA, Cospar and the Interstellar Probe workshop in New York.

» International Space University - we report our support for three 2018 ISU Thesis Projects.

» i4is Executive Director Andreas Hein and SF novelist & physicist Stephen Baxter announce results of two year's work, Artificial Intelligence for Interstellar Travel.

» Angelo Genovese, i4is, spoke at the European Mars Society Convention in Switzerland,

We also have News Features covering events at our HQ, The Mill, our *First Five Day i4is Summer School - Starship Engineering* and a presentation by Professor Greg Matloff and C Bangs, *Holographic Photon Sails - A Merger of Science and Art*. Our chief model maker, Terry Regan reports on *The Andromeda Probe Model*. Sadly no i4is team members were able to be at TVIW 2018 this year. So

no report this time but we reproduce the programme showing that the Tennessee Valley Interstellar Workshop continues to be a major event in the interstellar studies calendar.

Readers will recall the cosmic scale thinking of Dmitry Novoseltsev (Дмитрий Новосельцев), last year. This time he

brings us *Engineering of new worlds - goals, motives and results*.

The features, *Nomadic Planets and Interstellar Exploration* by Marshall Eubanks and Patrick Mahon's *Idiot's Guide to Project Daedalus* are postponed. We aim to have both in P24 and a précis of the Amerigo paper from 2018 i4is Summer School plus more from IAC Bremen 2018.

Comments on i4is and all matters interstellar are always welcome,

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

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Contact us on email via info@i4is.org.

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

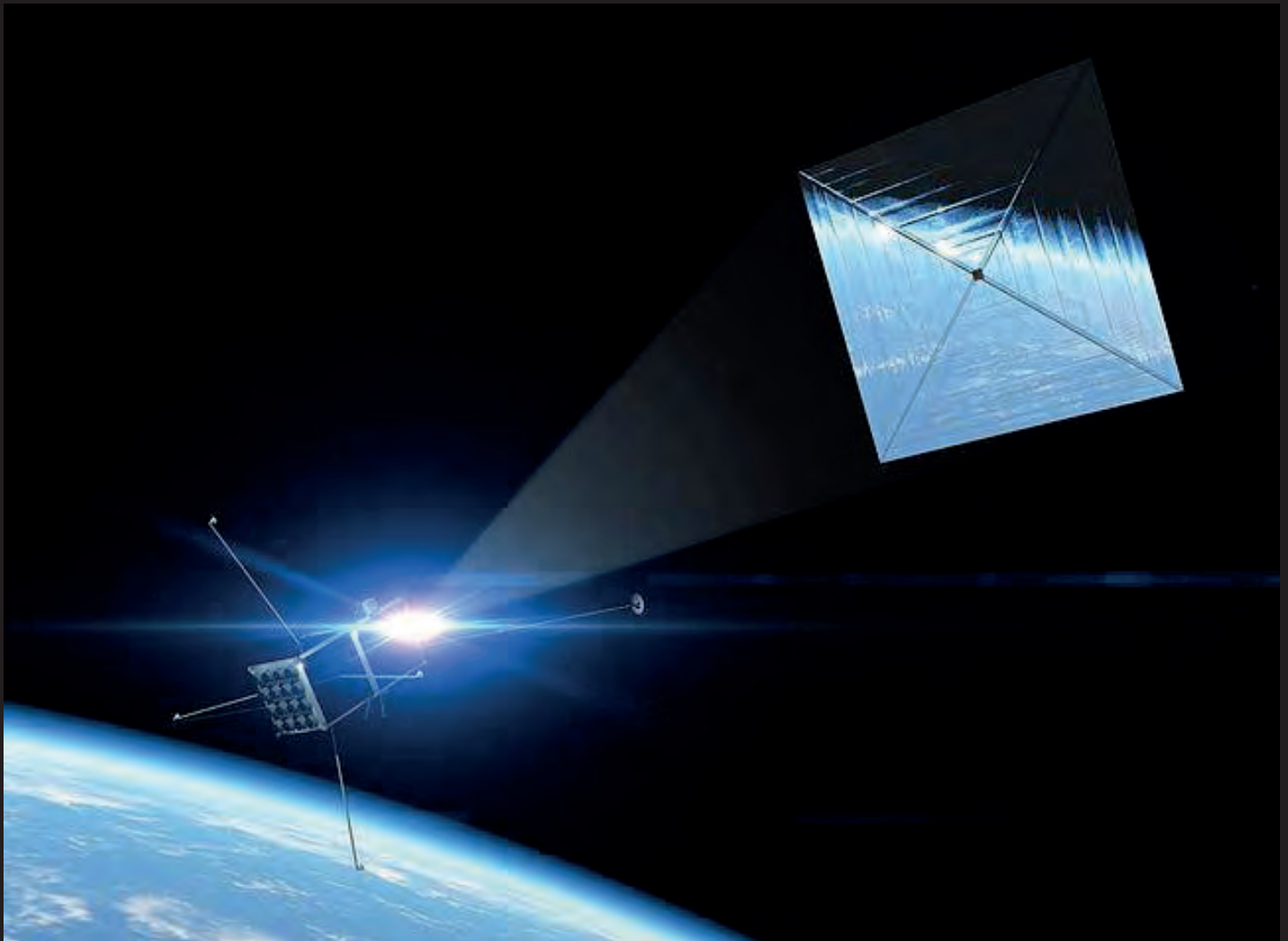
The views of our writers are their own. We aim for sound science but not editorial orthodoxy.

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.

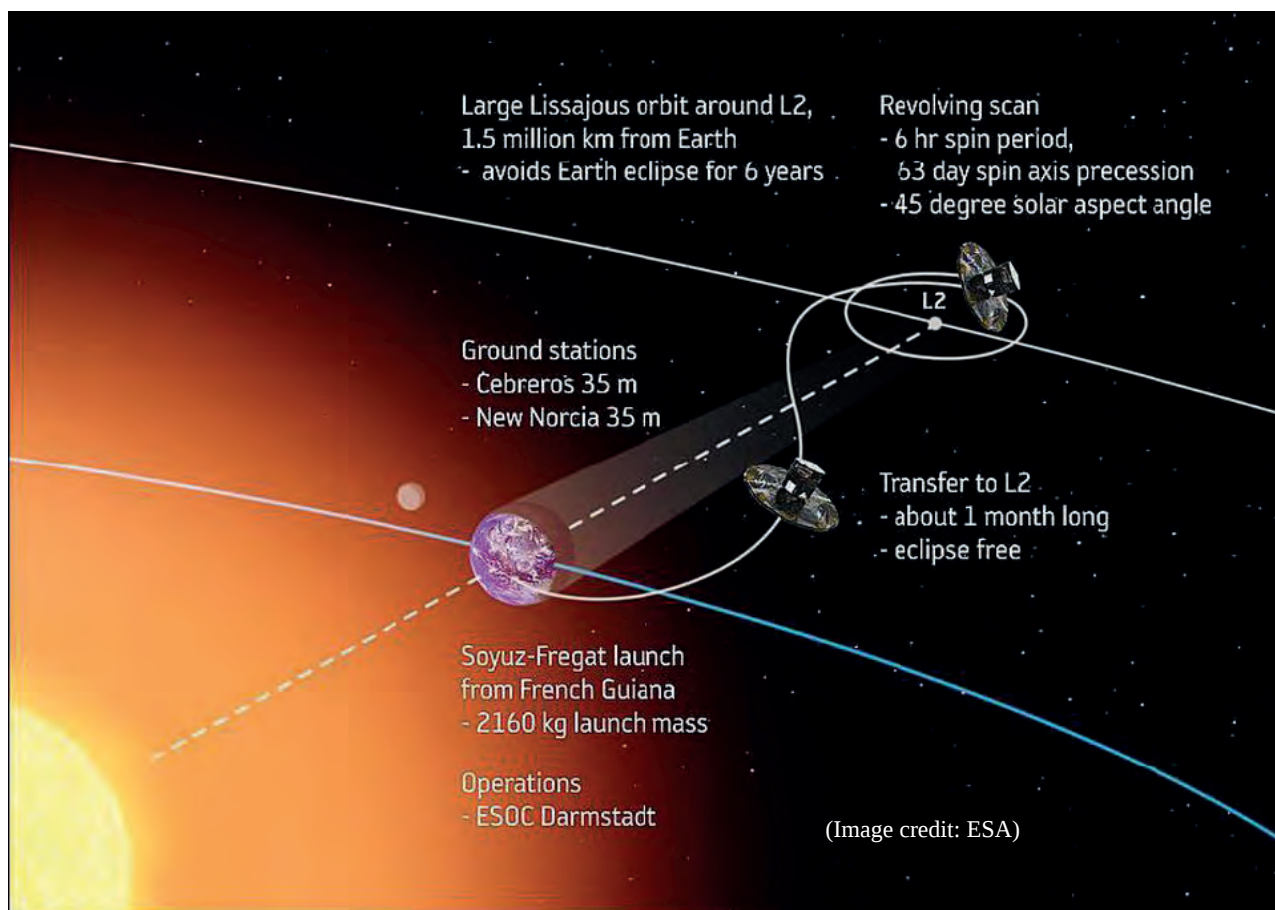
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Implications of the Gaia Mission for Future Interstellar Travel

Phil Sutton

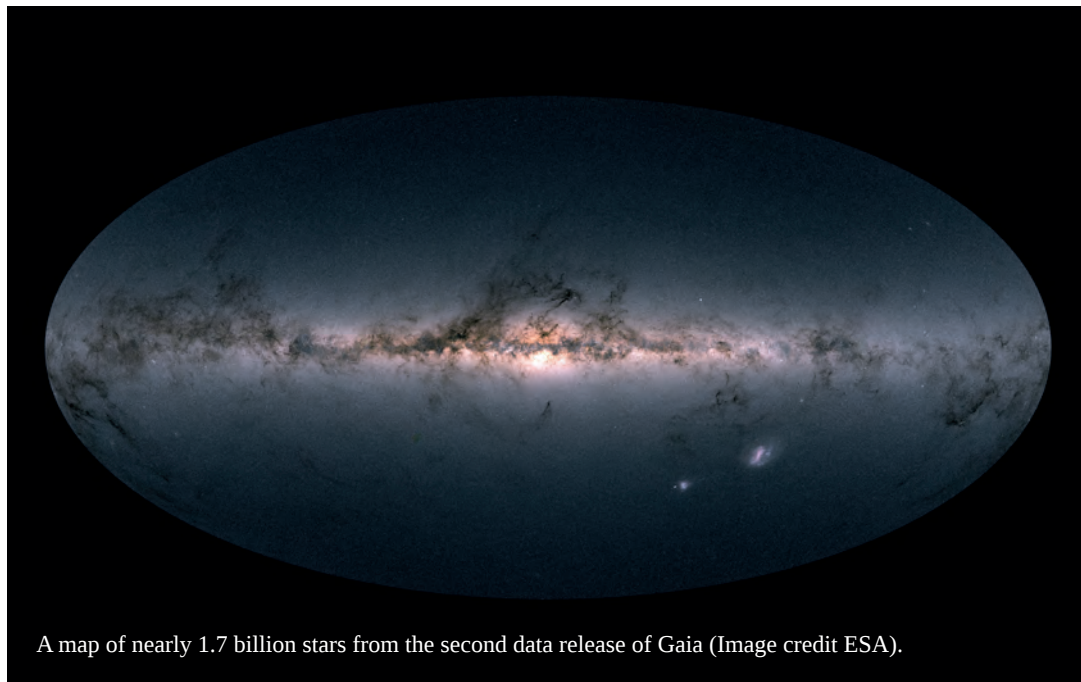
In this article, Dr Phil Sutton, Lecturer in Astrophysics, University of Lincoln, UK, discusses how the Gaia astrometry mission creates our first full "map of the neighbourhood". This data has immediate supporting value for all astronomical investigation but also has both cosmological and astronautical significance as we begin to contemplate missions to the near stars.

Over 1 billion stars have now been surveyed in extraordinary detail by the Gaia spacecraft since it was launched in late 2013. For the last 3.5 years Gaia has been in a large Lissajous orbit about the L2 Lagrange point of the Sun-Earth system. Spacecraft are often placed into these types of orbits as they require minimal propulsion to stay reasonably stationary relative to Earth for long periods of time.



Gaia's main aim is to measure the precise position of stars, astrometry, using triangulation between measurements of the stars apparent position as seen from different places in its orbit around the sun. This will give a more detailed 3-dimensional map of the Milky Way that is complemented by spectroscopic measurements of the same stars. Here, along with the precise position of stars, the Doppler Effect is used to find relative velocities of stars by a shift in wavelength of their observed light. The result is a detailed kinematic map of stars in our local neighbourhood, which is important; as we still do not fully understand why stars move the way they do in galaxies.

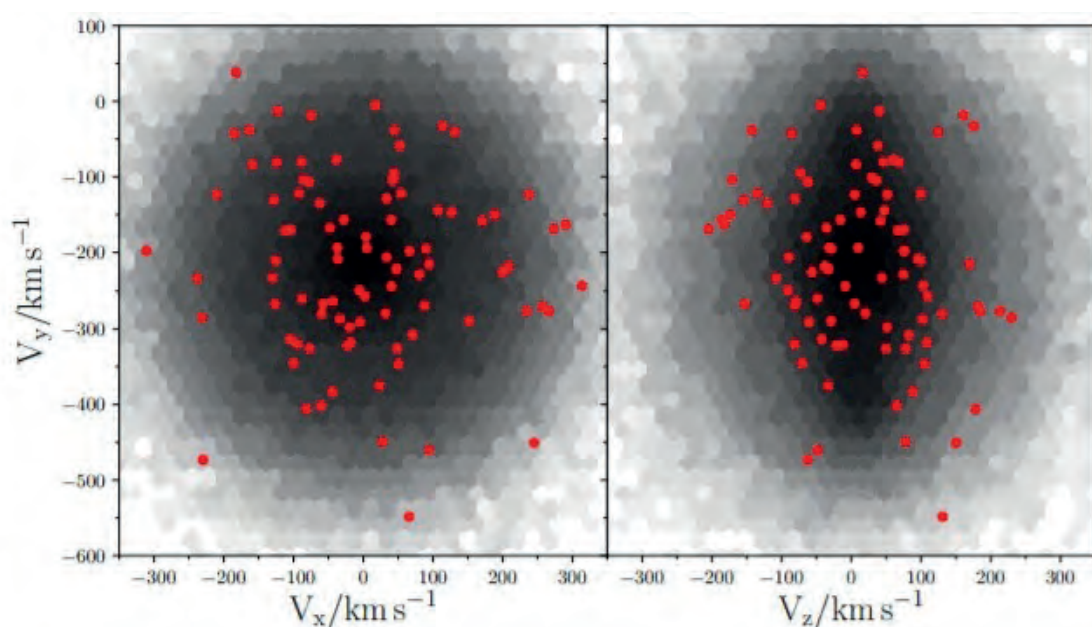
INTRODUCTION - Phil Sutton



Observations dating back to the 1930's suggested that the rotation curves of galaxies do not fit with standard Keplerian orbits. For planets and asteroids in the solar system their orbits are generally well understood and follow Keplerian laws. However, at a galactic scale it was found that galaxies rotated far too fast for the matter we could see. This led to the concept of dark matter, which would give the increase of orbital velocities of stars as that observed. Along with the increased orbital velocities, stars also exhibit some randomness to their motion around the centre of galaxies. All of this points to additional gravitational perturbations which may be significant enough to influence interstellar journeys.

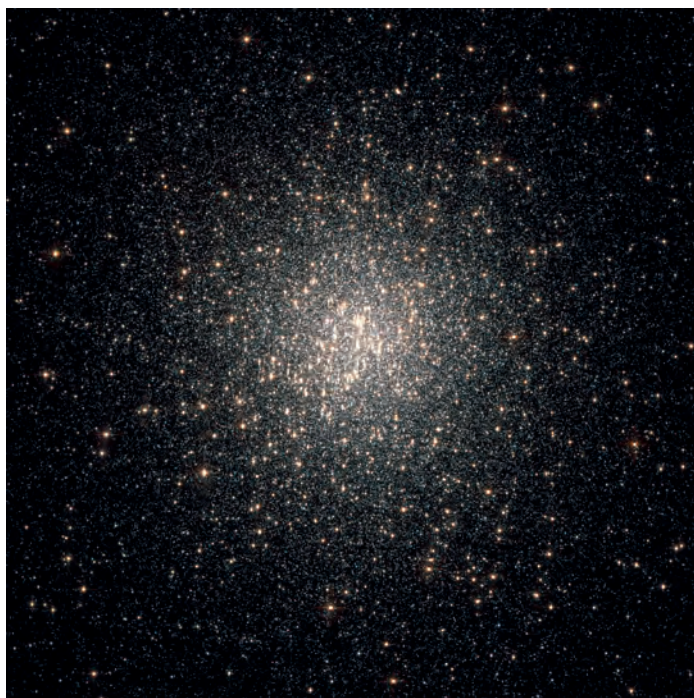
One way we can show the distribution of this elusive dark matter is to study how objects behave in the presence of its gravity, since dark matter is thought to only interact gravitationally. Posti & Helmi (2018) looked at the dynamics of 75 globular clusters from Gaia to map out the dark matter in the Milkyway. The dynamics of these globular clusters, which generally orbit outside of the main galaxy, help constrain the total mass and the distribution of mass. Ultimately, they found that over 2/3 of the total mass inside a radius was dark matter.

