PRINCIPIUM

The Newsletter of the Initiative for Interstellar Studies

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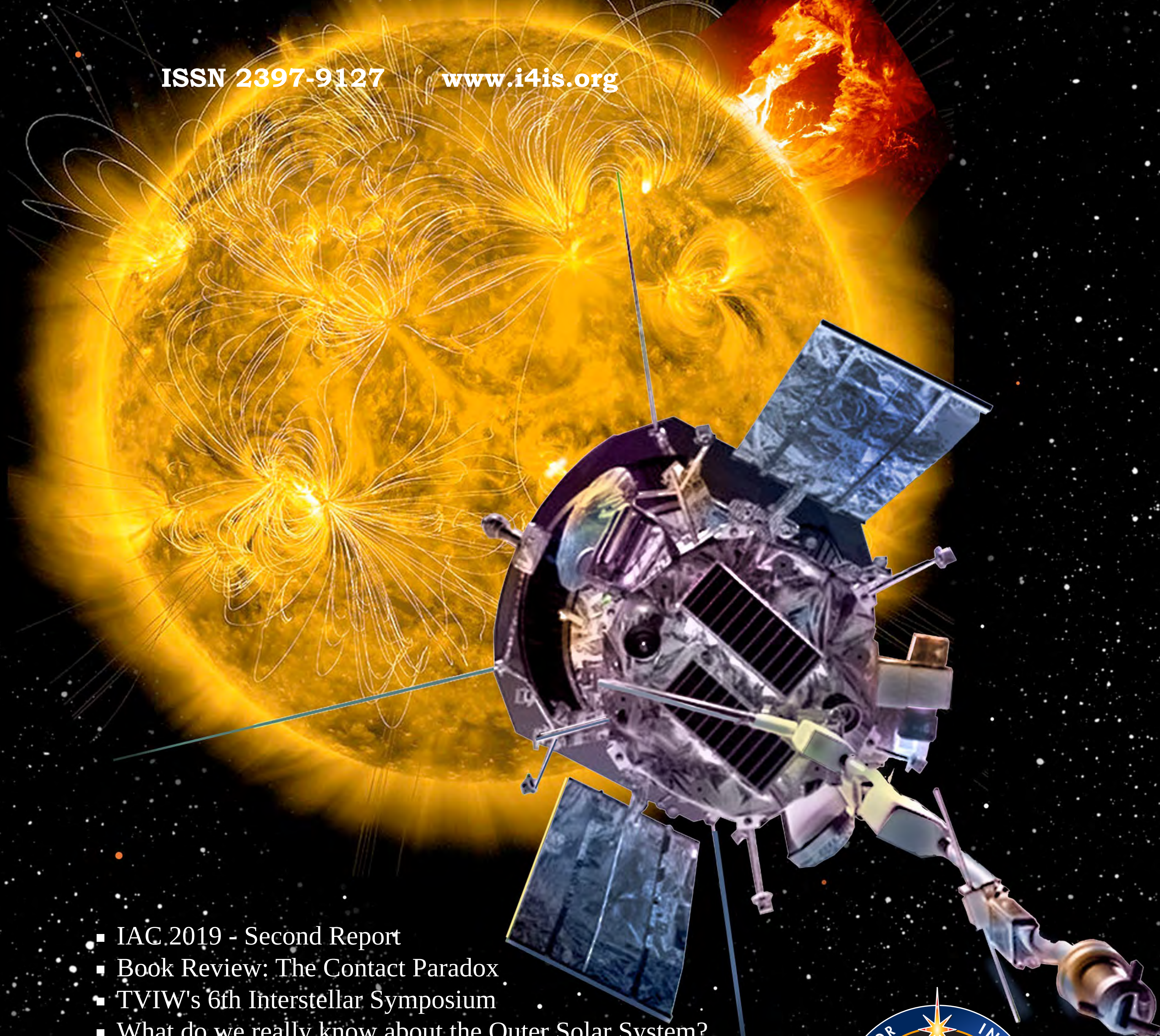

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Scientia ad sidera
Knowledge to the stars

Editorial

Welcome to issue 28 of Principium, the quarterly newsletter about all things interstellar from i4is, the Initiative and Institute for Interstellar Studies.

The front cover image is a vision of the Parker Solar Probe by David Hardy (David A Hardy/ www.astroart.org). This probe pioneers not only solar research but the technology of *How low can you go?* (see P27) as for the Oberth Manoeuvre so useful for high deltaV missions such as i4is Project Lyra and Johns Hopkins ideas for very deep space missions (as reported from IAC 2019 in P27). The back cover image is one of two paintings also by David Hardy commissioned by Andreas Hein illustrating his work on AI probes and based on an earlier image by Adrian Mann.

The Lead Feature for this issue is *What do we really know about the Outer Solar System?* by Phil Sutton, Lincoln University. Plans to tread in the footsteps of the Voyagers are advancing, notably the proposal from Johns Hopkins University reported in P27, but what do we already know?

We have the second report from the 70th International Astronautical Congress, Washington DC in October 2019. There will be a final report in our next issue - members should look out for a preprint well ahead of this.

Patrick Mahon reviews *The Contact Paradox* by Keith Cooper, recently published by Bloomsbury. Adam Hibberd provides a derivation of *The Equation used in the Benkoski Paper*, John Davies notes *Interstellar Objects (ISOs) - Oumuamua, Borisov and objects in between* and Joe Meany reports *TVIW's 6th Interstellar Symposium and Advanced Interstellar Propulsion Workshop*. There is more on the i4is membership scheme, plus our regular member's page with more about members-only website content.

We report recent Interstellar News, including numerous recent papers, the 60th anniversary of the Bussard Ramjet and good political news, *US Congress directs NASA to assess Interstellar Mission Technology*. But we kick off with a memoriam of Chris Corner by Andreas Hein.

In our next issue, P29 May 2020, will include more from IAC 2019, our postponed News Feature about the Education Team and much more.

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

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

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

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

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

Remembering Chris Corner

Dr Andreas Hein, Executive Director i4is

With great sadness, we received the information that Chris Corner, a Corporate Member of i4is for many years, and a regular contributor to the Technical Committee, has passed away in early 2019. In the following, I will commemorate Chris as a person but also what he has left behind.

Chris contacted i4is in September 2014. At that time, we were working on setting up the Project Dragonfly competition. During the competition, international student teams worked on a feasibility study for a small laser-propelled interstellar probe. As a side note, the design of the UCSB Team later evolved into Breakthrough Starshot. Chris and I immediately worked together on defining the Project Dragonfly competition requirements and he also provided additional material on distributed space systems. It took until July 2015 to meet him personally for the first time at the final Dragonfly Competition Workshop in London. The international student teams presented their results in the rooms of the British Interplanetary Society. Chris acted as a reviewer of the team presentations. After the workshop, the participants moved to the bar The Riverside, taking a spot with a beautiful view of the Thames. Chris and I soon engaged in a long conversation, as we already knew that we are both passionate about space and systems architecting. We spoke the same language. My impression was that here was someone with great experience but also great modesty. Someone calm but passionate. It was easy to like Chris.

During this conversation, we came up with the idea that we could further explore the topic of self-replicating machines. In particular, as new manufacturing methods such as 3D-printing using AI for design automation might allow us to move closer to this vision. Soon after the workshop, Chris founded Project von Neumann. Chris contributed to i4is in many ways over the years (small spacecraft asteroid mining, i4is Breakthrough Starshot proposal, etc.). However, his key contribution will likely remain Project von Neumann (initially called "von Neumann Universal Constructor Project"). Its objective is the development of an interstellar probe which is capable of manufacturing a space infrastructure, which would ultimately allow for self-replication. Although often talked about in the literature, self-replicating interstellar probes are fairly poorly understood from an engineering point of view.

In German, there is the word "Wirken", which is difficult to translate into English. It might be translated as "work", "action", or "activity" of someone. However, it can both pertain to a living person or a person that has passed away. Chris' Wirken is ongoing. Should we ever practically send spacecraft which are capable of designing and manufacturing in space, its origin can be traced back to Chris. Chris' work planted the seed for subsequent i4is papers on AI and interstellar travel. The results of the project have now even found a fertile ground within the ESA Advanced Concepts Team, where work on this topic will soon start. Project von Neumann lives on and we will publish exciting news about this project very soon. Chris' Wirken is yet to unfold.

More at : i4is.org/what-we-do/technical/von-neumann-ai-probe/

What Do We Really Know About The Outer Solar System?

LEAD FEATURE

Phil Sutton, University of Lincoln

The School of Mathematics and Physics at the University of Lincoln runs an annual series of Distinguished Public lectures named after scientists connected to Lincoln and Lincolnshire. These include the Robert Grosseteste Lecture in Astrophysics, Edmund Weaver Lecture in Astronomy, Edward Delaval Lecture in Physics, Newton Christmas Lecture, Charlotte Scott Lecture in Mathematics and Boole Lecture in Mathematics. The Edmund Weaver Lecture in Astronomy celebrates the work by Edmund Weaver (1683 – 1748) from Frieston in Lincolnshire. Edmund was an English astronomer whose publication of astronomical tables "The British Telescope ephemerides" was highly regarded in the 18th-century for the movement of planets. In honour of Edmund Weaver, the annual lecture is always on planetary science.

The 3rd Edward Weaver Lecture in Astronomy was given this year by Dr Phil Sutton about the outer solar system titled "What do we really know about the outer solar system?" Dr Sutton is a Lecturer in Astrophysics at the University of Lincoln whose research interests are planetary rings, exoplanets and exomoons.

UNIVERSITY OF LINCOLN

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More information about upcoming public lectures and the School of Mathematics and Physics can be found at the following link: www.lincoln.ac.uk/smp

Footnotes in this article are commentary by John Davies and Rob Swinney of i4is.

Since the 1950's thousands of spacecraft have been put into orbit or sent further afield, with the majority of those leaving Earth's gravity only making it as far as Mars or Venus. The number of spacecraft that have made it past Neptune and into the Kuiper belt can be counted on one hand. These include Pioneer 10 & 11, Voyager 1 & 2 and the New Horizons spacecraft.

Dr Sutton began with a brief look at the four giant outer planets Jupiter, Saturn, Uranus and Neptune. Both Jupiter and Saturn have had spacecraft, in the form of Cassini for Saturn and Juno and Galileo for Jupiter, studying them in-situ for several years. The scientific discoveries made by these spacecraft have exceeded original predictions but more importantly have raised more questions about the two furthest planets. Uranus and Neptune have never been orbited by spacecraft; in fact, most of what we know about these cold giants comes from the single flyby of the Voyager 2 spacecraft.

Pioneer 10 & 11 did not fly past Uranus or Neptune and instead focused other important scientific observations of the outer solar system like the solar wind and magnetic field. Voyager 1 was also taken out of the equation for exploring the outer most planets with a diversion past Titan which sent it on a trajectory out of the ecliptic*.