When travelling further afield the warping of spacetime due to this dark matter will need to be considered when planning the trajectories of spacecraft.



The above image shows the velocity distribution of globular clusters in the V_x - V_z plane in the Milky Way (red dots) overlaid on a model of the dark matter Halo. (Image credit: Posti & Helmi 2018).

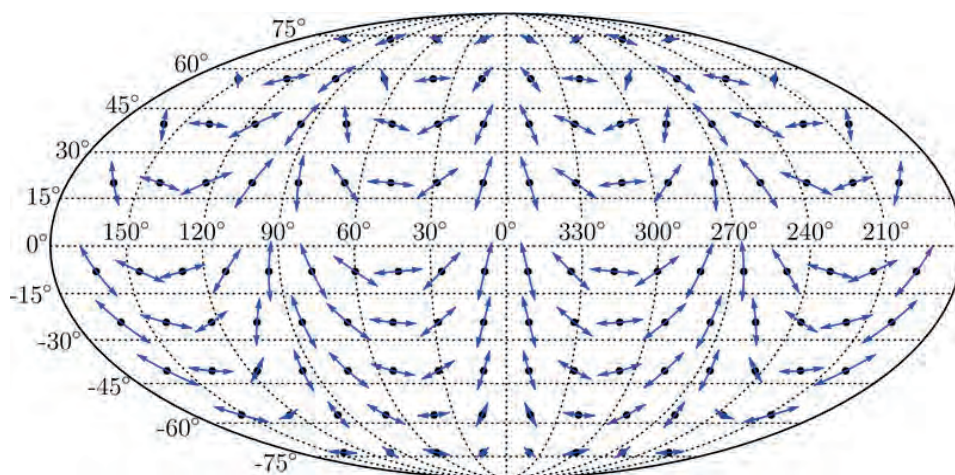
NGC 2808 is a globular cluster which, like most, orbits at the edge of the Milkyway as a satellite (Image credit: NASA, ESA).



Creating detailed maps of dark matter in our local neighbour then becomes very useful. The main science goal of another space telescope, Kepler, was to find new planets around other stars. It succeeded with now thousands of planets discovered and confirmed. However, secondary to the main mission it also discovered many new types of variable stars, like the heartbeat star*. Due to the nature of the Gaia mission and its measurements, other secondary science is also possible. For example, it could be something simple such as a survey of large asteroids in the Solar System. Or more esoterically the detection of certain frequencies of gravitational waves would help constrain the cosmological constant (the rate at which the universe is known to be expanding). Gravitational waves are of particular interest to astrophysicists as they exist over a very broad range of wavelengths.

* Heartbeat stars are binary stars with relatively eccentric orbits. [Wikipedia\(German Translation\)](#)

Positions of stars (black dot) oscillates as a gravitational wave passes through. The overall pattern can be used to derive the amplitude, frequency and polarization of the wave. (Image credit: C J Moore/ Univ. of Cambridge)



At some of the smaller scales, compact binary systems comprised of black holes or neutron stars can emit gravitational wavelengths on the order of km, while waves from the early universe in the form of a polarisation of the Cosmic Microwave Background can be on the order of Mly. Detecting different wavelengths allows us to probe different physics and astronomical objects and get a better understanding of the universe we reside in. It has been proposed that the signatures of gravitational waves are hidden in the astrometric data of stars measured by Gaia (Klioner 2018). Gravitational waves are disturbances in the curvature of spacetime and will cause the position of distant stars to oscillate slightly over time as they pass through. A much greater understanding of our local environment will aid our far future endeavours in interstellar travel, with Gaia already delivering unprecedented detail of the nearby stellar population.

If we know the types of stars and their movement within the galaxy more precisely we can better plan our interstellar journeys.

If stars in a galaxy are found to move in a non-Keplerian way due to the gravitational perturbations from dark matter, should we make considerations in spacecraft trajectories? It is also worth noting that there is an element of randomness in the motion of stars in a galaxy that is caused when they pass close to one another. It is almost Brownian in nature which actually increases with the age of the galaxy and is in addition to any effect dark matter might have on the movement of stars. The dark matter increases the global orbital velocities, assuming it is evenly distributed, while the stellar encounters add in a smaller element of randomness to their motion. Nonetheless, detailed maps of star types in our local environment will also guide our future expeditions. What type of stars systems do we want to visit? Stars like our Sun with potential habitable planets, young protostars to get a glimpse how stars and planets form up close, or older stars that have moved off the main sequence to give insight into the

fate of our solar system? As well as producing a spatial map of stars in our neighbourhood, Gaia data has also created a map of stellar types in the form of the H-R diagram* which might aid in planning our future interstellar missions.

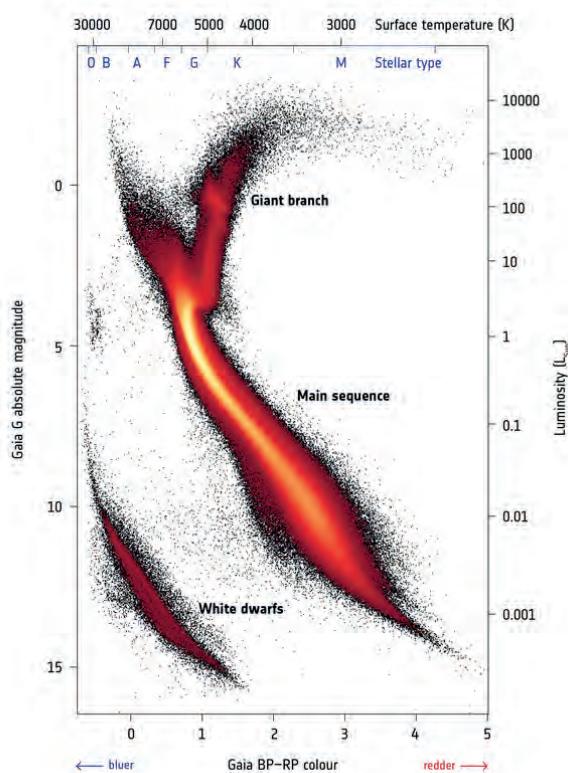
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* en.wikipedia.org/wiki/Hertzsprung–Russell_diagram

→ GAIA'S HERTZSPRUNG-RUSSELL DIAGRAM



H-R diagram of 4 million stars within 5Kly of the Sun which falls approximately in the middle of the main sequence. Location on the H-R diagram is mostly dependent on stellar mass and age. (Image credit: ESA).

About the Author

Dr Phil Sutton, Lecturer in Astrophysics, School of Mathematics and Physics, University of Lincoln, UK. Phil graduated in Physics with Astrophysics from Nottingham Trent University in 2006. He took his PhD in Astrophysics at Loughborough University in 2015. He worked as a technician and technical tutor at Loughborough University for ten years, involved in teaching observational techniques in astronomy, physics laboratories and astrophysics.

NEWS FEATURE - What is Oumuamua?

The Loeb/Bialy Conjecture and i4is Project Lyra

John I Davies

Principium editor John Davies offers a personal view of the continuing mystery of the interstellar object Oumuamua. More than one year since its discovery we still do not know what this object is. Here John summarises analysis so far and suggests that a mission to Oumuamua may be our only way of solving the mystery.

The object 'Oumuamua (IAS MPC designation 1I/2017) has intrigued astronomers, science journalists, the popular press and the interstellar studies community since its discovery by Meech et al as announced in Nature Letters on 20 November 2017 [1].

The key issue is - **What is Oumuamua?** This article attempts to summarise where we stand on this issue.

I hope to establish two key points -

- The nature of Oumuamua remains unclear but it is certainly unprecedented
- Since it is reachable by currently available launchers a mission should be considered

The article is a piece of science journalism based on my own analysis rather than an academic paper. The conclusions are my own and do not represent an official i4is point of view.

The nature of Oumuamua

Meech (cited above) et al discovered Oumuamua had the following characteristics -

1. No evidence of out-gassing even at closest approach to the Sun (0.25 AU, well within the orbit of Mercury) so not a comet.
2. Elongated to a degree unknown in any extant asteroid of its size with dimensions of several hundred metres by about one hundred metres.
3. Spectrally red.
4. Albedo (reflectivity) of 0.04 - typical of comets and the majority of asteroids [2].

A number of observers confirmed that the cyclical variation in sunlight reflected from Oumuamua suggests that it is tumbling. Assuming that its surface has a uniform albedo this means it could be either extended in one dimension, spindle shaped, or in two dimensions, flattened [3].



So two more facts established -

5. Tumbling.

6. Spindle shaped or flattened.

Naturally such a strange object excited speculation about the possibility of an artificial origin but attempts to detect any non-natural electromagnetic radiation from it failed. In any case, natural scientific caution has produced a consensus that all reasonably possible natural explanations should be sought before artificial origins are considered. For what it's worth the present writer, an engaged amateur in these matters, agrees with this.

The plot thickens

However in June of this year, 2018, "the plot thickens"[4]. Oumuamua was discovered to be receding from the sun at an increasing speed. Reporting data from a number of optical telescopes, both terrestrial and orbital, Marco Micheli et al [5] reported small velocity increases, specifically "all astrometric data can be described once a non-gravitational component representing radial acceleration proportional to $\sim r^{-2}$ or $\sim r^{-1}$ is included in the model".

In other words, the acceleration is inversely proportional to the square of its distance from the Sun or to some lower exponent. It is accelerating, but that acceleration is decreasing as it gets further from the Sun. Micheli et al provisionally conclude that the best explanation of this acceleration is outgassing and that therefore Oumuamua is a very peculiar type of comet.

Here is a quick summary tour of their other possible explanations -

1. Solar radiation pressure. The simplest physical phenomenon that could cause a radial acceleration following an r^{-2} dependency and directed away from the Sun is pressure from solar radiation [but] the magnitude of the observed acceleration implies an unreasonably low bulk density roughly three to four orders of magnitude below the typical density of Solar System asteroids of comparable size.
2. Yarkovsky effect [6] (rejected as too small and in the wrong direction)
3. Friction-like effects (rejected since they would slow it down!).
4. Impulsive event. ...such as a collision [but] continuous acceleration is a far more likely

explanation.

5. Binary or fragmented object. ...center of mass of the combined system does in fact follow a purely gravitational trajectory, and the detected non-gravitational signature is an artifact, caused by us tracking only the main component of 'Oumuamua* [but] no secondary body or fragment is visible ... down to a few magnitudes fainter than 'Oumuamua, and any object smaller than the corresponding size limit (~ 100 times smaller than 'Oumuamua) would be insufficient to explain the observed astrometric offsets.

6. Photocenter offset. (the effect would be too small)

7. Magnetized object. (the effect would be too small)

To support their cometary explanation the writers suggest -

- [this] reconciles 'Oumuamua's properties with predictions that only a small fraction of interstellar objects are asteroidal.
- A thermal outgassing model, which treats 'Oumuamua like a common cometary nucleus, creates a non-gravitational force proportional to $\sim r^{-2}$ in the range of distances covered by our observations.
- Outgassing at this level is not in conflict with the absence of any spectroscopic signs of cometary activity, since the quoted values are well below the spectroscopic limits on production rates.
- The model, however, also predicts 0.2 kg s^{-1} of dust production, which should have been detectable in the images. While problematic at face value, this discrepancy could be resolved by adjusting the dust grain size distribution, the pore size of the nucleus, and the ice-to-gas ratio.

Examining that first point the term "confirmation bias" sprang to my mind.

Micheli et al go on to say "In-situ observations would be required to determine conclusively the nature, origin, and physical properties of 'Oumuamua and potentially similar objects yet to be discovered."

In other words, we need to go and have a look! I'll come back to that in the second half of this article.

Interested readers should take the link via spacetelescope.org (see reference [5]) and read the original paper.

* Editors note - Here and elsewhere the object is named simply Oumuamua except where quoted using other forms such as 'Oumuamua or 1I/2017 U1, minorplanetcenter.net

The Loeb/Bialy Conjecture

Most recently Abraham Loeb and Shmuel Bialy [7] looked in more detail at that "simplest physical phenomenon that could cause a radial acceleration following an r^{-2} dependency ", as Micheli et al put it. Citing a recent paper by Rafikov [8] they suggest that "... if outgassing was responsible for the acceleration (as originally proposed by Micheli et al. 2018), then the associated outgassing torques would have driven a rapid evolution in 'Oumuamua's spin, incompatible with observations."

Building on Micheli et al, Loeb and Bialy look at the possible nature of Oumuamua if that "simplest physical phenomenon" is the explanation (ie explanation 1 above). They have to account for the Micheli et al objection that "the magnitude of the observed acceleration implies an unreasonably low bulk density roughly three to four orders of magnitude below the typical density of Solar System asteroids of comparable size"

They consider the material and geometry required to achieve that low bulk density while producing the required solar radiation pressure and maintaining integrity for such a thin structure travelling interstellar distances. They cite Belton et al [3] on the possible flattened shape of the object. They conclude "If radiation pressure is the accelerating force, then 'Oumuamua represents a new class of thin interstellar material, either produced naturally, through a yet unknown process in the ISM or in proto-planetary disks, or of an artificial origin."

They go on to speculate about the purpose of a possible artificial object, a light sail.

They end by saying "Since it is too late to image 'Oumuamua with existing telescopes or chase it with chemical propulsion rockets (Seligman & Laughlin 2018, but see Hein et al 2017), its likely origin and mechanical properties could only be deciphered by searching for other objects of its type in the future."

A Mission to Oumuamua

Based on the Project Lyra conclusions I beg to differ from the Loeb/Bialy statement "it is too late to ... chase it with chemical propulsion rockets (Seligman & Laughlin 2018, but see Hein et al. 2017) ".

The i4is Project Lyra paper, Hein et al [9], cited in the Loeb/Bialy paper shows that a Falcon Heavy class launcher could project a probe to reach Oumuamua via a variety of "slingshot" manoeuvres and the Seligman & Laughlin paper [10], also cited by Loeb/Bialy, supports this view - though they "adopt a complementary approach" considering only a direct mission, no slingshots, launch within a few months of periastron (closest approach to the Sun) and a mission time of a few months rather than the years of the Project Lyra study. They address only future objects and not Oumuamua itself.

This article will not re-examine the feasibility of a mission to Oumuamua since this has been established by Hein et al, supported by Seligman & Laughlin, but will examine the case for a mission based upon what we know now (November 2018).

STOP PRESS:

Abraham Loeb has announced there may be more interstellar objects gravitationally-trapped between Jupiter and Neptune, *Identifying Interstellar Objects Trapped in the Solar System through Their Orbital Parameters* arxiv.org/pdf/1811.09632.pdf. They are Centaurs, an established class of asteroids. [en.wikipedia.org/wiki/Centaur_\(minor_planet\)](https://en.wikipedia.org/wiki/Centaur_(minor_planet))

And our colleague, **Marshall Eubanks** suggests that *Interstellar Asteroid 1I/'Oumuamua is a member of the Pleiades Dynamical Stream* (paper to be published)



Falcon Heavy reusable side boosters returning 6 February 2018.
Credit: contributed to public domain by SpaceX

Summarising the current state of astronomical opinion -

- The "peculiar comet" explanation is widely supported despite Rafikov's view that this does not accord with observations that its spin has not changed.
- The solar radiation pressure explanation is a minority view and the Loeb/Bialy conjecture that this implies a "solar sail-like" nature is not popular.

To this engaged amateur it seems that the majority view rests on some fairly demanding assumptions -

- that we have a comet whose outgassing material is very unusual, even unprecedented
- that an elongated comet is outgassing so that the resultant thrust vector is through the centre of mass, so that no change in spin is imparted

The solar radiation pressure explanation is unpopular perhaps because -

- it does not fit with the majority view that only a small fraction of interstellar objects are asteroidal.
- that the peculiar shape required by the Loeb/Bialy conjecture implies a new type of astronomical object.

And of course, the eternal search by the popular press for "little green men" and "wacky scientists" - and the consequent wish of scientists to avoid anything which might be interpreted as such.

However, what is almost certain is that we have a very strange object here, that the majority explanation for it seems weak and that we don't know how frequent such objects are since we have only seen one. The Spitzer non-observation of Oumuamua [11] indicates that, if it is a comet, it is a very strange one, able to produce significant non-Keplerian motion without visible gas and dust emissions. The dismissive scepticism in much of the science media could start to look like damage control and controlling perceptions rather than serious scientific criticism.

Given these circumstances our descendants (and ourselves in later life) may curse us if we do not follow this up. Imagine the situation which seems distinctly likely in, say, ten or twenty years time - that Oumuamua remains a mystery which we now regret not having investigated when the opportunity was there. So my personal conclusion is that this needs further investigation now and that, given that time presses and a mission is feasible if we act soon, that we should build upon the mission planning of the i4is Lyra team and of Seligman & Laughlin and begin a major study of a possible mission to Oumuamua. Kennedy gave NASA eight years to launch to the moon - we may have as little as eighteen months or perhaps three years.

References:

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About the Author

John I Davies is a retired software engineer and mobile telecoms consultant. He was part of the UK space industry including an early design study for the Hubble telescope and the later stages of the European ELDO launcher. His later experience was in mobile data communications, both technical and commercial..

Interstellar News

John I Davies with the latest interstellar-related news

i4is at the Royal Institution

i4is presented a summer school event at that oldest of UK scientific organisations, the Royal Institution (RI), on Monday 20 August. John Davies and Satinder Shergill were assisted by Rob Matheson and two RI volunteers. The school students, aged 13-15, had applied via the RI website. We showed how to get from Skateboards to Starships via the story of three heroes of maths, science and engineering - Al-Karismi for algebra, Isaac Newton for his equations of motion and Konstantin Tsiolkovsky for the tyrannical rocket equation. The whole day was brilliant and RI feedback showed a very positive response from the students. The support from RI staff, especially Amelia Perry, helped us to make it a lot smoother!

We aim to do it again soon at Satinder's school, Space Studio West London. Other schools UK-wide should get in touch if interested and we can supply media and ideas anywhere in the world. Contact john.davies@i4is.org.

Starship Engineering – How to Design a Starship

Our Deputy Director, Rob Swinney, was at BIS West Midlands on 17 November. Here's a summary of what he told them - To many, certainly outside the BIS, it may seem like science fiction that there are people today trying to work out how the human race might really travel to the stars. Worldwide there are professionals, part-timers, students and enthusiasts working toward this goal right now, dreaming big and holding a realistic expectation their goal will be achieved, if not by themselves personally, perhaps the next generations in the decades to come.

Rob looked at the background to designing Starships, illustrated the challenges involved through some seminal work of the past and brought things up to date with a look at the surge in spacecraft designs and designing in an effort to bring what was just imagination in to reality.

Nuclear fusion is arguably one of the most plausible near-term solutions for deep space travel and he highlighted the work of the BIS, from the renowned fusion powered Project Daedalus concept in the 1970s to current activities, such as Project Icarus which now involve other organisations and collaborations. Project Icarus was launched in 2009

at the BIS HQ in London to revisit Daedalus and evolve an improved engineering design and move us closer to achieving interstellar exploration. Now a collaboration between members of Icarus Interstellar, Inc, a US non-profit, and the BIS, the key was to produce a credible design and mission profile using near future technology along with other similar terms of reference to the Daedalus.

After years of struggle by members of the 'interstellar community', with little budget or investment, a Russian billionaire philanthropist, Yuri Milner, is planning to spend \$100 million over 10 years in his Breakthrough Initiative Starshot programme which should show how to send a laser sail probe to the nearest target in the next 20 years. This may well see the start of a new space race; this time to the stars.

At The Mill

It's only just over a year since it opened but the list of speakers at the i4is HQ, The Bone Mill, is an illustrious one. In chronological order -

Alfred Worden, Apollo 15 Command Module pilot

Simon 'Peter' Worden, former Director of NASA Ames Research Center and now Pete Worden, Executive Director, Breakthrough Starshot

Robert Kennedy III, President of the Institute for Interstellar Studies, our US sibling organisation

David Ashford, founder and managing director of Bristol Spaceplanes

Rob Swinney, Co-Founder and Deputy Director of i4is, Chair of Education Committee

Patrick Mohan, Deputy Editor of Principium

Kelvin F Long, Co-Founder and founding Executive Director of i4is, Author of Deep Space Propulsion

Dr David Johnson

Stephen Ashworth, Principium contributor and prolific writer on space matters, notably in the Journal of the British Interplanetary Society (JBIS)

Mark Hemsell, consultant in astronautical systems engineering, Past President of the BIS and formerly Future Programmes Director at Reaction Engines

Gregory Matloff, Adjunct Associate Professor at New York City College of Technology and co-author of The Starflight Handbook

C Bangs, artist and author of numerous books on space topics

Ian Crawford, Professor of Planetary Science and Astrobiology at Birkbeck, University of London

John Davies, Editor of Principium

Marshall Eubanks, founder of Asteroid Initiatives LLC, formerly at JPL and US Naval Observatory

Carl Murray, Professor of Mathematics and Astronomy in the School of Physics and Astronomy at Queen Mary, University of London

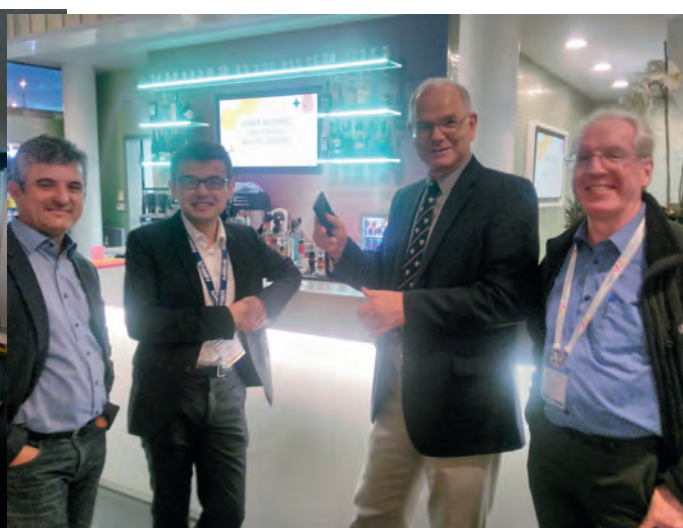
David A Hardy, the longest-established living space artist in the West (December 2018)

International Astronautical Congress 2018, October, Bremen

The interstellar presentations at this, the big show of the Astronautical year, are reported in a major item in this issue of Principium but these events are often as important for the connections made and the informal exchange of knowledge which always takes place. Below are a couple of pictures illustrating i4is activity.



Andreas shows Terry Regan's two models of the Andromeda probe



Angelo Genovese, Andreas Hein, Rob Swinney and Patrick Mahon

Cospar 2018, July, Pasadena

Kelvin F Long, i4is researcher and co-founder, spoke on *The Prediction of Particle Bombardment Interaction Physics due to Ions, Electrons and Dust in the Interstellar Medium on a Gram-Scale Interstellar Probe*. He estimated that dust particles of mass $M \sim 10^{-16}$ kg (about the mass of the average bacterium!) and velocity $v \sim 0.15c$ (15% of the velocity of light) would produce impact energies of $\sim 10^{11} - 10^{12}$ MeV (nearly one joule or about one watt-second).

Much work has been done, starting with work on the 1970's BIS Daedalus study but gram scale

probes like the Breakthrough Starshot ideas are looking closer to feasibility and the impact of particles of all types at the velocities envisaged requires much further study.

Interstellar Probe Exploration Workshop, October, New York City

Kelvin also addressed this workshop at the illustrious Explorers Club in New York (famously the place where Thor Heyerdahl planned the Kon-Tiki expedition). His subject was Measurement of Dust in the Interstellar Medium for Interstellar Probes. He outlined a mission to about 100 AU (well into the Kuiper belt) that would use x-ray radiographs to image interstellar dust grains.

BIS West Midlands Space Day, October, Worcester

Marc Casson introduced i4is to visitors to Space Day. This was a major event of Space Week 2018 and our stall was one of 42 including major organisations such as Liverpool John Moores University, The Institution of Mechanical Engineers (IMechE), the Rocket Propulsion Establishment Westcott and major BIS figures including Mark

Hempsell, Gill Norman, Vix Southgate, Stuart Eves and David Hardy. A special welcome to all those who requested a subscription to Principium at this event.

Room Magazine

i4is Executive Director Andreas Hein contributed an article to Issue #2(16) 2018 of the space journal, Room (room.eu.com), *Flying to the Stars*.

i4is and Space in Scotland

i4is has strong connections in Scotland. Not only is most of our membership implementation team based there (in Glasgow and St Andrews) but

we are in good touch with BIS Scotland who are headquartered in Edinburgh and Glasgow but whose reach extends well to the north. For example, one of the principals, Matjaz Vidmar of the University of Edinburgh spoke on *From Standing Stones to Blasting Rockets: Scotland is Off to Space!* to Moray's Astronomy Club – SIGMA in Birnie Village Hall in Thomshill, Elgin. And our board member Richard Osborne is now Programme Manager at Skyrora, based in Edinburgh. New launchers in Scotland!

2018 ISU Thesis Projects

Each year the i4is proposes technical subjects that constitute individual thesis projects for the ISU Masters of Space Studies students. These are subjects for which i4is have an interest or believe are important to the technological and strategic roadmap of interstellar flight. Although the ISU will assign a formal academic supervisor to the thesis we appoint members of our team to act as expert external advisors. We have been building on this collaboration for several years now and this year (2017/2018 Academic Year) we have helped students with ISU/i4is Individual Thesis projects on these subjects. Two of them presented their results at the IAC 2018 conference (reported elsewhere in this issue). All three are listed here -

Ana Cristina Baltazar Garduño, "Laser-Powered Electric Propulsion for Interstellar Precursor Missions" External Advisor Angelo Genovese. Presented at IAC, 2018, Bremen

Abstract - <https://iafastro.directory/iac/paper/id/47501/abstract-pdf/IAC-18,D4,4,4,x47501.brief.pdf>

Zachary Burkhardt, "Glowworm: Demonstrating Laser Sail Propulsion in LEO", External Advisor Nikolas Perakis

Paper: www.researchgate.net/publication/328202365_Project_Glowworm_Testing_Laser_Sail_Propulsion_in_LEO



Angelo ponders a question at Euro Mars Soc

Wenjing Hu, "A Minimal Chipsat Interstellar Mission: Technology and Mission Architecture" External Advisor Elena Ancona, Presented at IAC, 2018, Bremen

abstract - <https://iafastro.directory/iac/paper/id/46958/abstract-pdf/IAC-18,B4,8,16,x46958.brief.pdf>

Artificial Intelligence for interstellar travel

The i4is team have long taken an interest in the application of Artificial Intelligence to interstellar objectives. The most recent result of this, and perhaps the most substantial so far, is now published

Artificial Intelligence for Interstellar Travel, Andreas M Hein and Stephen Baxter

<https://arxiv.org/pdf/1811.06526.pdf>

It's the result of two years of collaborative work by Andreas Hein, our executive director and SF author and physicist Stephen Baxter. We congratulate Stephen and Andreas on this very substantial piece of work (35 pages and 134 references). We'll be featuring a more widely-accessible summary of their research and conclusions in a future issue of Principium.

European Mars Society Convention, October, Switzerland

Angelo Genovese, Thales Deutschland and i4is Director of Experimental Programmes, spoke at the European Mars Society Convention, 26-28 October 2018, at the Musée International d'Horlogerie in La Chaux-de-Fonds, Switzerland. His subject was [Advanced Electric Propulsion for Fast Manned Missions to Mars and Beyond](#).

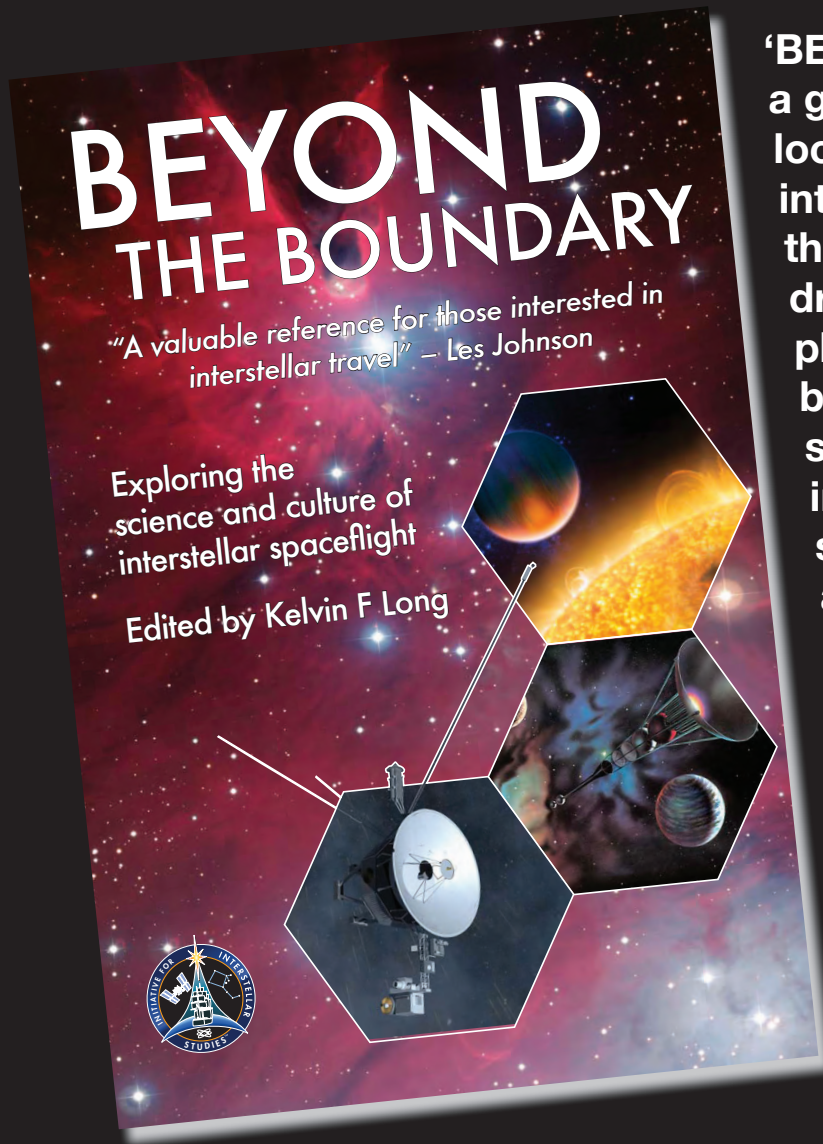
Pictures below (credit Mars Society Switzerland) show Angelo confronting his audience and attending to the conference our old friend and colleague, Sam Harrison, formerly of the i4is board.



Angelo and Sam Harrison at Euro Mars Soc

THE INITIATIVE FOR INTERSTELLAR STUDIES

PRESENTS



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



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



www.i4is.org

NEWS FEATURE - Starship Engineering

First Five Day i4is Summer School

Authors: Rob Swinney, Kelvin F Long and John I Davies

The world's first ever dedicated interstellar summer school was held at the Initiative for Interstellar Studies HQ, The Bone Mill, in Gloucestershire UK from Wednesday 15th to Sunday 19th August 2018. A small select group of students attended the summer school and their response to the course and commitment to their team project made it a complete success.



Rob with students Angelo Bellofiore, Jamie Bockett, Mike Swain

The i4is course leaders set them workshop problems such as solving the Tsiolkovsky equation for a number of cases. We went through the Marshall Savage 8 steps for colonising the galaxy and looked at aspects of a redesign of Daedalus, the first and still most complete interstellar spacecraft design.

In addition to the course material, each day the students had a session to work as a team on a complete Interstellar Precursor Probe concept, with a mission requirement -

- a 1,000 AU mission in 50 years travelling at 20 AU/year
- a payload mass delivered to the target not exceeding 500 kg.

This was inspired by the Thousand Astronomical Unit (TAU) mission that JPL looked at in the 1990s, a mission distance now being revisited by Johns Hopkins University Applied Physics Laboratory under contract from NASA, in response to the Congressional 2069 'interstellar' mission.

The team worked at an increasing rate on the project, beginning on day 1 with a briefing on the project and their first team meeting about it.

On day 2 they worked together for 2 hours and on day 3 they had a deep dive session at the Mill planned for around 3 hours although finishing around 10 pm.

On day 4 we had planned a relaxing social evening but team enthusiasm won out and they had a further deep dive session of around 3 hours, finally relaxing with the course leaders over a few movie clips.