* Voyager 1 was diverted out of the planetary ecliptic after it's passage of Saturn (deliberately as the only way to get the spacecraft past Titan). It didn't flyby Uranus or Neptune. Voyager 1 makes, and Pioneer 10 &11 made, useful scientific observations of the outer solar system (solar wind, magnetic fields etc) but not the planets further out. The Pioneers are now defunct.

Uranus is a strange planet that rotates backwards compared with the other planets with an inclination at almost 9 degrees to the orbital plane. The orientation of the moons, rings and Uranus' rotation all point towards a catastrophic collision with another planetary sized object*.

The final planetary stop when on an outward journey through the solar system is Neptune, another cold gas giant. Although not the biggest planet it does hold a few records within the solar system. It has the highest recorded wind speeds of any planet in excess of 2,000 km/hr and the largest moon to orbit in a retrograde motion, Triton. The unusual orbit of Triton which is backwards and very inclined to moons compared to those that would normally form in-situ around a planet. Despite being a moon Triton shares many characteristics with Pluto, a Dwarf planet in the Kuiper belt. They both have a tenuous nitrogen atmosphere, similar surface compositions, similar mean densities and even evidence of cryovolcanoes. Triton is larger than Pluto so if it was not captured by Neptune it would likely be the largest object in the Kuiper belt discovered to date.

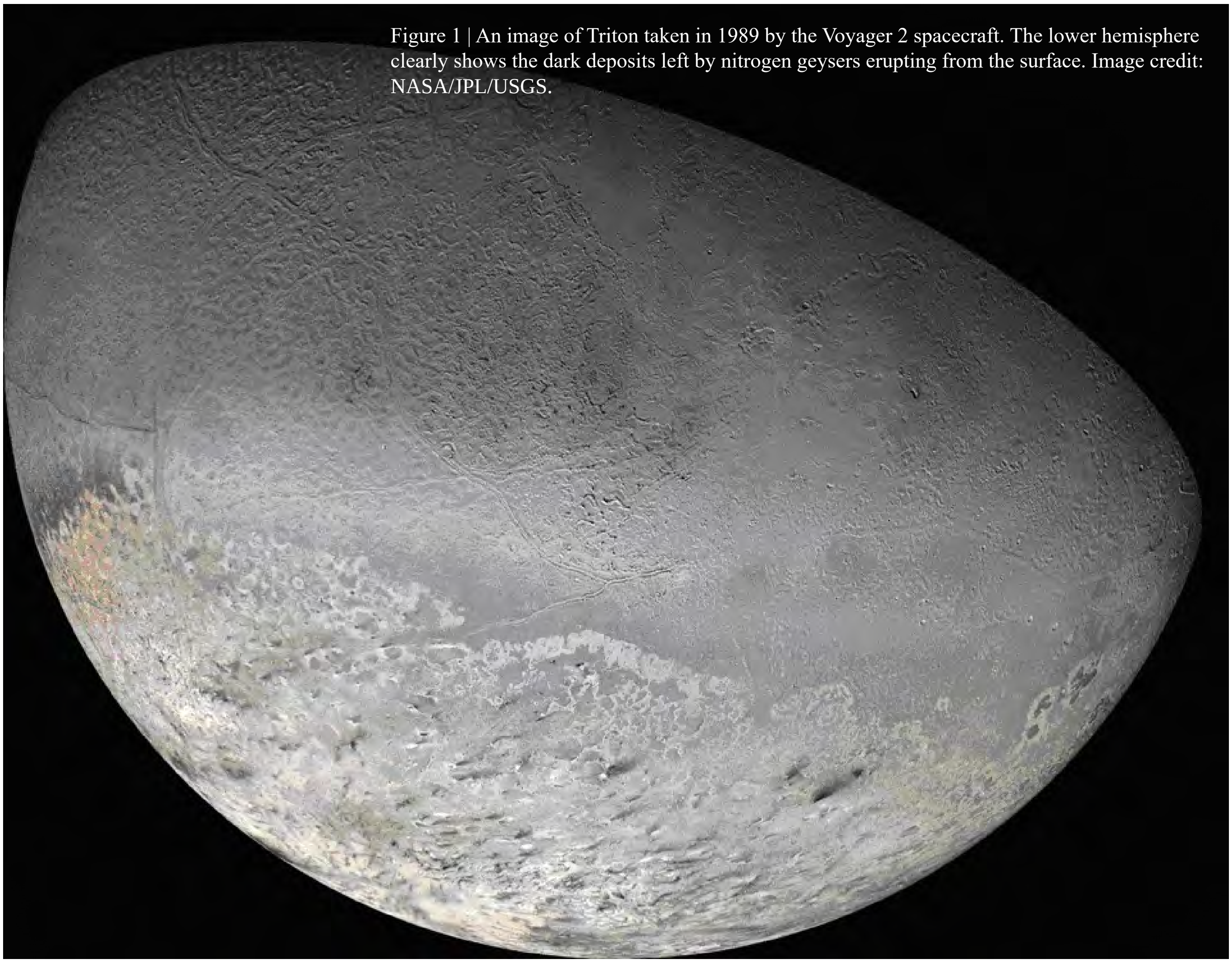


Figure 1 | An image of Triton taken in 1989 by the Voyager 2 spacecraft. The lower hemisphere clearly shows the dark deposits left by nitrogen geysers erupting from the surface. Image credit: NASA/JPL/USGS.

Viewed from Earth Pluto looks small and featureless, but in 2015 the New Horizons spacecraft made it closest approach revealing a fascinating frozen terrain. Large water ice mountains towered over polygon shaped frozen nitrogen planes formed by convection cells in the frozen nitrogen, suggesting a warmer interior.

Pluto resides in the Kuiper belt which begins at the orbit of Neptune (30 AU) and extends all the way to 50 AU. Millions of icy objects orbit the Sun in this disc that were left over from the formation of outer planets.

* *Consequences of Giant Impacts on Early Uranus for Rotation, Internal Structure,Debris, and Atmospheric Erosion*, J A Kegerreis (Institute for Computational Cosmology, Durham University, Durham, DH1 3LE, UK) et al, The Astrophysical Journal, July 2018, iopscience.iop.org/article/10.3847/1538-4357/aac725/pdf

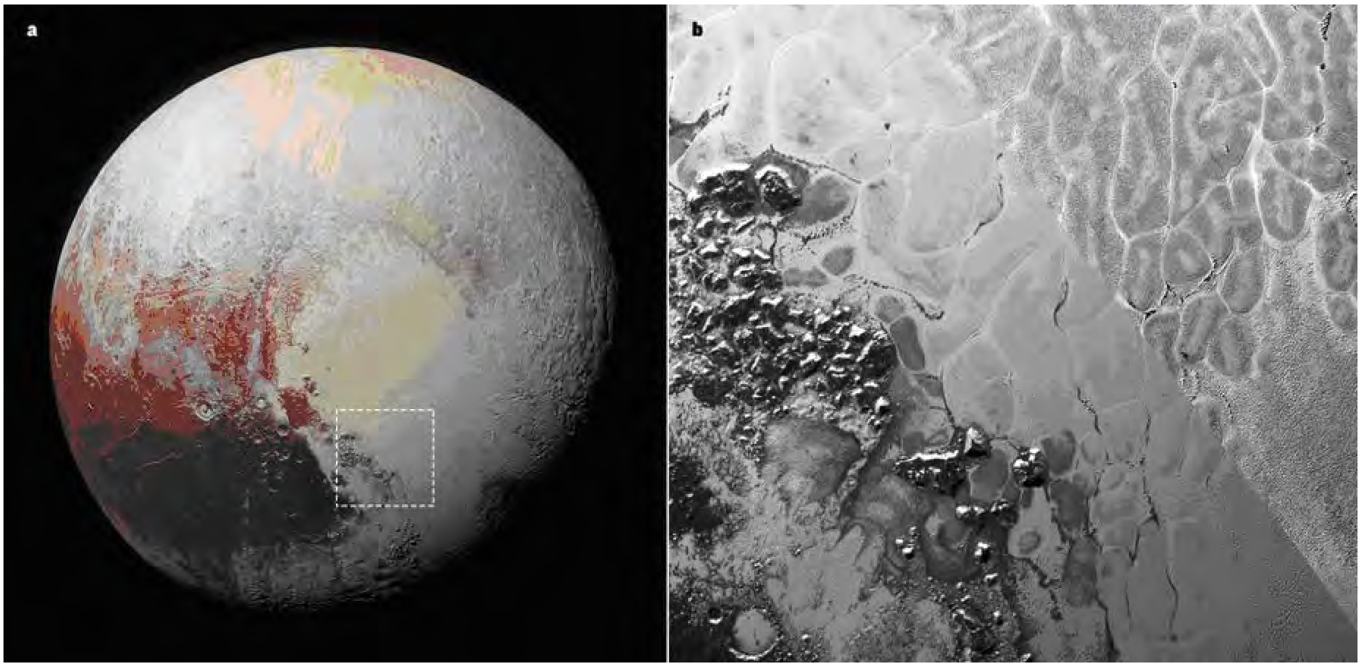


Figure 2 | Convection cells in the frozen nitrogen creates these unusual polygon shaped structures.
Image credit: NASA/Johns Hopkins University Applied Physics Laboratory / Southwest Research Institute.

Compared to the planets the orbits of Kuiper belt objects are very elliptical and inclined which can cause them to cross each other's orbits. Thus, collisions have played an important role in shaping the present-day Kuiper belt. Pluto and its moons are thought to be the result of a catastrophic collision at some point in its past. Many Kuiper belt objects, like Pluto and its moon Charon, are binary systems. Here, the two main bodies are of a similar size and orbit a common centre of mass. In some cases, like the Kuiper belt object Ultima Thule they are touching, which is known as a contact binary. Triton, Neptune's largest moon, was originally thought to be in a binary system with another Kuiper belt object before passing close to Neptune. The process that captured Triton, as a moon of Neptune, put it on a retrograde orbit while ejecting the second component of the binary (solarsystem.nasa.gov/moons/neptune-moons/triton/in-depth/). Theoretical work has suggested that earth-like planets are capable of being captured onto stable orbits around larger gas giants in similar events. Therefore, future searches for life outside the solar system do not have to be confined to finding earth like planets but can be extended to exomoons.

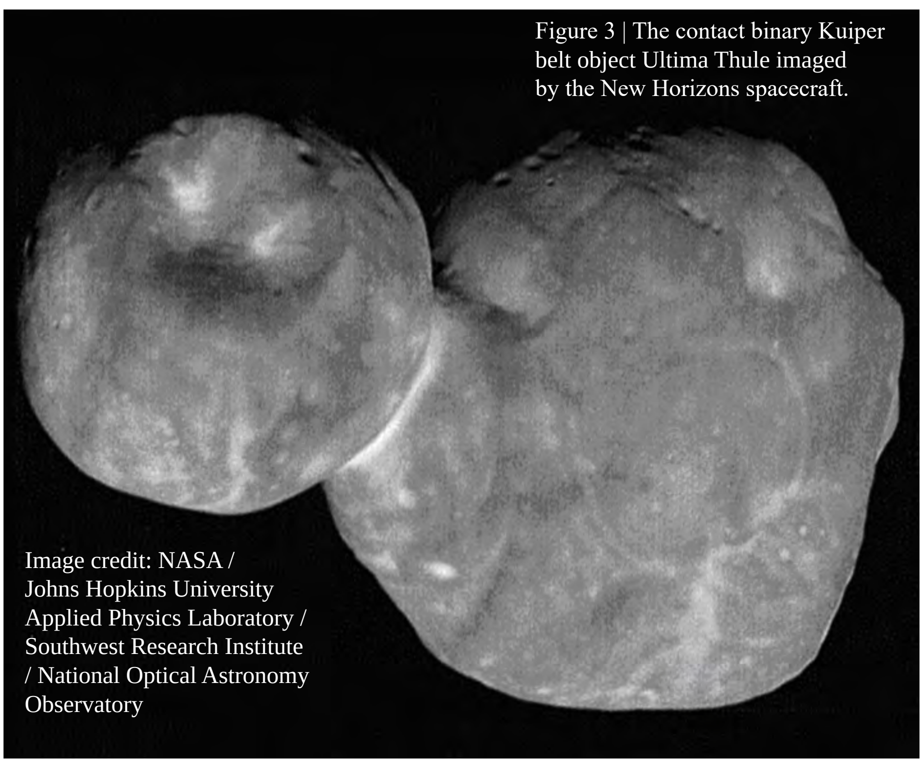


Figure 3 | The contact binary Kuiper belt object Ultima Thule imaged by the New Horizons spacecraft.

Image credit: NASA / Johns Hopkins University Applied Physics Laboratory / Southwest Research Institute / National Optical Astronomy Observatory

The study of binary objects in the Kuiper belt can give important clues to its origin. Since most are formed by either dynamic capture or collisions the frequency of such events can help constrain things like the mass and distribution early in the evolution of the solar system.

Compared with other groups of minor planets Kuiper belt objects live very safe and stable lives. For example, a group known as centaurs have orbits that lie between the orbits of the four outer planets. They are known as centaurs as they show characteristics of both asteroids and comets. Their orbits are dynamically unstable as they regularly cross the orbits of Jupiter, Saturn, Uranus and Neptune. Within around a million years most centaurs will have their orbits perturbed by close passes to the outer planets such that they are captured as new moons, sent inwards to become a comet, sent inwards to plunge into the Sun or be ejected into interstellar space. It is thought that many centaurs originated from the Kuiper belt but had their orbits perturbed by the planets over time, sending them onto orbits that crossed the paths of the outer planets. Many of the irregular moons of the outer planets, which have retrograde orbits, likely originated as centaurs.

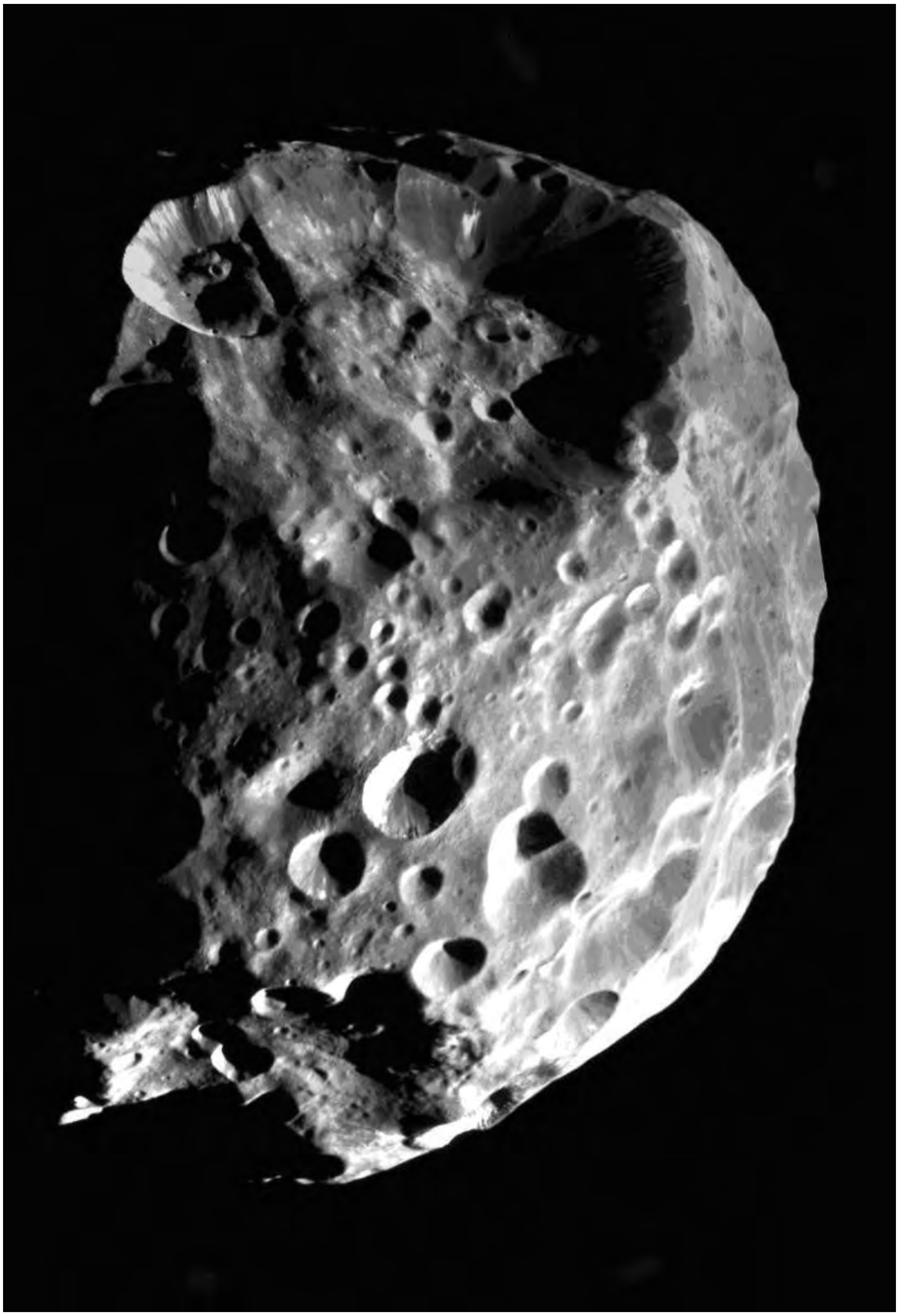


Figure 4 An image of the irregular moon of Saturn, Phoebe, taken by the Cassini spacecraft in 2004. Phoebe is thought to be a captured centaur due to its retrograde and inclined orbit, something that is not possible if it formed in-situ around Saturn.

Image credit: NASA/JPL/Space Science Institute.

As if centaurs weren't strange enough some have been discovered to have narrow rings orbiting them. Up until the discovery of two narrow rings around the Centaur Chariklo in 2013 only the large outer planets were thought to have rings of material orbiting them. Many of the rings around the planets also have moons nearby which gravitationally herd ring material to create gaps and truncated edges. Planetary rings in the absence of moons would undergo a viscous spreading which result in less defined edges and no narrow rings. Yet the two centaurs Chariklo and Chiron and the Kuiper belt object Haumea have been found to have narrow rings without the gravitational perturbations of nearby moons. How are they able to support stable narrow rings? One clue can be found with Haumea which is of a similar size and composition to Pluto but instead of being spherical it is very elongated. Its fast rotation causes it to be stretched out along its equator into a triaxial ellipsoid (en.wikipedia.org/wiki/Haumea#Size,_shape,_and_composition). Taking just under 4 hours to complete one rotation it is the fastest rotating object greater than 10 km in the solar system. Any faster and it would pull apart. The ring lies close to the 1:3 resonance with the rotation of Haumea which was found to be unstable. However, a stable region close to the 1:3 resonance was found to be stable and consistent with the location of the ring.

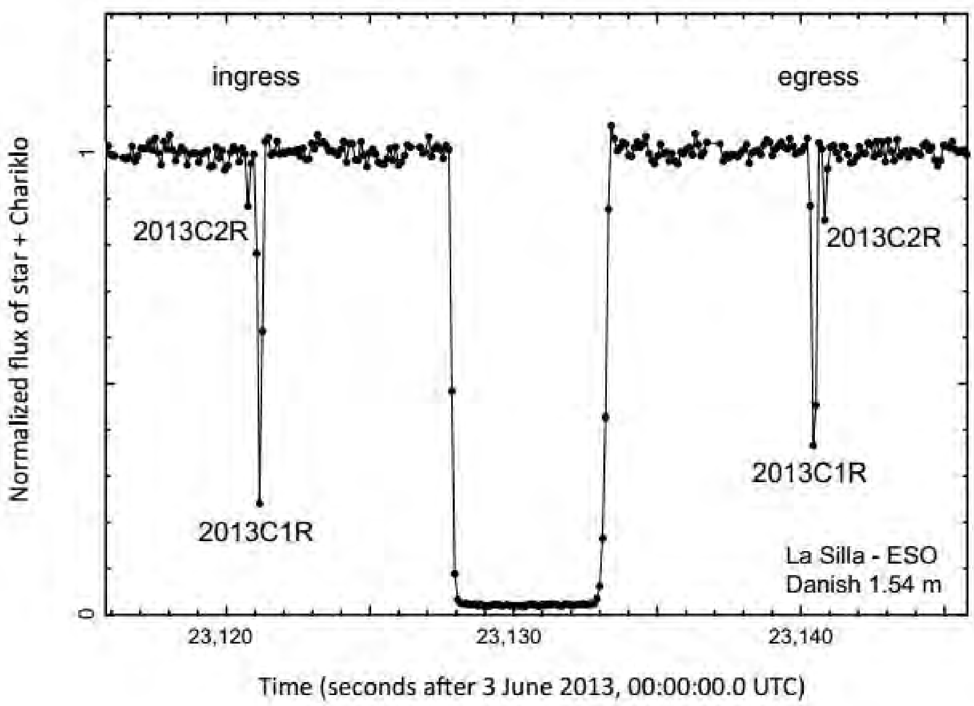


figure 5 Light curve of Chariklo's transiting a background star. The large central dip is due to Chariklo blocking light from the background star while the two narrower dips, identified as 2013C1R & 2013C2R, are due to two rings transiting.

Credit: F. Braga-Ribas et al.