On the final day the team had had around 2.5 hours to pull their presentation together. In the total of around 12 hours team time they had produced an outline solution.

This was in addition to doing substantial lectures and solving other workshop problems on each of the 5 days.

The team presented their results on that last day including a system architecture description, graphics to illustrate their ideas, and a description of the main spacecraft systems. They also costed the mission and suggested the launch system with a description of the mission trajectory. Finally the course leaders asked them to describe the ideas that they had considered but rejected.

The course was developed and delivered by Kelvin Long and Rob Swinney, with contributions from John Davies at The Mill and Dan Fries and Andreas Hein by video.

A draft paper "Amerigo: A 1,000 AU Interstellar Precursor Mission Study From the i4is Starship Engineer Summer School Class of 2018" is already in draft and publication is planned for next year. We will have more about this in the next issue of Principium.

We aim to run a similar course next year. Get in touch with us via ssengss2019@i4is.org to express an interest.

NEWS FEATURE -

Holographic Photon Sails: A Merger of Science and Art

Co-Presenters: Dr. Greg Matloff, Science Board i4is, FBIS, Member IAA, Hayden Associate AMNH, Prof. Physics NYCCT / CUNY, Proj. Starshot Advisor

C Bangs, Artist, Represented by Central Booking Art Space NYC, Former NASA Faculty Fellow

We are indebted to Kelvin F Long for an account of this public lecture at our HQ, The Mill on 29 September 2018. Adapted here by John I Davies.

Holograms apply the interference of two collimated light beams to produce three-dimensional images on a two-dimensional surface of selected objects. A hologram of an optical element, for instance a lens, will behave optically in the same manner as that lens. The late Dr Robert Forward realised before 2000 that holographic surfaces could be used for application in solar sailing. It is very difficult to use a conventional sail to escape Low Earth Orbit (LEO). But, since the orientation of the light source is significant in a hologram's reflective efficiency, a sail with a holographic coating could be designed so that sunlight behind it is reflected and sunlight in front of it is transmitted, which will result in an increase in the sail's orbital energy and ultimate escape. Forward arranged in the summer of 2000 for NASA Marshall physicist/manager, Les Johnson to fund artist C Bangs on Greg Matloff's University Grant to produce a prototype holographic interstellar message plaque to demonstrate to the NASA staff the propulsion possibilities of holography. The resulting commissioned art work has been described in a NASA report and elsewhere. In 2016, Matloff was appointed to the Advisor's Board of Project Starshot. The goal of this effort is to propel a wafer-sized spacecraft massing a few grams to $\sim 0.2c$ using a ~ 50 - 100 GW laser mounted on a terrestrial mountain top.

The laser is pointed at Alpha/Proxima Centauri and the spacecraft is deployed at the apogee of a very elliptical Earth orbit. Very high sail reflectivity is necessary as is tolerance to accelerations of about $5,000$ g. Also, the sail must have an appropriate shape to remain within the moving beam during the minutes-long acceleration run. One way to satisfy these requirements is to create a hologram of an optical element that is highly reflective to the laser wavelength and to emboss this hologram on an appropriate temperature tolerant thin film. The optical element should be shaped to be stable within the beam. Bangs and Martina Mrongovius, Creative Director of the Holocenter have submitted a proposal in response to an RFP from the Starshot Sail Committee. Mason Peck of Cornell University, who is on the Starshot Advisors Board, has been funded to deploy wafer-sized spacecraft dubbed Sprites from CubeSats in LEO. Bangs and Mrongovius are creating six holograms to be flown in space on a Cornell CubeSat, to be launched within the next year. It is planned that each Project Starshot wafer-sized spacecraft will have a message plaque mounted on the space-facing sail face. Holographic message plaques on these craft could be very low in mass and contain vast amounts of information describing terrestrial life to hypothetical extraterrestrials.



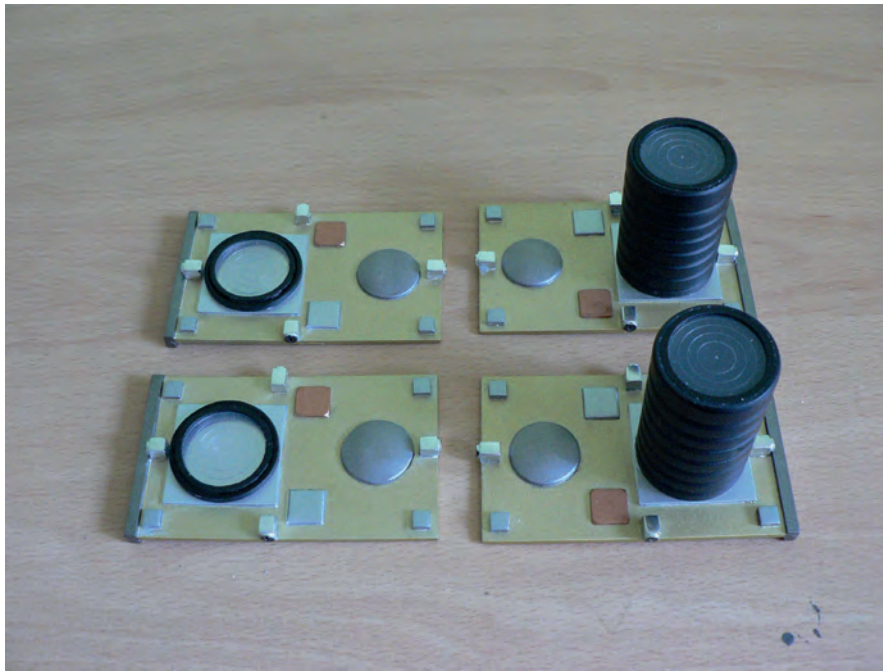
C Bangs (left) and Greg Matloff (right)

NEWS FEATURE -

The Andromeda Probe Models

John I Davies (words) and Terry Regan (pictures)

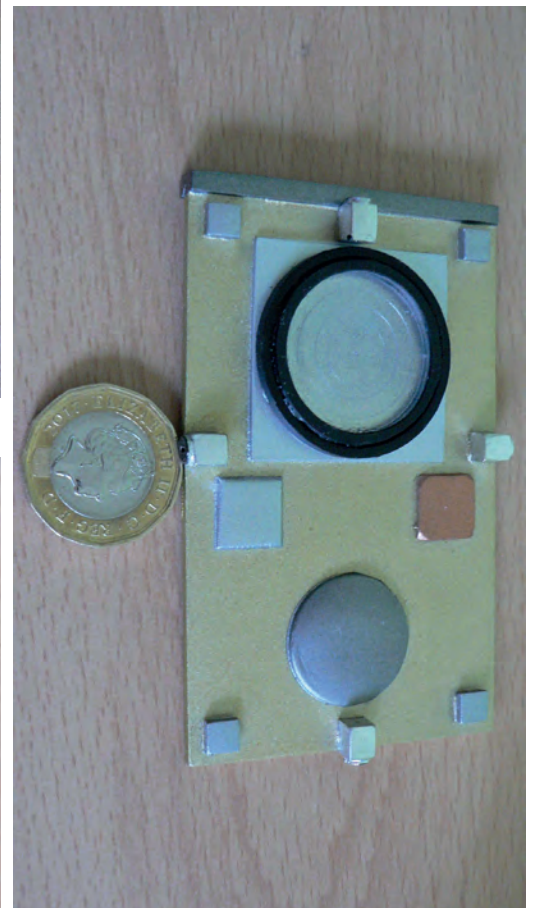
Principium readers will be familiar with the Andromeda study, conducted by an i4is technical team in March 2016 to design a Gram-scale interstellar probe to be sent to the nearest stars at 0.1c using current or near term (up to 20 years) technology, and delivered to Breakthrough Starshot. The final report was "Initial Considerations for the Interstellar (Andromeda) Probe: A Three Day Study". Our i4is model maker, Terry Regan has produced models of the probe. They show the probe with the camera lens extended and with the lens retracted. The photos here show them with a one pound coin (it's a similar size to the euro coin) and a ruler.



All four Andromeda probe models together. Two with lenses extended and two retracted



Probe with metric rulers to show size



Probe with lens retracted an £1 coin for scale

BOOK REVIEW: The Planet Factory

Elizabeth Tasker (Bloomsbury Sigma, 2017)

Patrick J Mahon

Our Deputy Editor reviews a detailed study of how planets come to exist.

When I first got interested in astronomy and space exploration as a child growing up in the 1970s, humanity only knew of the nine planets (as they were then) of our own solar system. It took until the mid-1990s for astronomers to find the first definite evidence of a planet orbiting a star other than our own Sun – an exoplanet, as they are known.

However, such is the pace of progress in space science that a mere quarter of a century later, around 3,500 exoplanets have now been discovered, with that number rising higher every year. How have we found these distant worlds, what do we know about them, and what – if anything – might that tell us about the likelihood of finding life elsewhere in the universe?

‘The Planet Factory’, a 2017 popular science book by Dr Elizabeth Tasker [1], a British astrophysicist who works for JAXA, the Japanese Space Agency, aims to answer these questions and many more. I was lucky enough to meet Dr Tasker when she launched her book with a lecture at the British Interplanetary Society’s headquarters in September 2017, and can attest to her evident expertise and enthusiasm for the subject.

The book starts by recalling how the first exoplanet was discovered in 1994 by a pair of French astronomers, Michel Mayor and his graduate student Didier Queloz, using the radial velocity technique, where the presence of an orbiting exoplanet is detected by measuring minute but regular changes in the parent star’s redshift. The redshift tells you how quickly the star is moving towards or away from the Earth, but the changes in that redshift indicate that the star is wobbling back and forth as it, and an exoplanet, orbit around their mutual centre of mass. Such wobbles are likely to be small, as planets weigh so much less than stars. For example, the most massive planet in our own solar system, Jupiter, weighs roughly one thousand times less than the Sun, so its ability to put a wobble in the Sun’s movement is pretty limited. However, if a gas giant of around Jupiter’s size orbits much

closer to its parent star, the wobble in the star’s orbit will be larger. That was the case here, and Mayor and Queloz announced in 1995 that they had discovered 51 Pegasi b, an exoplanet around half the size of Jupiter, but orbiting the star 51 Pegasi more closely than Mercury orbits our Sun, so that its orbit lasted only four days!



Elizabeth-Tasker
credit BIS

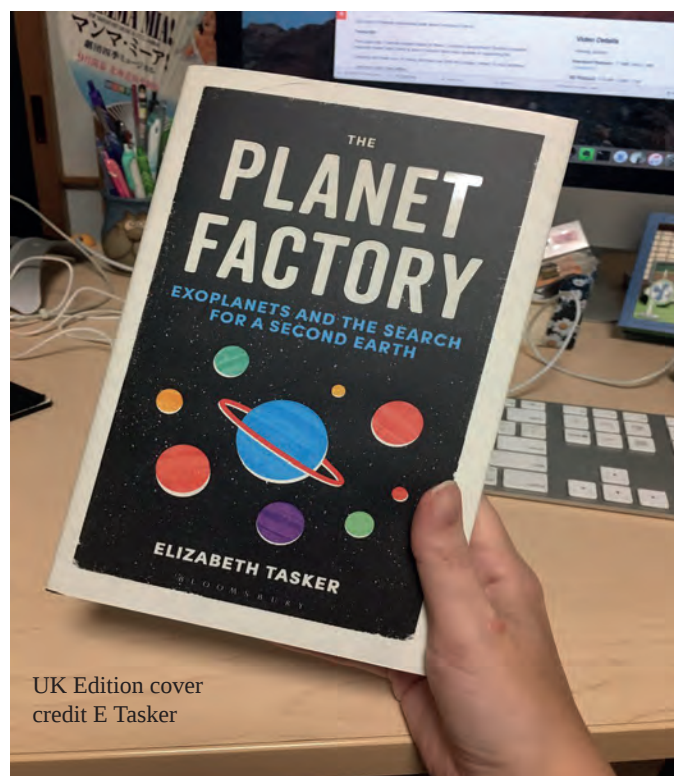
Within four years, a second technique had been added to exoplanet hunters’ armouries. The ability to measure the amount of light coming from a star got precise enough to be able to notice the small dip in the light curve when a large exoplanet crossed the face of its star while orbiting it. This is a much less dramatic version of what happens when our Moon’s orbit takes it in front of the Sun from the perspective of an observer on Earth, giving that observer a solar eclipse. This so-called transit technique increased the rate of exoplanet discoveries significantly.

However, as we will see throughout the book, the difficulty of measuring these tiny changes, whichever technique is used, does lead to a huge problem with measurement bias across the entire field of exoplanet studies. To take an analogy, if I

was a short-sighted alien that wanted to establish what sort of creatures moved around the surface of the Earth, but my equipment could only detect objects that were more than five metres long and travelled faster than 50 kilometres per hour, then the only things I would be able to see would be trucks, lorries and aeroplanes. I would see neither cars nor humans nor supertankers, and it's likely I would draw some very misleading conclusions from these findings – unless I was aware of the limitations of my equipment and kept them in mind throughout. In the same way, I think it's important for readers of this book to keep constantly in mind the fact that it's a lot easier to detect a large exoplanet orbiting very close to a small star than it is to detect a small exoplanet orbiting far away from a large star. The small planet may well be there; we just don't have the ability to detect it yet.

Tasker splits her book into three main sections, which in turn explore how solar systems form, the wide diversity of exoplanets that have been discovered to date, and the conditions under which an exoplanet might be able to harbour some kind of life.

Part One of the book includes four chapters on the early history of a model solar system, based on observations from our own, finished system and from protoplanetary discs in various stages of formation around other stars. We quickly encounter a major problem: protoplanetary discs only appear around stars that are less than ten million years old. That may sound like a long time in human terms, but if your task is to get dry dust grains that are about a millionth of a metre in size to stick together repeatedly, until you're left with a spherical planet at least one thousand kilometres in diameter, and perhaps much bigger, doing it in that timescale is a serious challenge. Tasker sets out our current theories on how this might happen, covering the evolution of the solar nebula, the mechanisms for creating the cores of planets, how you then add atmospheres – which leads to a clear differentiation between rocky terrestrial planets, sitting closer to their host star, and massive gas giants further out, beyond the 'ice-line' (where water & other volatiles freeze) – and finally the tricky question of where all of Earth's life-giving water has come from, given that the proto-Earth should have been too hot to contain much water, sitting well inside the ice-line. The conclusion of Part One seems to be that the formation of our own solar system is tricky to explain, but the theoretical models that have been developed can just about do the job.



UK Edition cover
credit E Tasker

Part Two of the book then shows how the first few exoplanets to be discovered threw a massive googly* into these carefully developed theories. This partly comes back to the problem of measurement bias that I mentioned above. The earliest exoplanets to be discovered were bound to be unusual – huge gas giants orbiting ridiculously close to their star – otherwise we wouldn't have been able to detect them. Our theories, on the other hand, were based on the single data point of our own solar system, which contains no such oddities. It's therefore not that surprising that theory and observation didn't match in this case. However, that still left a big question to be answered. How could these so-called 'hot Jupiters' exist?

The most popular theories all involve such exoplanets forming further away from their stars, beyond the ice-line, so that they can build their huge gaseous atmospheres from frozen ice. Once fully formed, they then migrate inwards to their present positions. This explanation initially sounded pretty contrived to me, but Tasker explains how computational models of the evolution of such systems clearly demonstrate that the interactions between the proto-planets and the surrounding solar nebula can lead to a migration of large planets inwards.

The next chapter moves beyond the one percent of stars that host a 'hot Jupiter' to the nearly fifty percent of solar systems that contain a so-called 'super-Earth'; that is, a planet between the size of

* editors note: cricket metaphor.

[en.wikipedia.org/wiki/Delivery_\(cricket\)](https://en.wikipedia.org/wiki/Delivery_(cricket))

Earth and Neptune, but which orbits its star even more closely than a hot Jupiter does, ie well inside the orbit of Mercury! Measurement bias once again tells us why we see such odd exoplanets first. However, given their existence, that leaves three obvious questions: how did they form, where did they form, and why doesn't our own solar system have one if they're so common?

Tasker first establishes what sort of planets we're talking about here, sharing a rule of thumb that has been developed from the thousands of observed exoplanets to date: smaller super-Earths, having a diameter no more than fifty percent larger than the Earth's, are expected to be solid, rocky planets like Earth or Mars. Any larger than this and your super-Earth will most likely be a gas giant. Whatever their size, though, it remains difficult to explain how they migrate inwards from wherever they formed, and end up orbiting so close to the star without actually falling in.