In 2017 the first object in the solar system confirmed to be from an interstellar origin was discovered. Oumuamua* was discovered as it was already leaving the solar system. Its trajectory and velocity were too great to be gravitationally bound to the sun. Oumuamua was found to have a very elongated cigar like shape and was tumbling instead of rotating in one axis; something that collisions with other objects likely initiated. 2019 saw a second interstellar object (ISO) known as C/2019 Q4 (Borisov) discovered on a similar hyperbolic trajectory through the solar system. This object was travelling faster than Oumuamua and showed the characteristics of a comet, which made it the first known interstellar comet to pass through the solar system. Understanding these interstellar visitors as they pass through can reveal secrets to how planetary systems form. Although these are the first to be discovered it has been theorized for some time that these objects are out there in interstellar space.

It has been theorized for some time that Oort cloud objects could be ejected into interstellar space from our own solar system due to external perturbations. As stars orbit the centre of the Milky Way galaxy they sometimes pass very close to one another. The orbits of the outermost objects, in the case of the solar system the Oort cloud, can be perturbed by stars moving nearby. The most recent close encounter to the solar system occurred 70,000 years ago where a red dwarf and brown dwarf binary system, known as Scholz's Star, passed through the outer Oort cloud. This sent many long period comets into the inner solar system and ejected more into interstellar space, although comets will take 2 million years to travel to the inner parts of the solar system.

*see Principium, P19, November 2017 *Project Lyra: Sending a Spacecraft to the Interstellar Asteroid*. and Principium, P27, November 2019, *2I/Borisov - the second interstellar object*. Project Lyra is an ongoing endeavour by i4is to devise means of reaching such ISOs (i4is.org/what-we-do/technical/project-lyra/).

There is a group of Kuiper belt objects with semi-major orbital axes greater than 250 AU that appear to share a common interaction with an unknown object. The gravitational effects of a hypothetical planet about 10 times the mass of Earth with a semi-major axis of 400 – 500 AU from the Sun can cause the orbits of this group of Kuiper belt objects. Scientists are currently still divided on the possibility of a ninth planet in the solar system as other mechanisms could be responsible for the clustering of orbits, like a large icy disc instead of a planet. However, the presence of some unknown planetary object is still a good possibility.

A more intriguing idea recently proposed by two scientists is that planet 9 could be a primordial black hole. All of what we infer about the suspected unknown planet comes from its gravitational interaction with other objects. Any object of a comparable mass would give the same result so there is no immediate reason why a black hole of approximately 10 earth masses cannot be the culprit. Black holes are typically formed when large stars die or when objects like neutron stars collide. It is mostly defined by mass and a stellar black hole, one that has a stellar origin, will be greater than 3 solar masses. Lower mass black holes can be formed but from a different process early in the universe when density fluctuations would have exceeded critical densities to allow gravitational collapse into a black hole. These types of black hole are known as primordial as they must form early in the universe, which would be the case for planet 9.

There was another aspect that made the scientists consider a black hole as a candidate for planet 9. An experiment known as OGLE (Optical Gravitational Lensing Experiment) has found an excess of microlensing events in the outer solar system, interpreted as a population of primordial black holes*. The light from background stars is briefly bent by some unknown mass passing in front. To observers on earth this can look like a brightening of the star. Again, the mass of the objects responsible for the bending the light can be inferred and was on the order of earth masses. Until an object is found in the outer solar system to account for these anomalies, we will never really know. However, a black hole could also explain why it has been very hard to find despite dedicated searches over the last few years.

With limited resources to explore our solar system and beyond and the abundance of unknowns in the outer solar system, where should we focus our future missions? **

Editors Note

i4is programmes like Project Glowworm (laser sail demonstrator in low earth orbit), Project Lyra (methods of reaching interstellar objects) and ongoing studies of interstellar missions based on i4is work such as Projects Dragonfly and Andromeda are all, inevitably, relevant to the science of the Outer Solar System and the technology required to reach it. This is an area of increasing relevance worldwide, notably the Johns Hopkins University - Applied Physics Laboratory (JHU-APL) reported in *An Interstellar Probe for the next Heliophysics Decadal Survey* reported in the last issue of Principium, Issue 27, November 2019, page 23 and in other reports of IAC 2019 in the same issue.

*This perhaps suggests there could be many primordial black holes(/planets) in the outer solar system rather than one (the supposed Planet 9)? One example-type would only produce microlensing events in a very small part of the sky as it very slowly moved in it's orbit.

**There is interesting science to be done with flybys, orbiters and landers, and interesting science on the way (the Kuiper Belt, the heliosphere, the IS boundary, pristine ISM, solar focal point and beyond!). From an i4is point of view this would provide technology drivers which are on the technical roadmap for developing interstellar capable probes etc

About the Author

Dr Phil Sutton first contributed to Principium with *Implications of the Gaia Mission for Future Interstellar Travel* in Principium 23, November 2018. As a lecturer in the Lincoln School of Mathematics and Physics at the University of Lincoln, Phil is member of a team founded in 2014 researching in fundamental and applied mathematics and physics, ranging from pure mathematics to applied nano-science at the interface between biology, chemistry, physics, and mathematics. The Founding Head of the Lincoln School of Mathematics and Physics is Professor Andrei Zvelindovsky. His primary research field is Computational Physics.

BOOK REVIEW: The Contact Paradox: Challenging our Assumptions in the Search for Extraterrestrial Intelligence

Keith Cooper (Bloomsbury Sigma, 2019)

Reviewed by Patrick Mahon

Keith Cooper is a long-time friend of i4is, having been Principium's editor for the first eight issues of the magazine. In Keith's day job, he edits two popular science magazines, *Astronomy Now* and *Astrobiology Magazine*. However, he is also a freelance science journalist who has written for many outlets including *New Scientist, Sky and Telescope, Physics World* and Paul Gilster's excellent interstellar blog *Centauri Dreams*.

Credit: Bloomsbury Publishing

In *The Contact Paradox*, Keith Cooper* examines a question that is extremely relevant to readers of Principium: is humanity's current approach to the Search for Extraterrestrial Intelligence (SETI) the right one? If it is, what conclusion should we draw from the fact that six decades of SETI work has returned no verifiably positive results? Are we alone in the universe – or are we just doing SETI wrong?

What I liked about this book from the start was that Cooper didn't waste time with a long introduction to SETI. Like the best fiction authors, he jumped straight into his story, capturing the reader's attention immediately.

Cooper's starting point is the concept of altruism, meaning the principle and practice of exercising moral concern for the wellbeing of others. 'What does that have to do with SETI?', I hear you ask. In his first chapter, Cooper examines the extent to which our approach to SETI has been premised on this assumption: that any intelligent alien species which chooses to send messages out into the universe will inevitably do so for the best of reasons, altruistically transmitting information that will be of use to any recipients.

The case was famously argued by Carl Sagan in 1982, when US Senator William Proxmire was central to congressional attempts to delete any funding for SETI experiments from NASA's budget. Sagan visited Proxmire's office and, knowing that the senator was deeply concerned about the ever-present threat of mutually assured destruction, pointed out that while modern *homo sapiens* has only existed for around 300,000 years, the Universe is nearly 14 billion years old. Statistically, it's therefore almost certain that any intelligent species living elsewhere in the Universe will be much older than us. They will presumably have lived through and solved similar existential crises, such as the threat of nuclear war. Sagan drew two conclusions from this: first, that detecting a signal from extraterrestrials would prove that it was *possible* to survive these kinds of growing pains, and second, that any such aliens might even be willing to tell us *how* they did it. Proxmire was convinced, and NASA's SETI funding survived for another decade before another politician, Senator Richard Bryan, killed federal funding for SETI studies in the US in 1993.

Having set out the background, Cooper queries the widespread assumption amongst SETI's advocates that aliens will act altruistically. In the first place, sending signals out to the stars will inevitably cost energy, money, time and effort. A comprehensive attempt to tell others of your presence could potentially bankrupt an alien civilisation, or at the very least use up significant resources that could otherwise have been directed to domestic purposes. What is the payoff to the aliens for doing this? Amongst humans, we are generally more likely to act altruistically towards relatives and friends than towards complete strangers, because

* book launch at the Royal Institution November 2019 - www.youtube.com/watch?v=BV_DkQCNfu4

they’re more likely to return the favour in the longer term. But by definition, this ‘kin altruism’ does not apply to SETI, since they’re aliens and we’re not. Another argument is that Darwinian evolution will inevitably lead successful alien species (i.e. those that are still around to undertake SETI) to be ever more altruistic, as it makes survival to the next generation more likely, compared to selfish behaviour. However, the evidence behind this claim seems pretty weak. Finally, one look at the television news should be enough to make anyone sceptical that humanity is on a one-way trip towards universal altruism, and that it’s therefore a Darwinian imperative. So perhaps the jury’s out on the reason way aliens would indulge in SETI at all.

Cooper’s next target is the I in SETI. What do we mean by ‘intelligence’? He sees it as another huge assumption in the SETI field that when we say ‘intelligence’, we actually mean ‘a technological civilisation’, since we’re mostly looking for signals (e.g. radio waves) that only a species able to produce technological innovations would be able to generate. As Cooper points out, a moment’s thought is enough to see that this is an example of anthropomorphism, since it presumes that all intelligent alien species will be sufficiently like humanity to develop technologies of the kind that we would recognise. His killer argument involves auditing the ecology of Earth, and recognising that humans are not the only intelligent species on the planet, no matter how much we might like to think we are. At minimum several other species, including the great apes, many types of dolphins and whales, and both African and Indian elephants demonstrate many behaviours indicative of intelligence. However, none of these species are technological in nature, and were they, or their analogues, to exist on another planet, we could never expect to receive signals from them to confirm the fact.

Over the following four chapters, Cooper discusses a number of other assumptions that may skew the validity of our approach to SETI. First is the question of where we should be looking. Over recent years we’ve identified lots of exoplanets orbiting distant stars. In deciding which of these are the best potential SETI targets, a good starting point is obviously the conditions on Earth. These include a breathable atmosphere, liquid water on the surface, a planetary magnetic field to protect us from cosmic rays, and a host star that is pretty stable. At the same time, alien life could be very different from us, so perhaps we shouldn’t be quite so prescriptive?

So far, most of SETI has been based on the early decision that radio waves are the natural means of interstellar communication. That may be right, but it may also be an accident of the fact that radio astronomy and SETI started at the same time. Some researchers think that infrared lasers may provide a better technical solution to sending complicated messages between the stars. If we put all our eggs in the radio basket, might we be missing a trick?

A completely different approach to SETI that has come to the fore in recent years consists of searching not for deliberate signals from aliens, but instead for the by-products of organic life in general, and intelligent, technological life in particular. Such signs could vary in scale widely, from finding oxygen or methane in individual planetary atmospheres at one end, right up to finding so-called Dyson spheres (alien-made structures enclosing a star in order to capture its entire energy output; such structures are likely to be visible in the infrared as they will be a lot warmer than their surroundings) at the other. In the middle of this scale, we could look for evidence of alien spacecraft flying around. Cooper acknowledges here the work done by BIS, i4is, and many others on starship designs like Project Daedalus and Project Icarus, which may help us understand what to look for. These are all promising new avenues to explore, but you won’t be surprised to know that, from Cooper’s perspective, each of them comes with caveats and qualifications which he’s happy to spell out.

The next aspect of the SETI debate that Cooper considers is time. He contrasts two very different timescales: the rapid changes in recent human activity, varying significantly over decades and centuries, and the massively longer timescales of geological and astronomical activities, which typically change over millions of years at minimum. If intelligent technological civilisations evolve over relatively short timescales, like humans, the likelihood of them being alive and signalling during our first sixty years of doing SETI is very small. On the other hand, even if they are potentially long-lived, there are still many things that could wipe them out, including nearby supernovas, gamma ray bursts or the death of their own star. Either way, perhaps the reason we haven’t seen any signals yet is because intelligent civilisations never last very long. There’s a sobering thought.

In the penultimate chapter, Cooper discusses perhaps the most controversial aspect of the SETI debate: to

METI (Messaging Extraterrestrial Intelligence) or not to METI? Supporters of METI insist that we are a species of explorers, and our history proves the value of exploring, meeting new peoples, and exchanging knowledge and goods. They also note that the huge distances between the stars mean that the risks from METI are minimal, since it will be an awfullly long time before any aliens who see our signals could get to Earth, even if they wanted to invade or (unintentionally) infect us with their alien germs. Opponents of METI, on the other hand, point out that the risks of deliberately advertising our existence to aliens of unknown capabilities and attitudes are unquantifiable, and should not therefore be taken by anybody until the issue has been fully and properly discussed and debated by the entire world community.

This brings Cooper back to the name of his book. For him, the Contact Paradox is encapsulated in the SETI versus METI debate*. Proponents of SETI spend their time looking for signals from intelligent aliens. Opponents of METI insist that we should not send such signals out into the universe, because it's too risky. But if it's a bad idea for us to do it, why wouldn't the same be true for the aliens? Could this be the reason behind SETI's failure to date?

In the final chapter, Cooper reveals his own conclusions. He believes that we should develop a 21st century approach to SETI, which moves beyond our focus on radio waves to look for other types of signals, including infrared lasers and broader technosignatures. We should use the power of 'big data' to analyse the huge datasets coming from the new generation of telescopes, looking for anomalies and outliers. In addition to finding new exoplanets, he thinks we should spend more time trying to identify which of them might harbour life. Then, having identified the nearest potentially inhabited exoplanets, Cooper thinks that the Breakthrough Starshot project should send laser sails towards them at one-fifth the speed of light, to see what we can image. And finally, if and when we detect signs of intelligent life, let's study it remotely. Only if they look friendly should we then send them messages. It's a proposal that seems eminently sensible to me.

The Contact Paradox is a fascinating, wide-ranging and thoroughly enjoyable exploration of the issue of SETI. Keith Cooper brings the rational scepticism of a science journalist to the topic, looking cold and hard at the many anthropocentric assumptions that underpin our historical approach to the search for aliens. At the same time, Cooper is very widely read and brings a broad knowledge of many aspects of science fact and science fiction to bear upon his chosen subject. If you're looking for a single volume overview of the SETI debate, look no further.

Keith at the Royal Institution of Great Btitain (RIGB) - addressing an audeince in the Faraday Theatre. Credit RIGB

*See also Keith's 2017 contribution to this debate at www.centauri-dreams.org/2017/12/11/meti-a-longer-term-perspective/

Interstellar News

John I Davies reports on recent developments in interstellar studies

BIS Executive Secretary Vacancy

Having heard the news a little earlier, the i4is team was nevertheless sad to hear officially that Gill Norman is stepping down as Executive Secretary at our ancestral home, the **British Interplanetary Society**. The Society announced the vacancy on 15 February -

www.bis-space.com/2020/02/15/24017/executive-secretary-vacancy

These are tough boots to fill (Doc Martens in physical terms!). Gill has been a major asset to BIS as they announce -

> "We would like to thank Gill for the time that she has given to the organisation and to what many appears as an effortless contribution where Gill has worked tirelessly, giving up many hours and working above and beyond what was expected for this role. Bringing significant change to the Society so far has been a huge challenge but this change is clearly visible to many, and without Gill this never would have happened"

Gill was also an early supporter and major contributor to i4is. She is a superb organiser, a charmer of the most awkward of us and a personal friend to many of us. We hope that BIS can find someone of similar qualities and we wish Gill all the best in her future endeavours.

Galactic Matter and Interstellar Flight

By

R. W. Bussard[1]

(With 4 Figures)

(*Received February 1, 1960*)

Abstract — Zusammenfassung — Résumé

Galactic Matter and Interstellar Flight. This paper describes a vehicle which uses the interstellar gas as a source of energy (by nuclear fusion) and as a working fluid. By this means high ship velocities and consequent short flight times can be attained in spite of the inadequacy of nucleon rearrangement reactions for interstellar flight by rocket. Study of the relativistic flight mechanics of this interstellar ramjet shows that maximum vehicle accelerations of the order of earth-gravity can be achieved with fusion-powered vehicles only if the frontal area loading density per unit interstellar gas density is 10^{-8} (gm/cm^2) per (reactive nucleon/cm^3) or less. Graphs are presented showing the theoretical performance of such ramjet ships.

Galaktische Materie und interstellarer Flug. Diese Arbeit beschreibt ein Fahrzeug, welches das interstellare Gas als Energiequelle (durch Kernfusion) und als Arbeitsmedium benützt. Relativistische Untersuchungen dieses interstellaren Staustrahlantriebes zeigen, daß maximale Fahrzeugeigenbeschleunigungen von der Größenordnung der Erdbeschleunigung nur dann erreicht werden können, wenn die frontale Flächendichte kleiner oder höchstens gleich ist 10^{-8} g/cm^2 für jedes reagierende Nucleon. Diagramme zeigen die Wirkungsweise eines solchen Antriebes für verschiedene Werte dieses Parameters.

Matière galactique et vol interstellaire. Description d'un véhicule utilisant le gaz interstellaire comme source d'énergie par fusion et comme fluide propulsif. La mécanique relativiste de ce statoréacteur interstellaire promet des accélérations de l'ordre de celle de la pesanteur terrestre si la charge frontale est au plus égale à 10^{-8} g/cm^2 par nucléon réagissant par cm^3. Les performances théoriques sont présentées graphiquement en fonction de ce paramètre.

1. Introduction

Characteristics of interstellar flight and the general prospects for its eventual attainment have been considered in some detail by several authors in recent years. In a pioneering paper, Ackeret [1] derived relativistically correct equations of motion for the powered flight of rocket vehicles. From these it was

[1] Presently with the Los Alamos Scientific Laboratory of the University of California, Los Alamos, New Mexico, U.S.A.

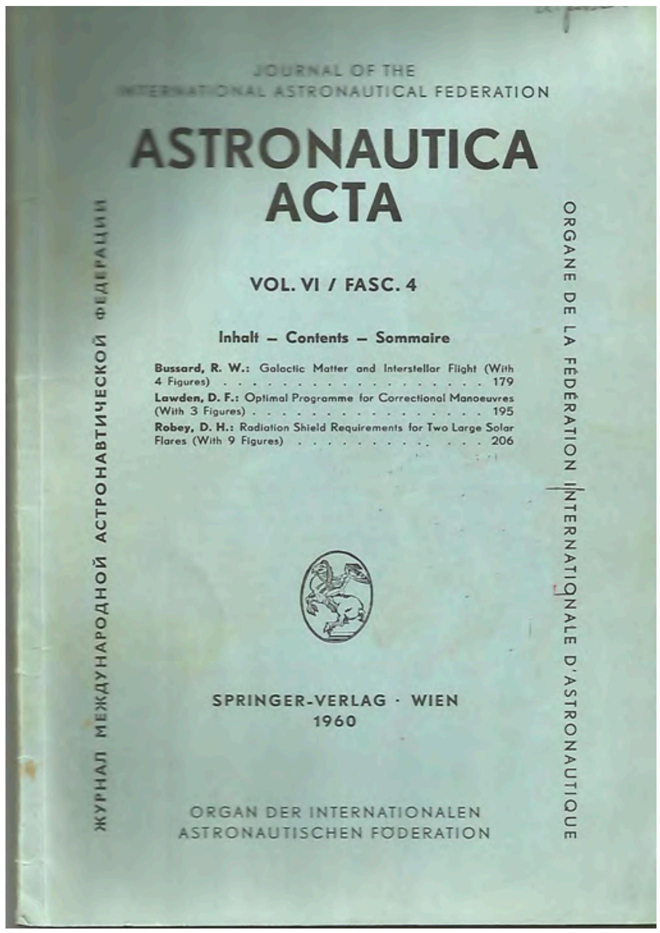
Astronaut. Acta Vol. VI Fasc. 4 13

60th anniversary of the Bussard Ramjet

This year is the 60th anniversary year of publication of the paper *Galactic Matter and Interstellar Flight*, by Robert W Bussard (Los Alamos Scientific Laboratory, University of California - Astronautica Acta, 1960, Volume 6, Fasc. 4).

Despite it having been found infeasible in its original form the influence of this paper in interstellar studies is hard to overestimate, from propulsion technology to fiction see *Retrospective: The Bussard Ramjet*, Principium, Issue 3, February 2013 Page 9 and the Bussard ramjet in Poul Anderson's 1970 novel 'Tau Zero'.

Taavishe Gupta of ISU is currently working on a review of the literature on Bussard ramjets.