Turning to the question of why there's no super-Earth inside Mercury's orbit in our own system, it appears that the orbital resonance between Jupiter and Saturn – Saturn orbits twice as far from the Sun as Jupiter, and takes three times as long to complete one orbit as Jupiter does – is responsible for having stopped any super-Earths from migrating past them into the inner solar system. However, Tasker is careful to point out that many aspects of super-Earth formation and evolution remain unclear, requiring further data to refine the current models.

Chapter Seven provides some examples of the most unusual exoplanets that have been discovered to date, including rocky planets covered with exotic phases of water, worlds made almost entirely from diamonds, and those that are completely covered in volcanoes, much like Jupiter's innermost Galilean moon, Io. The point of this chapter, I think, is to indicate just how diverse exoplanets can be, in order to help readers avoid the temptation to assume that all of them are bound to resemble one or other of the planets in our own solar system.

Chapters Eight and Nine switch the focus from exoplanets that are unusual themselves, to exoplanets in unusual solar systems. The first example is of planets orbiting millisecond pulsars. A millisecond pulsar is the remnant of a star that, at the end of its life, has collapsed down from a similar size to our own Sun to a ball around 10 kilometres in diameter, with all its mass turning into tightly packed neutrons. This incredibly dense neutron star rotates hundreds of times every second,

throwing out huge amounts of high energy radiation along its polar axis. The interesting thing here is that millisecond pulsars are expected to be young, because they lose energy so quickly through their polar emissions, slowing down as a result. Yet the ones that have been observed are old, and don't seem to be slowing down at all. Astronomers have theorised that this is because they are the visible half of a binary system, and the other star is losing mass to the huge gravitational pull of its tiny neighbour, spinning it up in the process. In any case, the timing stability of these pulsars makes it easy to spot exoplanets orbiting them, because the presence of an exoplanet messes with the timing of the pulsar's emissions, adding a tell-tale wobble. Several have been observed, but the jury is still out on the follow-up question: how is it possible that such a planet could survive the dramatic changes in their parent star? Yet survive they have.

Slightly less dramatic, the next chapter considers exoplanets in binary star systems. This will immediately bring to mind for many readers Luke Skywalker's home planet of Tatooine in Star Wars. For a long time, it was expected that any planetary orbits in a binary star system would be unstable in the long term. However, now that the Kepler Space Telescope has detected a few, theorists have revised their models and decided that stable orbits are possible after all. So well done to George Lucas!

The final two chapters in Part Two cover exoplanets in unusual orbits. Tasker first considers what can happen to push an exoplanet into a highly eccentric, and/or highly inclined orbit, rather than a nice circular orbit in the rotational plane of its parent star. The simplest explanation is a close encounter with a large mass like Jupiter, which flings the victim into a new and unusual orbit. However, this explanation sometimes doesn't work, and Tasker patiently explains the alternatives that theorists have come up with. She then ends this part of the book by considering what happens if such disturbances are so severe that they eject the exoplanet from its solar system completely. Without a parent star to orbit around, such 'rogue' exoplanets are extremely difficult to detect, but a few candidates have been identified in recent years, using the Pan-STARRS telescope and through gravitational microlensing. One team has estimated that our galaxy could potentially contain twice as many rogues as there are stars! Tasker ends by considering what such rogue exoplanets might be like. Would they all be cold and dead, or might it be possible for some of them to retain heat, an atmosphere and even,

perhaps, surface water?

That discussion nicely tees up Part Three of the book, whose six chapters consider the conditions that might enable an exoplanet to harbour life. Tasker starts by considering the conditions that will be needed for an exoplanet to be 'Earth-like', since the Earth clearly is capable of supporting living creatures. The key issue is to be in the parent star's 'habitable zone' (Tasker prefers the term 'temperate zone'), which is the range of distances from the star at which a rocky exoplanet on a near-circular orbit would be warm enough for any surface water to exist as a liquid. (This presupposes the existence of an atmosphere, so that the water doesn't just boil off into space.)

Although this tends to be the only variable referred to in popular science articles reporting on the discovery of yet another 'Earth 2.0', Tasker explains that a realistic assessment of the situation requires a little more consideration. Other issues that are crucial to the ability of an exoplanet to support living organisms include the size and composition of its atmosphere, the extent to which plate tectonics are active, the existence of a magnetic field, and the type, age and luminosity of its parent star. Tasker illustrates these points with multiple examples of exoplanets which some have dubbed as the next Earth, most of which she suggests would fail these other tests.

In the next chapter, she broadens the discussion beyond 'Earth-like' exoplanets. She suggests that other options that could still potentially be habitable might include worlds completely covered by oceans, gas giants that have migrated into the temperate zone (which inevitably brings to mind Arthur C Clarke's 1971 novella 'A Meeting with Medusa'), tidally-locked 'eyeball' planets, where life might be possible in the permanent twilight zone between the day and night sides, and even circumbinary planets (like Tatooine in Star Wars). The chapter concludes by considering what might make an exoplanet 'super-habitable' – in other words, better than our Earth at sustaining life.

Having addressed the habitability of exoplanets, Tasker then moves on to exomoons – that is, moons orbiting exoplanets. Given that our solar system contains only eight planets, and yet Jupiter has 79 moons (at the last count), several of which have turned out to be far more active and interesting than had been expected, prior to the Voyager fly-bys, might the same be true for some exoplanets? Is it possible that some of them have their own moons?

If so, might these be potential locations for alien life? Tasker motivates the discussion by considering the most interesting features of moons in our own solar system, including the volcanoes of Io, the subsurface ocean of Europa, the hydrothermal vents on Enceladus, and the thick atmosphere that encircles Titan. These features illustrate the diversity of environments to be found on our moons, and the surprisingly high levels of energetic activity found on several, despite them being located well outside the supposedly vital temperate zone.

Starting from the experience of our own backyard, the next chapter considers the conditions likely to be needed if an exomoon is to be habitable. Probably the most challenging condition is to be heavy enough, so that it can hold on to a substantial atmosphere. This probably requires a moon with a similar mass to Mars. Only one of the moons in our own solar system satisfies this criterion: Titan. So how do you produce a large moon? She suggests that the most likely solution is for it to form around a large hot Jupiter, during its early life outside the ice-line, and then to stay with the exoplanet as it migrates towards the inner solar system. This also has the potential advantage of ensuring the exomoon includes a lot of frozen water, useful for later habitability.

Tasker concludes this chapter by noting that, at the time of writing, no exomoons had been detected, although many teams were looking for them. It's therefore a pleasure to be able to bring things up to date by noting that a paper announcing the first candidate exomoon was published by Alex Teachey and David Kipping in *Science Advances* just last month [2].

Tasker concludes her survey of exoplanet studies with a thought experiment. Suppose we identify a potentially habitable exoplanet (or exomoon). How will we prove, beyond reasonable doubt, that life is present on it? A team led by Carl Sagan decided to test their approach on the only planet we know to definitely harbour life – our own Earth – in the early 1990s, using the Galileo spacecraft. This was headed to Jupiter, but via a roundabout route which enabled them to train all of Galileo's scientific instruments back at the Earth to see what signs of life they could detect. This experiment showed what a challenge it is, because several of the most obvious biomarkers, such as oxygen and methane, can also be created inorganically, and ruling those non-biological origins out is tricky. Any

confirmation of extraterrestrial life will therefore probably have to be done on the basis of multiple independent measurements, all of which point towards the same conclusion, with alternate non-biological explanations ruled out by one or other of them.

This is a book that is filled with detail, and that is simultaneously its biggest strength and weakness. On the plus side – and it’s a big plus – I felt throughout that I was getting the full picture from Dr Tasker. She doesn’t sweep anything under the table, to avoid having to deal with an issue deemed ‘too complicated’. That’s not always the case with popular science books, so it’s a pleasure to acknowledge an author who believes in the intelligence of her readers, and sets herself the task of presenting them with the whole picture. Her use of diagrams and analogies also helps to communicate many of the more abstruse ideas we come across.

At the same time, there are one or two parts of the narrative where the explanations are a little too long and dry. In these instances, I found myself getting lost in the technicalities, and had to re-read the last few pages to clarify what Tasker meant. However, these were definite outliers, compared to the majority of the text.

For readers of *Principium*, the information provided in this book should prove enormously interesting. As we work towards having the capability to send tiny scientific probes off towards the Alpha Centauri triple star system and its exoplanets, having a comprehensive understanding of the huge variability in exoplanet morphology should prove

extremely useful to those designing future missions of exploration.

‘The Planet Factory’ provides an excellent introduction to, and survey of, the current state of play in the field of exoplanet studies. Elizabeth Tasker is a skilled communicator who has managed to bring a young and extremely complex field of study to life for non-specialists. Highly recommended.

References:

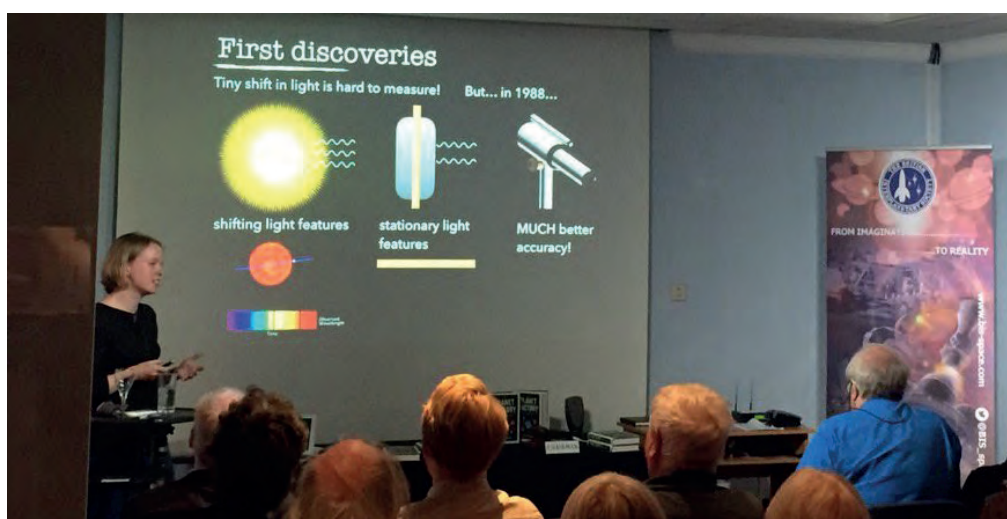
[1] ‘The Planet Factory: Exoplanets and the Search for a Second Earth’, Elizabeth Tasker, Bloomsbury Sigma, September 2017.

[2] ‘Evidence for a large exomoon orbiting Kepler-1625b’, Alex Teachey and David M. Kipping, *Science Advances* 4(10), eaav1784, 3 October 2018.



The Planet Factory has been published in Australia, USA, Japan and other countries. Here is the cover of the Polish edition.
Credit: Prószyński Media

Elizabeth Tasker talk and book launch, 7 September 2017 at British Interplanetary Society HQ, London,
Credit: BIS photo



About the Reviewer

Patrick is a physicist working in the waste and recycling sector. He is a long-committed space enthusiast who enjoys the challenges of interstellar science and technology presented by *i4is*. He is a regular contributor to *Principium* and is its Deputy Editor.

News Feature : 69th International Astronautical Congress 2018

The Interstellar Papers

Reported by Patrick J Mahon and John I Davies

The 69th IAC in Bremen 1-5 October was a massive and impressive event. Out of the thousands of presentations we could only schedule coverage of papers by the Initiative for Interstellar Studies (i4is) team & others of interstellar interest. Even so, we did not catch them all and we have been helped by accounts from other people associated with i4is. And we did see some of the rest of the show! Here is a brisk trot through what we saw and heard. We will treat some of them in a bit more detail in other News Features in this and later issues of Principium.

We distributed a single sheet timetable of interstellar-related topics at the event and included it in print issues of Principium 23 which we also handed out to all interested parties.

The quoted links to papers are accessible to all IAC 2018 participants. There are also copies of presentations in the same place. We have looked for versions of the papers on open access and quoted links where we found them. Please get in touch via Principium@i4is.org if you find more.

We must thank the IAF Media Office for press access to the Congress. Delegate fees would have been a significant expense in addition to the usual travel and accommodation overheads, which we both donated personally. This has been normal practice since the foundation of i4is; we are and will remain a very low-overhead organisation. Image credits - i4is, paper authors and IAC.

Evolving Asteroid Starships: A Bio-Inspired Approach for Interstellar Space Systems

Monday 1 October	IAC reference: IAC-18/D1/1
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Angelo Vermeulen, TU Delft, Netherlands

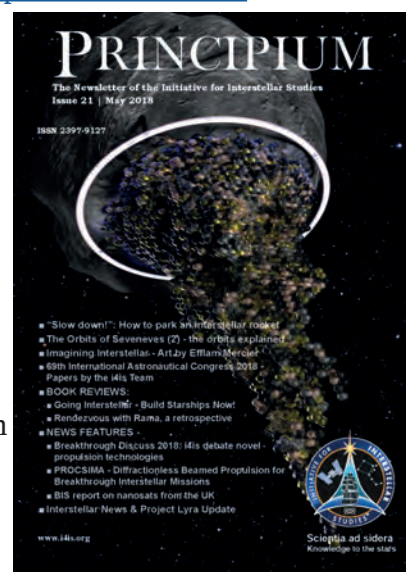
IAC paper: iafastro.directory/iac/proceedings/IAC-18/IAC-18/D1/1/manuscripts/IAC-18,D1,1,2,x45184.pdf

IAC presentation: iafastro.directory/iac/proceedings/IAC-18/IAC-18/D1/1/presentations/IAC-18,D1,1,2,x45184.show.pptx

Open paper: www.researchgate.net/profile/Angelo_Vermeulen/publication/328307121_Evolving_Asteroid_Starships_A_Bio-Inspired_Approach_for_Interstellar_Space_Systems/links/5bc5b68fa6fdcc03c789052a/Evolving-Asteroid-Starships-A-Bio-Inspired-Approach-for-Interstellar-Space-Systems.pdf

Angelo explained why the hostile and unpredictable environment of deep space requires a new conceptual approach for interstellar flight, one that differs radically from any current design in aerospace. His team proposes a starship attached to a C-type asteroid (carbonaceous, the most common type) and whose architecture evolves over time. They propose using a form of additive manufacturing (3D printing) using the material of the asteroid (ISRU - in-situ resource utilisation, see also *Adaptive in-situ resource utilisation (ISRU) for long term space exploration*, Shergill, below).

Distributed building and an evolutionary approach allow the whole craft to confront hazards such as radiation and particle impact. Life support thinking builds on the regenerative closed loop systems such as ESA's long



Principium Issue 21 cover with TU Delft visualisation
Courtesy Angelo Vermeulen

established Micro-Ecological Life Support System Alternative (MELiSSA) - www.esa.int/Our_Activities/Space_Engineering_Technology/Melissa.

The team are simulating their proposed architecture based on an initial human population of 100 with a number of simplifications at the present stage. Simulations run on timelines addressing the dynamic state regenerative ecosystem (including radiation impact), growth starship architecture (including mining and wear), anticipated interstellar medium impact (on ecosystem and architecture) and evolution of starship architecture (nested simulation). They use a multi-method simulation modelling tool, AnyLogic (www.anylogic.com) which supports simulation techniques including agent-based modelling (ABM) of the regenerative life support system, discrete event system specification (DEVS) of travel time, impact events, differential equation system specification (DESS) of asteroid mining, 3D manufacturing and genetic algorithms for reconfiguration of the spacecraft layout.

Questions ran to the limit of the timetable and Kelvin Long of i4is offered to communicate present knowledge of the interstellar medium (ISM) to Angelo.