1960 Acta Astronautica cover announcing *Galactic Matter and Interstellar Flight*

and first page of Bussard's paper

Credit: Acta Astronautica, thanks to Al Jackson

*available at - pdfs.semanticscholar.org/4bf2/79e8a95eb6408285f48c7d0f1e2757bcf384.pdf

Interstellar related papers at the LPSC

Interest in interstellar objects continues to grow, as demonstrated by a number of items at the 51st Lunar and Planetary Science Conference next month (LPSC, Woodlands Waterway Marriott Hotel and Convention Center, The Woodlands, Texas, March 16–20, 2020 www.hou.usra.edu/meetings/lpsc2020/). Some papers on this and related topics-

Comet Interceptor: A Mission to an Ancient World, Prof Geraint H Jones (Mullard Space Science Laboratory, University College London and The Centre for Planetary Sciences at UCL/Birkbeck, London), Dr Colin Snodgrass(University of Edinburgh) and others too numerous to mention at www.cometinterceptor.space/people.html

Comet Interceptor is a newly-selected European Space Agency mission to target a long period comet, preferably dynamically new, or an interstellar object. Launching to Lagrange point 2 in 2028 to await a suitable comet or ISO and taking a 3 component flyby probe from L2 on target detection and assignment. Details at -

www.hou.usra.edu/meetings/lpsc2020/pdf/2938.pdf

Bridge to the Stars: A Mission Concept to an Interstellar Object, Samuel W Courville (Planetary Science Institute, Lakewood, CO - swcourville@psi.edu) and 24 others

Presenting Bridge, a mission concept to flyby a yet-to-be discovered interstellar object as it passes through our solar system. Rapid launching on an Atlas V 431 class launch vehicle on target detection and assignment carrying flyby and impactor components. Details at -

www.hou.usra.edu/meetings/lpsc2020/pdf/1766.pdf

Interstellar Meteoroids: Distributions of Velocities, Motion Time, and Heliocentric Distances Upon Densities and Sizes, N I Perov (V V Tereshkova Cultural and Educational Centre, Yaroslavl, Russian Federation) and V E Pakhomycheva (K D Ushinskii State Pedagogical University, Yaroslavl, Russian Federation)

Arrivals in the Solar System from the interstellar medium have been found but their nature is not clear. Discovery and characterisation is a problem of modern astronomy and assumed velocities near the Earth's orbit are from dozens to hundreds kilometres per second. This paper suggests some heliocentric velocities may close to zero given light pressure, the Poynting-Robertson effect and Solar gravity. Details at -

www.hou.usra.edu/meetings/lpsc2020/pdf/1014.pdf

Double Jupiter Gravity Assist for Achieving High Heliocentric Asymptotic Escape Speeds and Missions to Interstellar Objects, Adam Hibberd, (Initiative for Interstellar Studies, London) and T Marshall Eubanks (Space Initiatives Inc, Newport, VA, USA)

Demonstrates ways of achieving high heliocentric asymptotic escape speeds required for missions to interstellar objects and/or the interstellar medium using Hibberd's OITS (Optimum Interplanetary Trajectory Software), a preliminary mission design tool. Suggesting a mission including a Jupiter gravity assist, a deep space manoeuvre out of the ecliptic plane and a Jupiter Oberth manoeuvre thus avoiding a solar Oberth manoeuvre and the requisite heat shield.

See also *News Feature: Interstellar Objects (ISOs)-Oumuamua, Borisov and objects in between* - elsewhere in this issue. Details at -

www.hou.usra.edu/meetings/lpsc2020/pdf/1110.pdf

Our i4is and Space Initiatives colleague T Marshall Eubanks also has another paper - *Local Navigation in Lunar Polar Regions with COMPASS, LunaCell, and Mobile Ad Hoc Geodesy* describing a “LunaCell” navigation system that can be deployed onto the lunar surface in advance of a new landing, either crewed or robotic. Details at -

/www.hou.usra.edu/meetings/lpsc2020/pdf/2805.pdf

Acta Astronautica - Another i4is Project Lyra paper

Project Lyra: Catching 1I/‘Oumuamua – Mission Opportunities After 2024 was published last month, January 2020. DOI: 10.1016/j.actaastro.2020.01.018

URL for paper on arXiv : arxiv.org/abs/1902.04935

Congratulations to authors Adam Hibberd, Andreas M Hein and T Marshall Eubanks - addressing the question of the feasibility of a mission to 1I/’Oumuamua in 2024 and beyond using Adam's OITS trajectory simulation tool to develop scenarios including a powered Jupiter flyby and Solar Oberth manoeuvre, a Jupiter powered flyby, and more complex flyby schemes including a Mars and Venus flyby.

Sadly for this writer the later, more feasible, launch dates in 2033 and 2048 mean he would reach age 84 and 102 respectively and the encounter dates 2048 and 2052 would make him 102 for the first and 106 for the second!

Amateur Astronomers Join Hunt for Exoplanets

In another step forward reported by Centauri Dreams, Alberto Caballero, coordinator of a project called the Habitable Exoplanet Hunting Project (exoplanetschannel.wixsite.com/home/project), drew our attention to another report on Paul Gilster's brilliant Centauri Dreams site, www.centauri-dreams.org/2019/12/10/amateur-astronomers-join-hunt-for-exoplanets/. Paul reported Alberto's project and the work of an Australian amateur astronomer, Thiam-Guan Tan, who has been involved in exoplanet hunting since 2016 at least. Alberto, a dedicated amateur astronomer in Spain, proposes that an amateur exoplanet hunters work in a coordinated fashion. He cites enthusiasts belonging to organisations such as TRESCA (TRansiting ExoplanetS and CAndidates) the American Association of Variable Star Observers (AAVSO) as examples.

Technology now accessible to amateur astronomers produces quite staggering results in many fields of the subject and we may find that they can become as important in this area as they have long been in comet and nova detection.

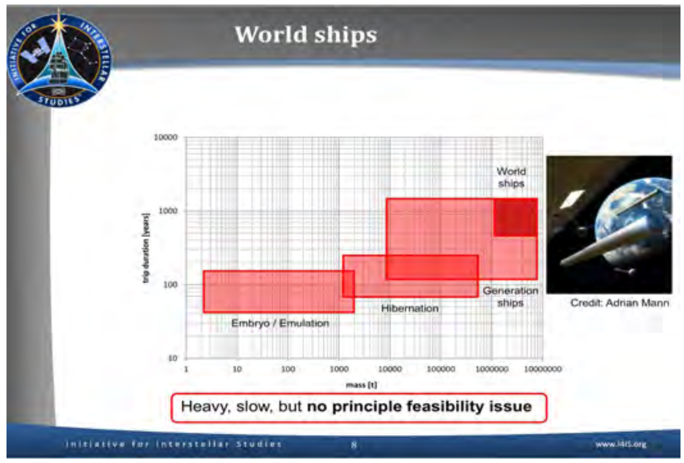
More press mentions for i4is

Appearing in the "popular" press is not always welcome to serious researchers. We all know the tabloid press stories which amount to "Wacky scientist finds Little Green Men on the Moon". However lets make the best of it and see if we can make it true that "all publicity is good publicity".

A couple of recent examples -

In the UK Daily Express "Breakthrough Starshot: The plan to escape Earth to Proxima b at 134,123,326 MPH", Tom Fish 27 December 2019 writes that Andreas Hein, executive director of the nonprofit Initiative for Interstellar Studies, told One Zero: “We know people can live in isolated areas, like islands, for hundreds or thousands of years; we know that in principle people can live in an artificial ecosystem. It’s a question of scaling things up. There are a lot of challenges, but no fundamental principle of physics is violated.”

In fact the One Zero article, *Scientists Are Contemplating a 1,000-Year Space Mission to Save Humanity,* featured our world ship work: onezero.medium.com/scientists-are-contemplating-a-1-000-year-space-mission-to-save-humanity-70882a0d6e47. This is a rather more considered piece by Corin Faife reporting the European Space Agency (ESA)’s first ever Interstellar Workshop, as reported in Principium *News Feature: Interstellar Workshop of the European Space Agency* Principium Issue 26 | August 2019 page 30.



Feasibility of Worldships from World Ships – Feasibility and Rationale, Andreas M. Hein, Cameron Smith, Frédéric Marin Kai Staats - presented at ESA Advanced Concepts Team Interstellar Workshop 20 June 2019.

A similar story appeared in the UK Daily Mail, more widely read though mainly, it seems, for its comprehensive coverage of celebrity gossip. As a wittier man once said "there is only one thing worse than being talked about and that is not being talked about!".

EMITS News -Request for Information - The Comet Interceptor F-Class Mission

ESA has issued a Request For Information (RFI) to collect preliminary information and initiate a dialogue with potential providers of small planetary spacecraft in ESA member states, preliminary to Invitations to Tender planned for Q2 2020. ESA is the Mission Architect in charge of *Comet Interceptor* spacecraft A and B2 procurement and development, of the procurement of the launch services and of both mission and science operations (Spacecraft B1 is the responsibility of the Japanese JAXA agency).

The RFI is at emits.sso.esa.int/emits-doc/ESTEC/esa_news/Comet-I_Cover_letter_RFI_31Jan2020.pdf

Challenges in Scientific Data Communication from Low Mass Interstellar Probe

David Messerschmitt, Philip Lubin and, Ian Morrison - respectively UC Berkeley, UC Santa Barbara (USA), Curtin University (Australia) - have addressed a major challenge for laser-push interstellar probes (open publication at - arxiv.org/abs/1801.07778). Even with the large swarm of probes made inevitable by relative scale economies of probes versus laser source, the 4 light year downlink results in a link budget to appal communications engineers. The paper looks at problems and possible solutions while being clear that new and greatly improved technologies may be available in the timeframe of the first operational downlink (see example table opposite)

They propose a novel burst-pulse-position-modulation (BPPM) with direct detection enabling high photon efficiency and innovations including a high peak-to-average transmit power ratio, the shortest atmosphere-transparent wavelength , adaptive optics for atmospheric turbulence, very low dark-count single-photon superconducting detectors and optical phased arrays for sky coverage shaping and coronagraph functionality. There is much food for thought in this 43 page paper and Principium hopes to revisit it more thoroughly in the next issue, analysing both research and proposals while maintaining our objective of intelligibility to the general interested reader.

Detecting Interstellar Objects Through Stellar Occultations

Professor Avi Loeb (Harvard and Breakthrough Starshot) will be familiar to Principium readers. In this paper (arxiv.org/abs/2001.02681) Amir Siraj and Abraham Loeb point out that incoming Interstellar Objects (ISOs) will pass in front of known stars and briefly block the light from them; this is occultation. They note that occultations have already been used to search for Kuiper Belt and Oort Cloud objects.

The network of telescopes proposed would be substantial so it would be useful to have an early estimate of costs.

Table 2. Physical parameters and performance metrics

	Description	Swarm	Single
A_e^T	Effective transmit aperture area (cm^2)	100	
Ω_A	Coverage solid angle (arcsec^2)	10.	0.01
ζ	Probe mass ratio	1.	
λ_0^R	Received optical wavelength (nm)	400	
P_W	Probability of weather outage	0.1	
P_D	Probability of daylight outage	0.52	
η	Optical detector efficiency	1.0	
K_s^R	Avg. detected signal photons per PPM slot	0.2	
BPP	Non-outage photon efficiency (b/ph)	10.9	
P_A^T	Avg. transmit power (mW)	29.4	0.8
P_P^T	Peak transmit power (kW)	638.	17.4
PAR	Peak-to-average ratio	4096.	
ρ_M	Reduction in moonlight irradiance relative to full moon	1	
Λ_D^S	Avg. rate of dark counts referenced to each sub-array (ph/yr)	32.0	
F_x	Optical source extinction ratio	10^{-7}	
F_c	Receive coronagraph rejection	0.01	
SXR	Signal-to-extinction ratio	2441.	
SIR	Signal-to-interference ratio	152.	4.15
SNR	Signal-to-noise ratio	8.3	226.
SDR	Signal-to-dark count ratio	8.2	223.
A_e^S	Effective receive sub-array area (cm^2)	6.8	6807.
N^S	Number of receive sub-arrays	$5.9 \cdot 10^7$	$2.2 \cdot 10^6$
$A_e^S N^S$	Total effective aperture area (km^2)	0.04	1.47
W_e	Effective optical bandwidth (MHz)	10.	
u_0	Probe speed (c)	0.2	
$D_{\{0,1\}}$	{Start,end} of downlink propagation distance (ly)	$\{4.24, 4.66\}$	

Physical parameters and performance metrics from Messerschmitt et al paper. Credit Messerschmitt et al

Have Starship, Will Travel Issue 19

Our friends and colleagues at the Tennessee Valley Interstellar Workshop (TVIW) announce the 19th issue of their newsletter, February 2020 (tviw.us/wp-content/uploads/2020/02/TVIW_Newsletter_N19_v02.pdf). They include more news of their 6th Interstellar Symposium and Advanced Interstellar Propulsion Workshop, see *News Feature: TVIW's 6th Interstellar Symposium and Advanced Interstellar Propulsion Workshop*, reported by Joe Meany elsewhere in this issue.

The major item in HSWT issue 19 an article by Marc Millis on work with the SpaceDrive project at Technical University of Dresden, *Testing Possible Spacedrives*. He describes thinking about this class of propulsion leading to a description of the Dresden team's work.

He begins with a discussion of hype versus reality in the area of breakthrough propulsion technologies and the unending conflict between popularisation of science and technology and the tendency of much journalism to seek sensation. This can lead to what Marc calls "reflexively dismissive reactions" and thus a tendency to reject all but the most conservative ideas. Marc has wide experience of this and other forms of hype and reaction to it with NASA's Breakthrough Propulsion Physics team and his long career in advanced space technologies (www.linkedin.com/in/marc-g-millis-050a801/) makes his musings a fine lesson on how interstellar studies needs to present itself. He surveys recent work in spacedrives - and how it has been presented.

Spacedrive ideas aim to go beyond the Newtonian physics of reaction propulsion, such as rockets, and the quantum physics of radiation propulsion, such as laser-push. Marc gives us a tour of ideas based on general relativity and the physics of space time, including Em drives, the Mach Effect Thruster and Mach's Principle (inertia exists because of the rest of the universe). For for more on this see *Breakthrough Propulsion Physics: Leave the fuel tank at home* by Dan Fries, see Principium 22 August 2018 page 39. Marc mentions the perils of false positives, derived from both physical and psychological effects.

Here HSWT gives us another contribution to the understanding of how we do interstellar studies, from the way we do it to the way we present it.

American Geophysical Union Fall Meeting 2019

The AGU has an increasing interest in matters relevant to interstellar. A couple of examples from their Fall Meeting (www.agu.org/fall-meeting)-

agu.confex.com/agu/fm19/meetingapp.cgi/Paper/502339

> *Electrostatic Solar Sail: A Propellantless Propulsion Concept for an Interstellar Probe Mission* - Anthony DeStefano
> .. a propellantless propulsion system that is driven by solar wind ions via electrostatic repulsion on multi-kilometer scale tethers...
> NASA Innovative Advanced Concept (NIAC) studies done at Marshall Space Flight Center, the feasibility of a heliopause mission within 10 years was shown, with escape speeds reaching up to 10 AU/year. One key advantage to the E-sail architecture is the 1/r force dependence on the solar distance. This slower drop off of force allows for longer, meaningful acceleration periods out to Saturn (10 AU) and beyond.

agu.confex.com/agu/fm19/meetingapp.cgi/Paper/547317

> T*hermal Heat Shield Analysis of Solar Thermal Propulsion during an Oberth Maneuver* - Jason J Benkoski, Johns Hopkins University Applied Physics Laboratory
> The feasibility of an interstellar probe hinges on the ability to achieve a high escape velocity.... One possibility is to perform a powered gravity assist around the Sun...The Oberth maneuver ... a spacecraft falls into the Sun's gravitational well and then performs an impulsive burn as it reaches its maximum speed. The asymptotic escape velocity is proportional to the square root of the change in velocity (ΔV) divided by the fourth root of the distance from the center of the Sun at the perihelion (r)... Combinations using current technology are either too heavy or generate too little thrust...therefore consider an unconventional approach that tackles both tradeoffs simultaneously–convert the heat of the Sun into usable thrust by passing a fluid through the heat shield...simultaneously increases ΔV and decreases r... calculations show that 500 kg of hydrogen flowing at a rate of 277 g/min-m2 over the course of a 30-minute acceleration makes it possible to go from 5.2 solar radii to 1.4 while maintaining the temperature of the heat shield constant at 2400 K. Taken together with the higher specific impulse, the escape velocity would increase by a factor of 2.3 versus a comparable hydrazine kick stage and heat shield.

For more about the latter see *The Equation used in the Benkoski Paper, A Derivation*, Adam Hibberd, elsewhere in this issue.

Interstellar communication network

A recent paper by Michael Hippke (Sonneberg Observatory, Sonneberg, Germany) follows up work by Greg Benford and suggests that if probes and planets with technological species exist in more than a handful of systems in our galaxy, it is beneficial to use a coordinated communication scheme. *Interstellar communication network. I. Overview and assumptions* is available on open publication at dec1.sinp.msu.ru/~panov/News/Texts/1912.02616.pdf and is published in The Astronomical Journal, February 5 2020 Volume 159, Number 3 iopscience.iop.org/article/10.3847/1538-3881/ab5dca/meta

Is Interstellar Object 2I/Borisov a Stardust Comet?

Our colleague T Marshall Eubanks, Space Initiatives Inc and i4is (US), has some further thoughts on our second known interstellar visitor- arxiv.org/abs/1912.12730.

He shows that Asymptotic Giant Branch (AGB)* stellar evolution may lead to the creation, out of stardust, of substantial numbers of nomadic Post-Main-Sequence Objects (PMSOs)* and that 2I/Borisov belongs to a kinematic dynamical stream, the Wolf 630 stream, with an age and galactic orbit consistent with its origination as a stardust comet.

* AGB - a region of the Hertzsprung–Russell diagram populated by evolved cool luminous stars - en.wikipedia.org/wiki/Asymptotic_giant_branch

PMSOs - What happens when a main sequence star runs out of hydrogen in its core? www.atnf.csiro.au/outreach/education/senior/astrophysics/stellarevolution_postmain.html

Recent interstellar papers in JBIS

The Journal of the British Interplanetary Society has again featured matters interstellar since we last reported.

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

General interstellar issue Vol 72 No.8 Aug 2019

ANOMALOUS VARIABILITY OF DYSON MEGASTRUCTURES Z. Osmanov & V.I. Berezhiani

SEARCHING FOR A STANDARD DRAKE EQUATION José Antonio Molina

ON FERMI'S PARADOX and Temporal Singularities Daniel Crevier

SOLAR-PUMPED BEAMED PROPULSION Interstellar Lightsail Mission Infrastructure Michiel Jacobus van den Donker

'OUMUAMUA AND SCOUT ET PROBES John Gertz

DETECTING EXTRATERRESTRIAL CIVILIZATIONS Utilizing Artificial Singularity Power Systems Robert Zubrin

ISSN 0007-084X PUBLICATION DATE: 2 DECEMBER 2019

Special issue: Foundations of Interstellar Studies Workshop II, 2019, Vol 72 NO.11 Nov 2019

IMPLICATIONS FOR SETI OF DARK MATTER Gary S Robertshaw

INTERSTELLAR PROBES: the Benefits to Astronomy and Astrophysics Kelvin F. Long

ADVANCES IN MACH EFFECT Gravitational Assist (MEGA) Drive Experimentation H. Fearn & J. F. Woodward

IS THE KUIPER BELT INHABITED? Gregory L. Matloff

THERE'S NO PLACE LIKE HOME (IN OUR OWN SOLAR SYSTEM): Searching for ET Near White Dwarfs John Gertz

ISSN 0007-084X PUBLICATION DATE: 30 JANUARY 2020

More about *Foundations of Interstellar Studies Workshop II* in News Feature: Foundations of Interstellar Studies Workshop 2019, Patrick Mahon, Principium 26, August 2019, page 4.

i4is at the Royal Institution - 2020

As we reported in Principium 26 August 2019 page 23 *i4is at the Royal Institution - 2019* i4is was invited back for a second year at the RI. We are proud to announce that we will be back for a third summer at this prestigious and venerable UK institution. We don't yet have dates but look out for *Skateboards to Starships* on their website www.rigb.org/families/summer-schools and reward your age 13-15 or 16-18 interstellar scientist, engineer or mathematician with a mind stretching day at the RI.

Foundations of Interstellar Studies Workshop 2020

The Interstellar Research Centre of Stellar Engines, UK and the Limitless Space Institute, USA, have announced an additional Foundations of Interstellar Studies Workshop, FISW2.5-2020, ahead of the already planned FISW3.0-2021. Organised by Co-Chairmen Kelvin F Long, Interstellar Research Centre, Rob Swinney, Initiative for Interstellar Studies, and Harold 'Sonny' White, Limitless Space Institute.

Our co-founder Kelvin Long, our Deputy Director, Rob Swinney, and Sonny White, Director, Advanced Research & Development, at the Limitless Space Institute and former Advanced Propulsion Theme Lead at NASA, plan a special more focussed workshop with an intended smaller attendance, designed to have enhanced discussions and calculations following on as an overflow from the FISW2.0 meeting to facilitate greater technical progress in certain areas. **This will be an invitation only workshop due to the 'work' nature of the workshop sessions.**

The workshop will take place at the Woolacombe Bay Hotel (www.woolacombe-bay-hotel.co.uk/), Woolacombe, Devon, United Kingdom, from Monday 8 to Wednesday 10 June 2020.

More at www.fisw.space/fisw252020

US Congress directs NASA to assess Interstellar Mission Technology

United States Congress has directed NASA to undertake an interstellar mission technology assessment report a recent NASA paper, *Prospects for Interstellar Propulsion* (ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20200000759.pdf) summarises the activities required and discusses the scientific and technical rationale for a long-term program.

The authors are both at Space Technology Mission Directorate,NASA HQ, Washington DC. They are Ronald J Litchford, Principal Technologist, and Jeffrey A Sheehy, Chief Engineer.

This is an important, maybe a landmark, paper - written for the United States Congress, hopefully an intelligent lay audience.

As a taste, here is the Technology Readiness Level (TRL)* table from the paper-

Table 1. Candidate Interstellar Propulsion Technology Concepts.