Reported by: John Davies

Interstellar Probes: The Benefits to Astronomy and Astrophysics

Monday 1 October	IAC reference: IAC-18,A7
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Kelvin Long, i4is

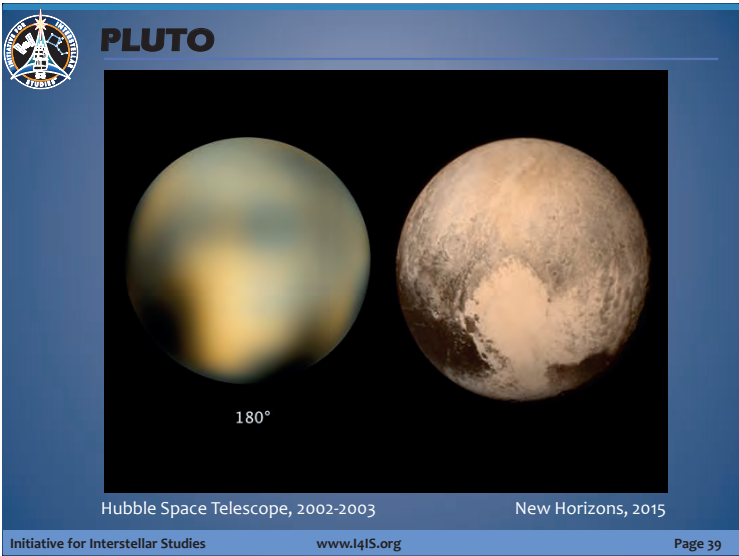
IAC paper: iafastro.directory/iac/proceedings/IAC-18/IAC-18/A7/1/manuscripts/IAC-18,A7,1,7,x43106.pdf

IAC presentation: iafastro.directory/iac/proceedings/IAC-18/IAC-18/A7/1/presentations/IAC-18,A7,1,7,x43106.show.pdf

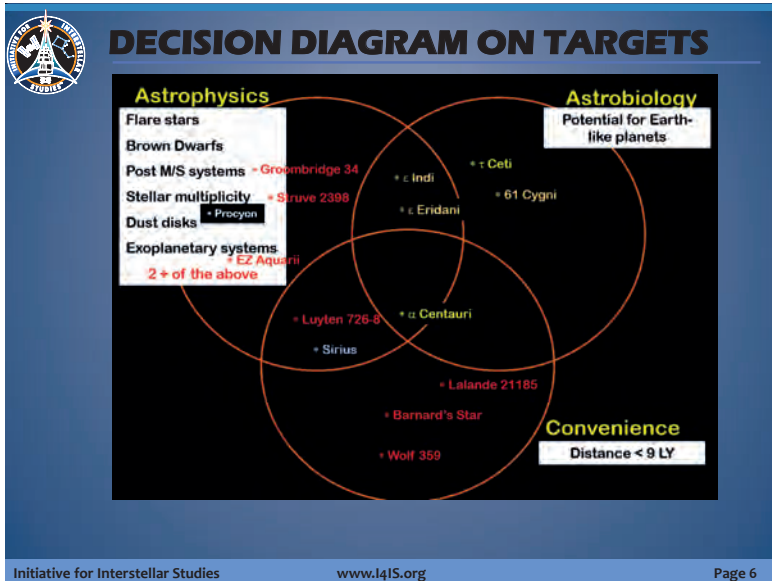
Open paper: not available

Kelvin discussed the scientific benefits that could be derived from sending robotic probes into interstellar space, in parallel with remote observation using space-based telescopes. Targets for such probes might include not only the nearest stars and any exoplanets around them but also the Kuiper Belt, Oort Cloud and the local interstellar medium. Such probes could enable in-situ measurements of many astrophysical phenomena, and could lead to huge advances in astrometry, accurately determining the distances to huge numbers of stars through ultra-long baseline parallax measurements. They could also allow detailed tests of relativity theory. Similarly, sending probes to exoplanets in their star’s habitable zone would enable astrobiological investigations, looking for the biosignature of extraterrestrial life.

The easiest probe missions would involve a flyby of the target. More complex missions could include orbiters, landers and even sample-return missions. Kelvin discussed large versus small spacecraft, considering the Voyager probes at the upper end, and at the lower end, i4is’s 420 gram Andromeda Probe concept, and Breakthrough Starshot’s proposal for laser sail-powered nanocraft weighing less than one gram, and accelerated to 20% of the speed of light. Starshot has identified 19 key challenges that will need to be overcome first. One benefit of the Starshot approach is that once the Earth-based laser infrastructure is in place, you can send thousands of tiny probes out in swarms to multiple targets. The challenges are huge,



Comparison of images from near-Earth and fly-by probe
Credit: K F Long



but comparing Hubble's best photo of Pluto with the images taken by the New Horizons spacecraft gives an indication of the potential value of 'going there'.

Reported by: Patrick Mahon

Science yield versus engineering challenge
Credit: K F Long

Long duration Genesis-type missions to exosolar planets

Monday 1 October	IAC reference: IAC-18,A7,1
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Claudius Gros, U of Frankfurt am Main, Germany

IAC paper: iafastro.directory/iac/proceedings/IAC-18/IAC-18/A7/1/manuscripts/IAC-18,A7,1,8,x42389.pdf

IAC presentation: iafastro.directory/iac/proceedings/IAC-18/IAC-18/A7/1/presentations/IAC-18,A7,1,8,x42389.show.pdf

Open paper: not available

In recent years, Professor Gros has been thinking of very long duration missions to kick-start evolution in the galaxy. He aims to demonstrate that his Genesis ideas are feasible and offer our species a new perspective of the cosmos. He is quite explicit that they offer no benefit for humanity (Developing ecospheres on transiently habitable planets: the genesis project, in *Astrophysics and Space Science*, October 2016, link.springer.com/article/10.1007/s10509-016-2911-0).

He began his presentation with some ideas for reaching interstellar destinations based on laser-push ideas from Lubin's group at UCSB and his own ideas for decelerating using a magnetic sail (see "*Slow down!*": *How To Park An Interstellar Rocket*, Tishtrya Mehta, *Principium*, Issue 21, May 2018 for an introduction to these ideas). For very long duration missions such as envisaged by his Genesis ideas (0.3% c and 1000s of years duration) it is possible to decelerate using a passive magnetic loop, dumping momentum to interstellar protons. But the objective of the Genesis missions would be to establish an autonomously developing ecosphere of unicellular organisms so that otherwise biologically sterile planets would evolve ecosystems. He points out that about 37% of known stars are M dwarfs possessing habitable zone planets and that these may not give rise to evolving life without this sort of altruistic intervention. But humanity has to answer the moral question - should we do this? He quotes COSPAR guidelines on

Long duration Genesis-type missions to exosolar planets

feasible
no benefit for humanity
a new perspective of the cosmos

Claudius Gros

Institute for Theoretical Physics
Goethe University Frankfurt, Germany



forward contamination “The conduct of scientific investigations of possible extraterrestrial life forms, precursors and remnants should not be jeopardized.” Prof Gros has discussed this with Ross Andersen in The Atlantic, August 25, 2016, ‘How to Jump-Start Life Elsewhere in Our Galaxy’ (www.theatlantic.com/science/archive/2016/08/genesis-missions/497258/)

Reported by: John Davies

The Breakthrough Listen Search for Intelligent Life: the first SETI results and other future projects

Tuesday 2 October	IAC reference: IAC-18/IAC-18/A4/1
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J. Emilio Enriquez UC Berkeley / Radboud University Nijmegen

IAC paper: iafastro.directory/iac/proceedings/IAC-18/IAC-18/A4/1/manuscripts/IAC-18,A4,1,1,x42328.pdf

Note this appears to be an error on the IAC website. The paper linked here is entitled "The Breakthrough Listen Search for Intelligent Life: results from with GBT" with similar authors

IAC presentation: <http://directory/iac/proceedings/IAC-18/IAC-18/A4/1/presentations/IAC-18,A4,1,1,x42328.show.pdf>

Open paper: not available

Emilio described the early work of Breakthrough Listen with searches conducted primarily on the Green Bank Telescope (GBT). He gave us a quick summary of the foundations of SETI (Drake, probabilities, etc) and the three search methods with their current scopes - probe (just Solar System so far), biosignature (less than 100 nearby stars) and technological signature (about 1 million nearby stars at our technological level and about 1 billion nearby stars at higher technological levels). He discussed the frequency distribution of detectable intelligences under a range of assumptions about them - with Voyager 1 as test subject. He cited a supporting paper "Breakthrough Listen Target Selection of Nearby Stars and Galaxies" arxiv.org/pdf/1701.06227.pdf (Publications of the Astronomical Society of the Pacific, 129:05450 1 (11 pp), 2017 May) with results from the GBT and Parkes telescopes and the Automated Planet Finder (APF - apf.ucolick.org). The GBT work has observed 692 Nearby Stars at 1.1-1.9 GHz (arxiv.org/pdf/1709.03491.pdf and seti.berkeley.edu/lband2017/). He gave examples of a number of false positives, concluding that non-detection of



BREAKTHROUGH LISTEN

SEARCH FOR INTELLIGENT LIFE

first results and future projects

EMILIO ENRIQUEZ
UNIVERSITY OF CALIFORNIA BERKELEY
Radboud UNIVERSITY NIJMEGEN

Andrew Siemion, Heino Falcke, Griffin Foster,
Vishal Gajjar, Jack Hickish, Howard Isaacson,
Danny Price, Steve Croft, David DeBoer,
Matt Lebofsky, Dave MacMahon



extraterrestrial signals puts an upper limit on the number of transmitters. There must be less than 0.2% of nearby stars and an EIRP (equivalent isotropic radiated power - assumed non directional (ie neglecting antenna gain) of 10^{13} Watts. He compared the Listen project with previous SETI efforts and concluded that these first results provide the most stringent limit to date on the rate of low power radio transmitters around nearby stars.

Reported by: John Davies

An update on the Australian activities of Breakthrough Listen

Tuesday 2 October	IAC reference: IAC-18,A4,1
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Daniel Price UC Berkeley

IAC paper: iafastro.directory/iac/proceedings/IAC-18/IAC-18/A4/1/manuscripts/IAC-18,A4,1,2,x42739.pdf

IAC presentation: not available

Open paper: not available

The Listen project work based at the Parkes telescope uses 25% of telescope time and also includes other telescopes. It will also use time on the upcoming MeerKAT telescope (www.ska.ac.za/gallery/meerkat) and will analyse data from other telescopes which has been gathered for non-SETI purposes. Parkes has wide bandwidth capability 700Mhz to 4 Ghz. The team are using the Pawsey supercomputing centre in Perth, Western Australia (pawsey.org.au).

The Murchison Widefield Array (www.mwatelescope.org) in Western Australia will survey lower frequencies in the low hundreds of GHz.

There are significant challenges in handling the volume of data from the newer radio telescopes and much has to be done in real time to reduce the amount stored to manageable levels.

Reported by: John Davies

Frequencies

To give an idea of the frequency range covered by the various Listen surveys it might be useful to look at some example practical applications of the frequencies concerned -

- around 100 MHz - VHF Broadcast Radio, analogue Land Mobile ("roger and out" radio)
- around 400 MHz - UHF Broadcast TV, digital Land Mobile
- around 800 MHz - 2G and 3G mobile / cellular phones
- around 1500 MHz == 1.5 GHz - 4G mobile phones and devices, GPS
- around 2 GHz - Satellite TV, marine radar
- around 4 GHz - general satellite communications, early 5G mobile phones and devices

SETI radio surveys of the distant Universe

Tuesday 2 October		IAC reference: IAC-18,A4,1
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Mike Garrett University of Manchester

IAC paper: not available

IAC presentation: not available

Open paper: arxiv.org/pdf/1810.07235 (SETI surveys of the nearby and distant universe employing wide-field radio interferometry techniques, Presentation at IAC 2018 Session SETI 1 and EVN Symposium 2018)

Mike discussed the advantages of interferometry (especially very long baseline - VLBI) for SETI as compared with both traditional single antenna systems (like the Jodrell Bank Mark 1 and the Green Bank Telescope) and the newer, large scale, beam forming systems (such as MeerKAT and Allen Telescope Array (ATA)). He particularly cited better rejection of radio frequency interference (RFI) and improved location information (RFI includes, of course, that bane of the SETI searcher, human originated signals!). Other advantages include redundancy and verification of faint and/or transient signals. Existing VLBI data has been reused in initial work. Software correlation supports time and frequency resolution important in SETI. Thousands of potential SETI targets can be studied simultaneously. Mike believes that this approach also justifies extra-Galactic sources since even sub-Kardashev civilisations (en.wikipedia.org/wiki/Kardashev_scale) may be able to produce detectable signals using beam forming in their transmitters.

Reported by: John Davies

Interdisciplinary Workshop on Human Habitation Concepts for Interstellar Space Travel

Tuesday 2 October		IAC reference: IAC-18,E1,4
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Marlies Arnhof Advanced Concepts Team, ESA

IAC paper: iafastro.directory/iac/proceedings/IAC-18/IAC-18/E1/4/manuscripts/IAC-18,E1,4,10,x46685.pdf

IAC presentation: not available

Open paper: not available

Ms Arnhof explained that if manned interstellar space travel was to be a success, one of the many necessary factors would be well-designed habitats that keep the crew safe, healthy and happy during the mission. This is a complex challenge requiring an interdisciplinary approach. ESA are planning to run a three-day workshop in the Spring of 2019 to allow postgraduate students to experience the benefits of working with many different disciplines. In preparation for this, she had reviewed several previous examples of such workshops, including ones run by ESA (2005), the Technical University of Vienna (2013), and ESA’s concurrent engineering workshops (2018). Arnhof discussed the benefits of an interdisciplinary approach, particularly for students at the start of their professional academic careers, and the need for such a workshop to focus on a broad topic that will require a diversity of disciplines. Manned spaceflight and interstellar travel both tick these boxes and also require creativity and innovation, hence their selection as the subject material for the planned workshop. In addition, she noted that the Advanced Concepts Team at ESA publish a yearly journal, ‘Acta Futura’, and the 2019 issue will be dedicated to interstellar issues.

Reported by: Patrick Mahon

Exploring the Kuiper Belt with Sun-Diving Solar Sails

Wednesday 3rd October	IAC reference: IAC-18.A7.2.5
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Elena Ancona, Telespazio VEGA Deutschland GmbH
IAC paper: [iafastro.directory/iac/proceedings/IAC-18/IAC-18/A7/2/manuscripts/IAC-18,A7,2,5,x47547.pdf](#)
IAC presentation: [iafastro.directory/iac/proceedings/IAC-18/IAC-18/A7/2/presentations/IAC-18,A7,2,5,x47547.show.pdf](#)
Open paper: [arxiv.org/pdf/1810.00407.pdf](#)

Elena presented the work done in collaboration with R Ya Kezerashvili and G L Matloff on Kuiper Belt exploration with Sun-Diving Solar Sails.

The Kuiper Belt, characterised by an ionized plasma and dust environment, is populated by more than 100,000 bodies larger than 100 kilometres across, including Pluto. Thanks to the low temperature (around 50K), it is considered to be “the Solar System’s ice box”. It is an extremely interesting target for obvious scientific reasons, however most of what we know about the Kuiper Belt comes from ground-based telescopes and the Hubble Space Telescope; In fact, only one spacecraft has visited the Kuiper Belt so far: NASA’s New Horizons.

The study presents the possibility to survey many Kuiper Belt Objects (KBO) with a single launch using a few small-scale spacecraft, each equipped with solar sails, which could be unfurled from a single interplanetary bus at the perihelion of that craft’s solar orbit. Each small-scale spacecraft would carry a scientific payload and would be directed to intersect one or more KBOs. The proposed scenario is the following: the sails are carried as a payload to a relatively small heliocentric distance (0.1 - 0.3 AU); once at the perihelion, the sails are deployed. Besides electromagnetic propulsion due to the solar radiation, another mechanism could be convenient: thermal desorption, a physical process of mass loss which can provide additional thrust as heating liberates atoms, embedded on the surface of a solar sail. Therefore, the sails experience additional propulsive force due to the thermal desorption that dramatically increases the distance that sails travel per year. At 100 km/s, or ~20 AU/year, post-perihelion travel times to the vicinity of Kuiper Belt Objects will be less than 3 years. Factoring in time required for the Jupiter flyby to perihelion, target KBOs could be encountered less than 6 years after launch.

Reported by: Elena Ancona

Exploring the Kuiper Belt with Sun-diving Solar Sails

Conclusions

- Thermal desorption results in high post-perihelion heliocentric solar sail velocities.
- At 100 km/s, or ~20 AU/year, post-perihelion travel times to the vicinity of Kuiper Belt Objects will be less than 3 years.
- Factoring in time required for the Jupiter flyby to perihelion, target KBOs could be encountered less than 6 years after launch.

Elena Ancona - Politecnico di Torino,
Roman Ya Kezerashvili & Gregory L Matloff- New York City
College of Technology, City University of New York

Technologies for the First Interstellar Explorer: Beyond Propulsion

Thursday 4th October		IAC reference: IAC-18,D4,IP,5
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Anthony Freeman JPL

IAC paper: (abstract only available) iafastro.directory/iac/proceedings/IAC-18/data/abstract.pdf/IAC-18,D4,IP,5,x46273.brief.pdf

IAC presentation: not available

Open paper: not available

Open presentation: [www.researchgate.net/publication/328175877 Technologies for the First Interstellar Explorer Beyond Propulsion](https://www.researchgate.net/publication/328175877_Technologies_for_the_First_Interstellar_Explorer_Beyond_Propulsion)

Dr Freeman introduced his talk by noting that Voyager 1, a spacecraft designed and built in the 1970s, became the first human artefact to leave our solar system in 2012. Its onboard systems are both primitive and very old. How much more science might it be able to do for us now if we were able to upgrade it to present-day technology levels? More generally, spacecraft on long-duration science missions spend most of their time in a propulsion phase, followed by a survival phase during the cruise. However, the interesting part is doing the science at the target, followed by communicating the results back to Earth. If we are able to upgrade the spacecraft during the mission, we can ensure that its form is more appropriate to these completely different functions at each stage. Nature may give us some useful clues on how to do this – for example, by considering the life-cycle of a butterfly, from egg to caterpillar to pupa to adult butterfly. Freeman discussed some of the technologies that are changing rapidly, which might therefore provide the greatest benefits if a spacecraft can be upgraded with them in-flight. Some examples included compact nuclear power plants, magnetoshells, 3D printing of on-board mineral stocks to form new components, making modular spacecraft that are recyclable or made from organic materials that can be digested at end-of-life, upgradable software using genetic algorithms, and optical communications enhanced by gravitational lensing. He concluded by noting that if all the above sounded a little far-fetched, it was worth recalling that interplanetary cubesats were a wild idea in 2011, and a mere 7 years later, JPL have got two on their way to Mars!

It was a pleasure to speak to Dr Freeman after his talk, and he was kind enough to send me his slides, from which these notes have been made.

Reported by: Patrick Mahon



Just one of the ideas from Anthony Freeman and Leon Alkalai

CubeSat Sundiver for Interstellar Precursor Missions

Thursday 4th October		IAC reference: IAC-18,D4,IP,10
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Martin Lades, Germany

IAC paper: not available

IAC presentation: iafastro.directory/iac/proceedings/IAC-18/data/abstract.pdf/IAC-18,D4,IP,10,x46286.brief.pdf

Open paper: not available

Martin proposed launching CubeSats on so-called ‘sundiver’ orbits, accelerating towards the Sun in order to reach much higher velocities than have been achieved to date by spacecraft within the solar system. Such interstellar precursor missions will get nearer to the speeds that future interstellar craft will need to reach if they are to complete their missions within a reasonable timeframe, and will thus enable the testing of the technologies and materials that future interstellar spacecraft will require.

The rapid evolution of CubeSat capabilities over recent years make them an affordable testbed for advanced technology options such as solar sails. Martin referred to recent proposals in this vein, including Project Icarus and i4is’s Andromeda Probe.

Reported by: Patrick Mahon



Intense discussion and concentrated attention were hallmarks of the Congress

In the foreground, Satinder in discussion with a fellow presenter.

In the background Patrick (with a beer!) listens to another interactive presentation

Adaptive in-situ resource utilisation (ISRU) for long term space exploration

Thursday 4th October		IAC reference: IAC-18,A3,IP,33
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Satinder Shergill Cranfield University

IAC paper: iafastro.directory/iac/proceedings/IAC-18/IAC-18/A3/IP/manuscripts/IAC-18,A3,IP,33,x42235.pdf

IAC presentation: not available

Open paper: not available

In this brief interactive presentation, Satinder discussed initial results of his work at Cranfield University on a pilot study assessing the feasibility of designing an ‘Adaptive ISRU system’, an in-situ resource utilisation resource extraction system adaptable to different rocky planetary bodies (eg the Moon, Mars and asteroids) designed to be adaptive in its ability to extract resources. Particle size and degree of regularity are key factors here. Adaptivity is especially important where autonomous operation is required. The study also concludes that solar power, even as far out as Mars, will be sufficient to drive the required processes.

This is part of Satinder's work towards his PhD at Cranfield.

Reported by: John Davies

A minimal chipsat interstellar mission: technology and mission architecture

Friday 5th October

IAC reference:

Elena Ancona Telespazio VEGA Deutschland GmbH

IAC paper: iafastro.directory/iac/proceedings/IAC-18/IAC-18/B4/8/manuscripts/IAC-18,B4,8,16,x46958.pdf

IAC presentation: iafastro.directory/iac/proceedings/IAC-18/IAC-18/B4/8/presentations/IAC-18,B4,8,16,x46958.show.pdf

Open paper: not available

Elena replaced her co-author Ms Wenjing Hu as presenter. This study at the International Space University explored the possible configuration and mission of the smallest feasible chip-based interstellar probe, a ChipSat equipped with a solar sail or other propulsion systems, escaping the Solar System. The project was suggested and advised by the Initiative for Interstellar Studies, see Interstellar News in this issue.

Three mission architectures were explored

- o ChipSat released in orbit by a Deep Space Gateway (DSG)
- o ChipSat released in orbit by a Space Station (eg the ISS)
- o ChipSat released enroute by another deep space exploration mission

Mission durations to Alpha Centauri (4.37 ly) of 138, 83 and 41 years would correspond to propelling laser arrays of 1.8, 3.1 and 6.3 MW and cruise velocities of 3%, 5% and 11% c, respectively. The configuration explored used a 15 mm square chip costing about 1000 USD in a craft weighing 0.01 kg.

Reported by: John Davies

A Minimal Chipsat Interstellar Mission: Technology and Mission Architecture

Results

No.	Name	Advantages	Disadvantages
1	DSG ChipSat release and control mission	● Enough space-based power for laser propulsion ● Sufficient uplink EIRP ● Big receiving antennas are available ● Simple operation	● The completion of DSG is a prerequisite for ChipSat mission ● Communication network between DSG and the Earth should be built
2	ISS ChipSat release and Relay Satellite interlink mission	● Other supportive Relay Satellite missions need to be designed ● Re-use of ISS ● Low cost ● Simple configuration ● Simple operation	● Mission schedule is limited to ISS lifespan ● Space-based laser propulsion is power limited
3	Other ChipSat carrying mission	● Relatively independent ● No new satellite needed except the one in the mission	● The schedule is not flexible ● The integrated interface and communication system need to be considered before Phase A ● Joint control makes operation complex

Credit: Wenjing Hu & Chris Welch - International Space University (ISU) - and Elena Ancona - Initiative for Interstellar Studies (i4is)

Exploring the potential environmental benefits of asteroid mining

Friday 5th October

IAC reference: IAC-18,D4,5

Andreas Makoto Hein, Ecole Centrale de Paris

IAC paper: iafastro.directory/iac/proceedings/IAC-18/IAC-18/D4/5/manuscripts/IAC-18,D4,5,11,x47396.pdf

IAC presentation: iafastro.directory/iac/proceedings/IAC-18/IAC-18/D4/5/presentations/IAC-18,D4,5,11,x47396.show.pdf

Open paper: arxiv.org/abs/1810.04749

Andreas opened with the question: why would we mine the asteroids? He explained that there are several potential benefits – economic, social, political, technological and environmental – when compared to ground-based mining. This talk would look at the environmental case. The question he and colleagues have addressed is under what circumstances could mining materials from an asteroid have a lower environmental impact than mining them on Earth. Two key reasons why this might be the case are that the mined materials, if used in space, reduce the number of launches of cargo vehicles otherwise needed to get the necessary material into orbit, and that mining the materials outside of Earth's ecosphere eliminates the pollution caused by ground-based mining activities.

They have measured these impacts using a standard life-cycle analysis (LCA) approach, following the ISO 14040 international standard, but at this initial stage focused purely on greenhouse gas emissions. A key variable is the mass of material produced by the space-based mining operation, compared to the mass that has to be launched into orbit to enable that operation to proceed. A 'bootstrapping factor' b is therefore defined as the mass of resources mined in orbit, divided by the mass of the spacecraft launched from Earth to enable the asteroid mining operation.

They looked at two case studies: delivering water to cis-lunar orbit, and sending platinum back to Earth. The analysis for water concluded that this would be environmentally beneficial as soon as the mass of water supplied to cis-lunar orbit exceeded the mass of the spacecraft launched from Earth to mine the water from an asteroid (ie $b > 1$). The results for Platinum are even clearer, due to the very high carbon impacts of ground-based platinum mining: space-based mining for Platinum will be better, from a carbon perspective, as soon as the bootstrapping factor b is greater than a number in the range from 0.004 to 0.08. Above this, space-based mining of Platinum is environmentally beneficial.

Reported by: Patrick Mahon

CONCLUSIONS

Findings:

- There seems to be a **clear case** for asteroid mining from an environmental point of view for both, **water and Platinum**.
- **Bootstrapping factor b** – Depends primarily on extraction process efficiency and spacecraft reusability, **lower b -values required for Platinum than for water**
- **Limitations:**
 - Only Kerosene and electricity have been taken into account (Scope I and II in carbon footprint accounting)
 - Only greenhouse gas emissions considered
 - Main environmental impact of Platinum industry from using coal-based energy supplies → might move towards renewable energy sources in the future → significantly reduced footprint
- **Future work:**
 - Fine-grained LCA
 - Combine economic and environmental analysis to determine sweet spots for both

Credit:
Andreas M Hein, Michael Saidani, Hortense Tollu -
Laboratoire Genie Industriel,
CentraleSupélec, Université
Paris-Saclay

A techno-economic analysis of asteroid mining

Friday 5th October

IAC reference: IAC-18,D4,5

Andreas Makoto Hein, Initiative for Interstellar Studies

IAC paper: iafastro.directory/iac/proceedings/IAC-18/IAC-18/D4/5/manuscripts/IAC-18,D4,5,14,x47407.pdf

IAC presentation: iafastro.directory/iac/proceedings/IAC-18/IAC-18/D4/5/presentations/IAC-18,D4,5,14,x47407.show.pdf

Open paper: arxiv.org/ftp/arxiv/papers/1810/1810.03836.pdf

In this sister talk to the previous one on the environmental benefits of asteroid mining, Andreas considered the economic viability of such operations, and in particular focused on identifying those technological improvements that could transform the economics. The same two case studies as in the previous talk – mining of water and platinum – were considered here. The approach is based on cost-benefit analysis, comparing space-based mining against its terrestrial equivalent, and supply and demand analysis for the case study of Platinum being returned to Earth; since Platinum is relatively rare on Earth, if a large amount of space-based Platinum is returned to the Earth, it has the potential to affect the market price for the metal, changing the economic case.

The starting point is a simple break-even analysis for asteroid mining. This finds that, in the case of water, the driver of profitability is the launch cost for the mining spacecraft, whereas in the case of Platinum, it's the throughput rate (the mass of mined ore produced per second, divided by the mass of the equipment doing the mining) that is crucial. Andreas concluded that the economic viability of asteroid mining depended on drastically reducing the cost of the spacecraft (eg through mass production), and making the mining process much more efficient.

Turning to the supply and demand analysis for Platinum returned to Earth, Andreas explained that his i4is colleague Robert Matheson had modelled the profitability of the operation, based on a large number of options for the price elasticity of demand, and the reduction in terrestrial production expected as a result of the supply from space. Out of 168 scenarios modelled, 120 (71%) turn out not to be profitable at all, a further 20 (12%) are only profitable in the long term (over 30 years), and only 28 (17%) are profitable in the shorter term. It is therefore vital that any plans for space-based mining of rare materials takes full account of the likely market reaction to a sudden increase in supply.

Reported by: Patrick Mahon



Conclusions

Findings:

- **Throughput rate** key technological parameter – Development of **efficient mining processes** key to economic viability;
- Platinum mining requires **very high** throughput rates;
- **Mass production** key to achieving low mining costs;
- **Reaction of Earth-based industry** on space resources key uncertainty
→ Overall supplies need to be stable;

Conclusions:

- Water and volatile asteroid mining attractive in cis-lunar space (consistent with Calla et al., 2017)
- Platinum and PGM mining requires **significant progress** in mining processes
- Resource return to Earth requires careful consideration of **market reactions**

Future work:

- Exploration of effects of **regulatory instruments** economic viability
- Estimation of **throughput rates** for mining processes

Initiative for Interstellar Studies 11 www.i4is.org

Credit: Andreas M Hein (i4is) and Robert Matheson (i4is)

A Project Based Learning Model for Space Education

Friday 5th October	IAC reference: IAC-18,E1,2
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Satinder Shergill Space Studio West London

IAC paper: iafastro.directory/iaac/proceedings/IAC-18/IAC-18/E1/2/manuscripts/IAC-18,E1,2,5,x43474.pdf

IAC presentation: iafastro.directory/iaac/proceedings/IAC-18/IAC-18/E1/2/presentations/IAC-18,E1,2,5,x43474.show.pptx

Open paper: not available

Space Studio West London is a state funded non-selective school for students aged 14-19 and specialising in Space, Aerospace, Science, Engineering and Maths - located near London's main airport, Heathrow. Satinder and his colleagues involve students with local, national and international experts in the field and employers including the National Physical Laboratory (NPL), Surrey Satellite Technology Limited (SSTL), Imperial College, Heathrow airport and the Initiative for Interstellar Studies (i4is.org). They concentrate on engaging students with science and engineering, overcoming negative peer and parental attitudes where required. Project Based Learning uses mentoring to bring students back to fundamentals via their natural interest in subjects like rocket engines, human spaceflight and breakthrough propulsion.

Reported by: John Davies



Satinder shows us his school

THE SCHOOL

- Space Studio West London is a state funded non-selective school that caters for 300 students aged 14-19 and specialises in Space, Aerospace, Science, Engineering and Maths. The Studio School offers students the opportunity to work with local, national and international experts in the field and some exciting employers including the National Physics Laboratory.
- Students in Years 10 and 11 follow the GCSE subjects on the English Baccalaureate, taught both as individual subjects and through Project Based Learning and students in Years 12 and 13 follow at least three mainstream A level or Level 3 BTEC courses alongside real industry led project work assignments, many of which are commissioned by companies/agencies

This presentation examines many aspects of the school's unique vision of developing independent and engaged learners through project-based learning (PBL) and by following guiding principles of Self-Worth, Engagement, and Purpose, and also documents some of the major achievements and challenges of this pioneering school in its opening three years

Credit: Satinder Shergill, Peter Brozny, Rory Cockshaw - Space Studio West London

CURRENT AND FUTURE DIRECTIONS

- Applied Transdisciplinary Learning
- Build a plane project
- Fly2school
- Imperial College InSAR Radar reflector data analysis
- UBO pocket satellite kit
- Royal institution year 12 Maths Masterclasses

A Critical Review on the Assumptions of SETI

Friday 5th October		IAC reference: IAC-18/A4/2
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Kelvin Long i4is

IAC paper: not available

IAC presentation: iafastro.directory/iac/proceedings/IAC-18/IAC-18/A4/2/presentations/IAC-18,A4,2,8,x43122.show.pdf

Open paper: not available

Kelvin dealt with assumptions old and new -

- 1. "interstellar flight is not possible" - difficult but no longer regarded as impossible (He also refuted the idea that a probe at velocity 20% c, eg Starshot, could be perceived as a threat at its destination);
- 2. Anthropocentrism - We should anticipate both our worst fears and our best hopes;
- 3. Fermi + Drake - the paradox and the equation

Chauvinist views - Is Mankind Unique? (Martin & Bond), A Crowded Galaxy (Drake & Sagan), We are probably the first intelligent life (Hart-Viewing);

4. Astrobiology -

Homeostasis: assertion that life is distinguished from inorganic matter by homeostasis

Living Systems: Erwin Schrodinger (1944) "Life can be defined by the process of resisting the decay to thermodynamic equilibrium.";

5. Radio waves and optical laser are the most likely method of interstellar communications;

6. Any single apparent ETI detection event is not amenable to scientific scrutiny since not reproducible;

7. Astrophysical Sources: Are assumed to be "natural".

Kelvin also commented on the ascription of all reports of ET visitors as fantasy, the assumption that our own history is uninterrupted and that our own mental events are all accounted for.

Reported by: John Davies



Professor Claudio Maccone closes the SETI session



Kelvin explores the assumptions of SETI

Engineering New Worlds: Goals, Motives and Results

Dmitry Novoseltsev

Dmitry Novoseltsev brought us some very large-scale thinking in two issues of Principium last year (2017), *Engineering New Worlds: Creating the Future*. Here he builds on this, pondering some outstanding questions in this universe - and others.

Dr Anna V Sedanova again contributes the striking images.

Earlier, in a number of publications in Principium [1-3], the author presented a large-scale picture of the possible development of intelligent life elsewhere in the Universe.

The author's model includes several stages. The first one is the distribution of catalytic biogenesis and a cultural code on a Galactic scale [1]. Next, the creation of artificial inhabited star clusters, and then of artificial inhabited massive objects like black holes, to accelerate the external passage of time (relative to their inhabitants), using devices similar to the Shkadov thruster [2]. Finally, the possible creation of artificial universes, with optimal conditions for the development of complex forms of organized matter, by using similar devices [3]. At the same time, the scenario presented left a

number of questions open.

The first problem is the possible limits of cognition. Complex forms of organized matter, which are inside an artificial supermassive object, like a black hole [2], in the absence of a more adequate term, are still called cosmic civilizations (CC). Such CCs are able to obtain and study, using external "beacons", all the available information of an "exohumanitarian" nature from other CCs in our Universe, for the entire period of its existence, during which physical conditions allow the existence of complex forms of organized matter. But as a result, they will inevitably face the problem of exhaustion of available sources of knowledge again. This problem becomes especially topical when such CCs are "locked" inside the event horizon.



Another problem is the provision and maintenance, over the long term, of a high level of motivation for an absolutely altruistic project – the creation of artificial universes optimal for intelligent life [3]. Such a project does not imply any pragmatic benefits – for example, in the form of scientific data. Moreover, there is no possibility of obtaining any information about whether its implementation was successful or unsuccessful. In this regard, it may be noted that the enthusiasm for the prospects of space exploration in the late 1950s and early 1960s was replaced by a significant loss of interest and stagnation following the completion of the programme of manned missions to the Moon in the early 1970s.

One possible answer, providing an opportunity to complete the described picture of the future, is based on the results of a seminar on space philosophy organized by the SETI Science and Culture Center of the Tsiolkovsky Academy of Cosmonautics, together with the sections "Life and Mind in the Universe" of the Astronomy and Astrobiology Scientific Councils of the Russian Academy of Sciences, on February 16, 2018 in Moscow.

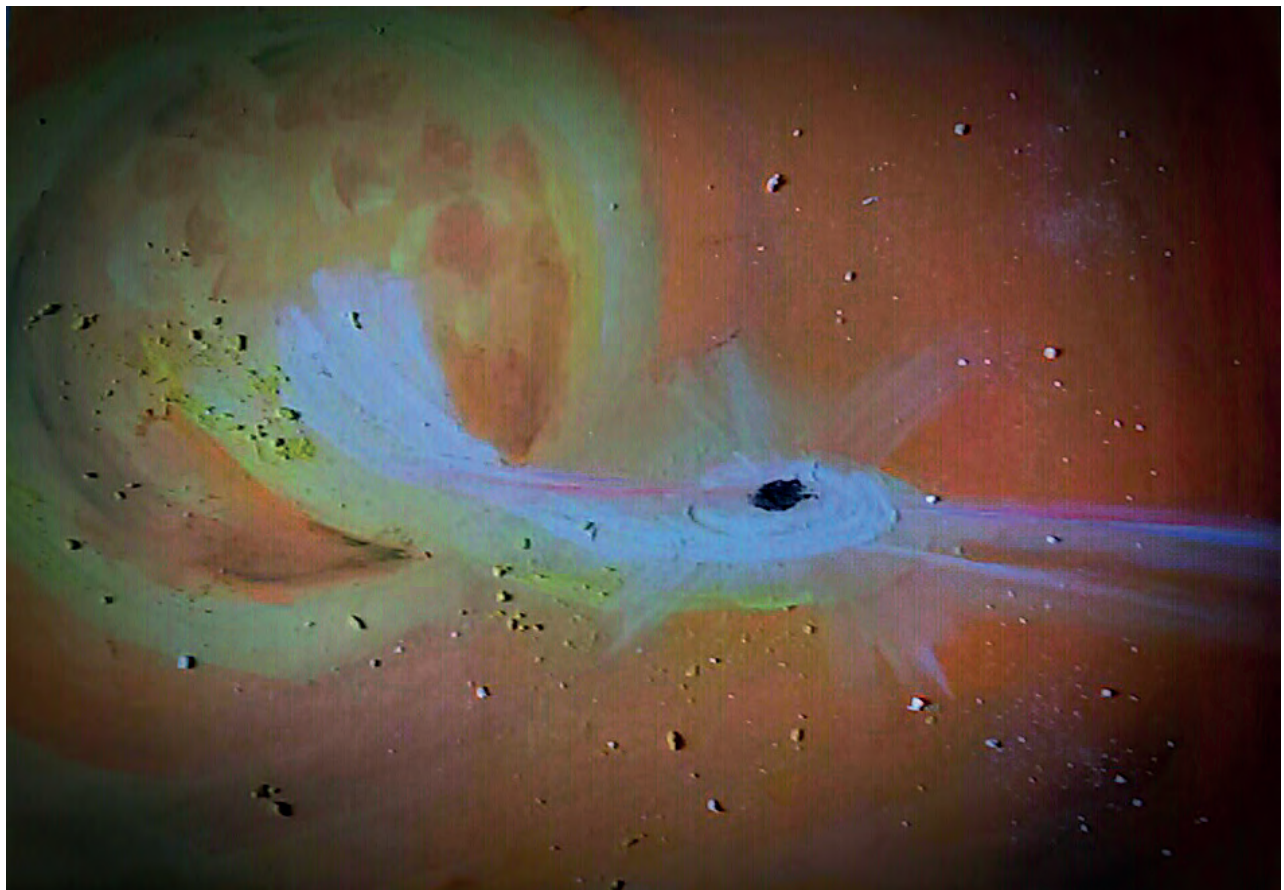
In his report to this seminar, "The SETI problem in the cosmology of the Multiverse", A D Panov presented different hypothetical ways of moving representatives of highly developed CCs between different universes of the Multiverse,

consistent with modern physical models. Among these options, the speaker noted the so-called "Kerr black holes". This is a hypothetical type of rapidly rotating gravitationally-collapsed objects. Their central singularity is not a point, but rather a wide ring permeable from the outside. According to the speaker, for a massive object weighing 4×10^9 solar masses, the radius of the ring will be about 75 AU. This allows the passage through it of whole groups of stars with Shkadov-type engines. The object, after passage from the outside through a ring singularity, might come out in another universe of the Multiverse.

From an engineering point of view, the creation of a rotating ring singularity, through the process of controlled gravitational collapse of an artificial star cluster using Shkadov thrusters, is possible, but it will be a more complicated problem than a "simple" collapse with a central point singularity.

In this case, the combined CC of an artificially collapsed star cluster, after gathering all the available information about its "native" universe, gets the opportunity to move to another universe. There, the CC will be able to continue its activities – provided that the conditions for this in another universe are favourable enough. It should have a sufficiently high complexity, including the existence of its own highly organized CCs, and be of interest to research.

This formulation of the problem completely



changes the approach to the question of purposeful creation of artificial universes with properties convenient for the development of highly organized matter forms, from absolutely altruistic to extremely pragmatic. The autocatalytic process of self-reproduction of optimal universes within the extended cosmological natural selection [3] becomes important for the CCs. By organizing such a process, the CC also guarantees unlimited expansion of its own "ecological niche" in the Multiverse and the inexhaustibility of its own sources of knowledge.

In a recent article by Stephen Hawking [7] it was argued that the number of possible variants of universes in a Multiverse is rather limited, and their fundamental constants cannot take random values. At the same time, in other recent articles [8, 9] it is shown that the change of such a fundamental constant as the cosmological constant Λ , even within a wide range, does not have a significant impact on the possibility of formation of galaxies. If this is true, the proportion of universes in the Multiverse suitable for the existence of intelligent life may be large, and the task of their artificial creation will be greatly simplified.

Thus it is possible to allocate the following hypothetical stage of evolution of CCs: a community of "travellers" moving between universes in an actual infinite Multiverse.

"Travellers" are gathering all available information about the universes and their intelligent inhabitants and contribute to the continuous emergence of new universes suitable for life. Each CC is autonomous, but on a Multiverse scale, there is an indirect exchange of information between them through the "beacons" created by them in the local universes, as well as through the specified properties of the artificial universes. This process is generally inaccessible to the observation of individual groups of "travellers", and even more so to the inhabitants of the local universes. However, it occurs across the whole Multiverse. By analogy with the "galactic cultural field" [4], it can be called the "cultural field of the Multiverse".

In the timeless environment of the Multiverse, the duration of the existence of communities of "travellers" becomes unlimited. For the hypothetical inhabitants of local universes, all "travellers" are themselves "transcendental" and unobservable, with the exception of cases where their output in the local universes are in regions accessible to observation by intelligent local inhabitants. However, there may be a number of indirect signs

of their existence.

To describe this phenomenon, it may be appropriate to use the concept of "tempoworlds" adopted in the Russian physical scientific school of S.P. Kurdyumov [6]. The defining characteristic of the "tempoworld" is the overall speed of development of all its constituent structures, self-consistent processes and phenomena. For example, geological and historical processes on Earth are developing in the same local space, but at different "tempoworlds". Similarly, planetary CCs, including the modern civilization of the Earth, and CCs of artificial star clusters, on the one hand, and CCs of artificial collapsors, on the other, coexist in different "tempoworlds". For the latter, our ordinary activities are as ephemeral as processes in the environment of virtual particles for us, and observed only through a long collection of artifacts – radio, optical, or other signals.

If the ability to travel through Kerr black holes is confirmed, at least in some cases, then in our Universe, from the earliest stages of its fairly cold existence, these may already be artificial collapsors, used by "travellers" from other universes of the Multiverse with similar properties. In this case, it should also be possible to record the signals from their "beacons".

In connection with the specifics of one-way transmission of "beacons" to very remote fast-moving objects through the gravitational lens of the artificial collapse, it may be possible to try to identify them among the so-called Fast Radio Bursts (FRBs) as soon as enough data is collected. This also leads to an important conclusion for existing and future SETI programs. In different universes of the Multiverse, time can have different speeds and different directions. The distant past of our Universe may correspond to the distant future of other universes in which communities of "travellers" have already emerged. Therefore, any anomalous signals, including those like FRBs, from remote areas of the Universe, the observed structure of which corresponds to its distant cosmological past, should not be ignored. Until a natural explanation for their causes is found, they should be considered, among other things, as a possible signal of "beacons" installed by "travellers".

It is important that groups of stars or white dwarfs collected in artificial clusters remain the main source of energy for the "travellers" CCs. In spite of the "Metauniverse" scales of their activity, from a formal point of view, they still correspond to type 2+ on the Kardashev scale. Thus, in the

case of the reliability of the model of transition to other universes through "Kerr black holes", the implementation of the proposed scenario does not require the unlimited evolution of each CC. This is necessary and sufficient only to achieve the level of technological and cultural development, providing the possibility of purposeful movement of stars and the preservation of stability and high motivation of CCs. In the actual infinite and timeless Multiverse, such a scenario can be implemented with a high probability, almost tending to 1. Under accepted assumptions, the "cultural field" should already exist there, although it remains unavailable to observers from our Universe.

It is also possible to note the important moment of fundamental change in the nature of the dependence of the available level of knowledge on the achieved technological level. At present, acquiring new knowledge requires increasingly complex and expensive tools, such as orbital telescopes or a Large Hadron Collider. This has allowed a number of authors to forecast the possible "end of science", when the technical and economic support necessary for the next level of research will be impossible for civilization [4]. On the contrary, the development of the technology of controlled motions of stars with almost constant levels of implementation may provide the possibility of an almost infinite expansion of knowledge. Starting with the

organization of the interaction between the nearest galactic CCs and their consolidation in an artificial star cluster, it will achieve unlimited access to the information in all universes of the Multiverse and its "cultural field". This is an essential argument for the development of such technologies and the first steps in their practical implementation.

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The report of A. D. Panov, "The SETI problem in cosmology of the Multiverse" at the seminar on space philosophy of the SETI Science and Culture Center of the Tsiolkovsky Academy of Cosmonautics, together with the sections "Life and Mind in the Universe" of Astronomy and Astrobiology Scientific Councils of the Russian Academy of Sciences, given on February 16, 2018, is available (in Russian) at: https://www.youtube.com/watch?v=W_EChvMFm2A



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NEWS FEATURE - TVIW 2018

Our friends at the Tennessee Valley Interstellar workshop held their latest major event in October. None of the i4is core team were able to attend this time so we have no report in the issue of Principium. In small compensation, we hope, here is the programme. You will see why we wish we had been there!

Day 1: Tuesday, October 23, 2018		Day 2: Wednesday, October 24, 2018		Day 3: Thursday, October 25, 2018	
09:00 - 09:05	Dean S. Hartley III, PhD – Administrivia	08:00 - 09:00	Pre-Meeting Tour	09:00 - 09:05	Dean S. Hartley III, PhD – Administrivia
09:05 - 09:13	John D. G. Rather, PhD - Symposium Welcome	09:00 - 09:05	Dean S. Hartley III, PhD – Administrivia	09:05 - 09:46	Mark Uran Keynote Address
09:13 - 09:18	Edward "Sandy" Montgomery - TVIW Welcome	09:05 - 09:26	Alan Icenhour, PhD ORNL Keynote Address	Theme 4: Ultimate Paths to the Future (Science Fiction to Fact Relationships)	
09:18 - 09:39	Morgan Smith, CEO, Y-12, Keynote Address		William Peter, PhD Large-scale 3D Printing & Complex Structures		
09:39 - 10:00	Hon. John Vonglis, DOE ARPA-E, Keynote		09:26 - 09:52	Jeffrey Slostad Persistent Space Platforms Bootstrapping Space Economy	09:46 - 10:12
10:00 - 10:10	John D. G. Rather, PhD - The Power of Synergy	09:52 - 10:17	Break	10:12 - 10:37	Marc Millis Sustaining Progress Beyond the Obvious
Theme 1: Large-Scale Space Development		10:17 - 10:47	Mark D. Carter, PhD VASIMR Plasma Propulsion	10:37 - 11:07	Break
10:10 - 10:36	John Mankins, Theme 1 Chair Realizing the Development and Settlement of Space	10:47 - 11:12	Ken Roy Problem of Low Gravity Physiology: A Possible Solution	11:07 - 11:32	David Brin, PhD Ultimate Paths to the Future
10:36 - 11:06	Break	11:12 - 11:37	Siegfried Janson, PhD Small Satellite Concepts at The Aerospace Corporation	11:32 - 11:57	Ruth E. Kastner, PhD Quantum Universe Properties
11:06 - 11:31	Franklin Chang Diaz, PhD Living and Working in Space, an Astronaut's Perspective	11:37 - 12:02	Lunch	11:57 - 12:57	Lunch
11:31 - 11:56	James Powell, PhD, Particle Bed Reactor & Maglev (Honored by John Rather, PhD, & John Mankins)	12:02 - 13:02	Theme 2 Synthesis	12:57 - 13:22	Buck Field Faster than Light Synergies
11:56 - 12:56	Lunch	Theme 3: Transformative Decadal Plan		13:22 - 13:47	Catherine Asaro, PhD – Award
12:56 - 13:21	Michael Houts, PhD Advanced Exploration with Nuclear Thermal Propulsion	13:42 - 14:08	Matt Hollingsworth, Theme 3 Chair Making Big Ideas a Reality	13:47 - 14:27	Theme 4 Synthesis
13:21 - 13:46	Joel Sercel, PhD Capture & Uses of Small Asteroids	14:08 - 14:33	James T. Early, PhD Transformative Decadal Plan	14:27 - 14:57	Break
13:46 - 14:11	John R. Adams What We Know About Closed Human Ecosystems	14:33 - 15:03	Break	14:57 - 15:07	Wrap-up
14:11 - 14:41	Break	15:03 - 15:28	John D. G. Rather, PhD Capture and Industrialization of Small Near Earth Asteroids	15:07 - 15:32	
14:41 - 15:21	Theme 1 Synthesis	15:28 - 15:53	John Mankins Critical Importance of Affordable, Abundant Solar Energy	15:32 - 16:47	
Theme 2: Breakthrough Candidates -- New Concepts & Technologies --		15:53 - 16:18	Dean S. Hartley III, PhD How To Integrate It?	16:47 - 16:57	Dean S. Hartley III, PhD – Symposium Synthesis
15:21 - 15:47	Jason Derleth, Theme 2 Chair NASA Innovative Advanced Concepts Program	16:18 - 16:43	Theme 3 Synthesis	16:57 – 16:42	Edward "Sandy" Montgomery – TVIW Futures
15:47 - 16:12	Jonathan K. Witter, PhD Particle Bed Reactor Nuclear Thermal Propulsion & Power	16:43 - 17:43	Reception	15:57 – 16:42	John D. G. Rather, PhD - Appraisal
16:12 - 16:37	Roger Lenard Timberwind PM remarks			16:42 – 17:42	Reception
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				

NEXT ISSUE

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An Idiot’s guide to Project Daedalus
News Feature - NASA Astrobiology event
More from IAC 2018, Bremen

Mission

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

Vision

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

Values

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

Editor: John I Davies

Deputy Editors : Andreas M Hein, Patrick J Mahon

Layout / Proofing: John I Davies, Carol Wright, Lindsay A Wakeman

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: Wrecked Solar Sail, credit: Alex Storer

Back cover: ISS track and Moon, credit: Dr. Leslie Wood



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Scientia ad sidera
Knowledge to the stars