Concept	**TRL**	**Description**	**Applicability**
Chemical Propulsion	9	Chemical reaction driven thermal propulsion (Isp < 500s & T/W or a_c ≈ 1-10^2 g's)	Not Applicable (energy density limited)
Solar Photon Sail Propulsion	≤ 4	Thrust production by solar photon pressure momentum exchange with thin, large-area, low-mass reflective sail material (Isp→∞ & T/W or a_c ≈ 10^{-5}-10^{4} g's)	Not Applicable to Interstellar Missions Applicable to ISM Missions (characteristic acceleration limited)
Solar Electric Propulsion	9	Electric thrusters driven by solar power (Isp < 10^5 s & T/W or a_c ≈ 10^{-4} g's)	Not Applicable (solar power range limited)
Nuclear Electric Propulsion	≤ 2	Electric thrusters driven by fission power (Isp < 10^{5} s & T/W or a_c ≈ 10^{-2} g's)	Not Applicable to Interstellar Missions Applicable to ISM Missions (energy density limited)
Nuclear Thermal Propulsion	≤ 4	Nuclear fission driven thermal propulsion (Isp < 10^3 s & T/W or a_c ≈ 1-5 g's)	Not Applicable to Interstellar Missions Applicable to ISM Missions (energy density limited)
Nuclear Fusion Propulsion	≤ 2	Nuclear fusion driven thermal propulsion (Isp < 10^5s & T/W or a_c < 10^{-5}-10^{-3} g's)	Applicable
Antimatter Annihilation Propulsion	≤ 2	Antimatter annihilation driven propulsion (Isp < 10^6s & T/W or a_c < 10^{-3}-10^{-2} g's)	Applicable
Directed Energy Photon/ Particle Propulsion	≤ 2	Directed energy driven sail (Isp ∞ & T/W or a_c is power scalable)	Applicable Nuclear Fusion Propulsion

ESA has taken initial steps towards interstellar technology, see *News Feature: Interstellar Workshop of the European Space Agency* in Principium 26 August 2019 page 30, is now the time for the UK and European parliaments to look to the future of our species beyond the Solar System? Perhaps beginning by reading this NASA paper?

* Technology Readiness Level(TRL) - NASA defines TRL in levels 1 to 9, with TRL 1 being initial exploitation of scientific knowledge with practical objectives. Of the levels above - TRL 2 is "very speculative, as there is little to no experimental proof of concept for the technology". TRL 4 is "Component and/or breadboard validation in laboratory environment" and TRL 9 is operational.

www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html

The Nucleus of Interstellar Comet 2I/Borisov

David Jewitt (Department of Earth, Planetary and Space Sciences, UCLA) with others (UCLA, University of Hawaii; Max Planck Institute for Solar System Research, Göttingen; Space Telescope Science Institute, Baltimore; Johns Hopkins University Applied Physics Laboratory) has published high resolution imaging observations of interstellar comet 2I/Borisov obtained using the Hubble Space Telescope in the *The Astrophysical Journal Letters* of the American Astronomical Society, Jan 2020, Volume 888, Number 2-

iopscience.iop.org/article/10.3847/2041-8213/ab621b/meta

The paper is available as open publication at -

iopscience.iop.org/article/10.3847/2041-8213/ab621b/pdf

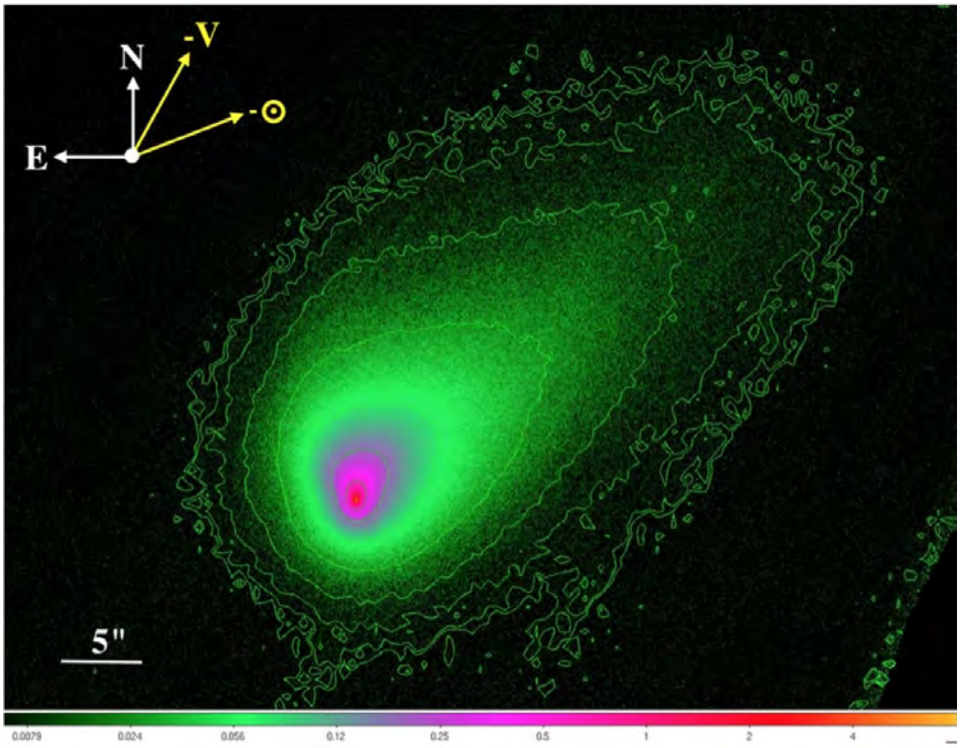
Naturally there are beautiful images but the paper is mainly detailed analysis of photometry, morphology, radius, spin and other details with some thoughts on the implications of the discovery of 2I and 1I before it on the number density of interstellar "interlopers" - as the paper dubs them.

Paper by i4is team cited in Science magazine policy recommendation

Principium is pleased to report that *Science*, the peer-reviewed academic journal of the American Association for the Advancement of Science includes an article making policy recommendations - *Sustainable minerals and metals for a low-carbon future* - science.sciencemag.org/content/367/6473/30.summary

The article* cites a paper by i4is team members Andreas M Hein, Robert Matheson, and Dan Fries - *A Techno-Economic Analysis of Asteroid Mining*, Acta Astronautica, May 2019. Quoting - "*Space mining, although potentially useful for developing lunar and planetary bases farther into the future, has less potential for meeting the demand for minerals for immediate decarbonization on Earth. A possible exception to this may be platinum group metals from asteroids, but here, too, the time frame and quantity of production would preclude its use in meeting immediate technology needs for climate mitigation* "

i4is team members are active in many areas of space technology and policy, both solar system and interstellar.



Composite WFC3 image of comet Borisov on UT 2019 October 12 with isophotal contours overlaid. The cardinal directions are marked, as are the projected antisolar vector (−e) and the projected negative heliocentric velocity vector (−V). A 5″ (10,000 km) scale bar is shown.

Credit: Jewitt et al and institutions as above

* open publication at - s3.amazonaws.com/academia.edu.documents/61668062/Sovacool_et-al-Science_Minerals_SM20200103-114447-3px9ap.pdf?response-content-disposition=inline%3B%20filename%3DSustainable_minerals_and_metals_for_a_lo.pdf&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Credential=AKIAIWOWYYGZ2Y53UL3A%2F20200220%2Fus-east-1%2Fs3%2Faws4_request&X-Amz-Date=20200220T104011Z&X-Amz-Expires=3600&X-Amz-SignedHeaders=host&X-Amz-Signature=fee02dae21a89681e098907665cce37f43c59a3f9c33c36f8120e9d96a1b1f5d

More from the ESA Comet Interceptor team

The paper *Potential Backup Targets for Comet Interceptor*, Megan E Schwamb (Astrophysics Research Centre, Queen's University Belfast) and others* (arxiv.org/abs/2002.01744) telling us that "In the event of a suitable LPC or ISO not being discovered before Comet Interceptor is required to leave L2 , the science team will select a known short-period comet as the mission target." The Comet Interceptor team therefore "has assembled a preliminary set of backup targets from the known Jupiter family comets, where a suitable fly-by trajectory can be achieved during the nominal mission timeline" and is thus "releasing our potential backup targets in order to solicit the planetary community's help with observations of these objects over future apparitions and to encourage publication of archival data on these objects" and "Any additional information that may assist scientific prioritization of these targets would be welcomed by the Comet Interceptor team."

Another paper by the Comet Interceptor team is of even greater interest to the interstellar studies community *The European Space Agency's Comet Interceptor lies in wait*, Colin Snodgrass (Institute for Astronomy, University of Edinburgh) and Geraint H Jones (Mullard Space Science Laboratory, University College London) - www.nature.com/articles/s41467-019-13470-1. They point out that, at launch to its Lagrange 2 initial destination, it will not know its target, or the precise geometry of the fly-by encounter and that this "leaves open the exciting possibility of encountering an interstellar object (ISO) like 1I/'Oumuamua", though they are pessimistic about detecting ISOs like 1I without a visible corona as opposed to cometary ISOs like 2I/Borisov.

If the latter is the case then we will still need Project Lyra type missions, which can chase late detected ISOs, as well as early detection missions like Comet Interceptor.

TVIW Updates

Since February 2018 the interstellar studies community have been provided with a very valuable source of information on work in the field and related field, this is TVIW Updates. As they say - tviw.us/interstellar-updates/ -

> These are items of interest to the interstellar exploration community that we've found in our quest for information that will help us advance toward our goals. If you know of anything we've overlooked, or any sources of such information we should monitor, or if you would like to be added to our TVIW-updates mailing list and receive these updates in you email every weekday, please send that information to info@tviw.us.

We at i4is have found TVIW Updates very valuable. We congratulate the Tennessee Valley Interstellar Workshop on this great source - as for much else.

Breakthrough Listen Releases Data Survey

Breakthrough Listen has release 2 petabytes of data from its SETI survey of the Milky Way. As in our second IAC 2019 report, elsewhere in this issue - *The BL Search for Intelligent Life: Public Data, Formats, Reduction and Archiving*, Matt Lebofsky of University of California Berkeley told us of the Breakthrough Listen policy of data access. More about this at www.sciencedaily.com/releases/2020/02/200217112739.htm

Upcoming i4is outreach and education

The Education team at i4is are going to be busy in the coming quarter. We have a one day event at Royal Holloway University of London in March and the next running of our now perennial two week electives at the International Space University (ISU) - 27 April to 8 May. And of course we support the ISU Masters programme with expertise from across the Initiative and Institute. More about all of these in our next issue

*Department of Physics, United States Naval Academy; Department of Astronomy, University of Maryland; Mullard Space Science Laboratory, University College London; Centre for Planetary Sciences at UCL/Birkbeck, London; Institute for Astronomy/Royal Observatory, University of Edinburgh; European Space Operations Centre, Darmstadt

The i4is Members Page

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

You need to login with your i4is identity to access members content. If you are not yet a member you can sign up via - i4is.org/membership - or simply find out more about membership. We'll keep you up to date as we add to this content, both in the next issue of Principium and in our members' email newsletter.

Members Newsletter

We have now sent out eleven exclusive email newsletters, including some specials, to members with the latest news of i4is and the whole interstellar endeavour. These arrive in your Inbox when there is something really worth reporting -

Subject	**date**
Member Newsletter	25/05/2019
Member Newsletter	15/06/2019
FISW 2019 – Opening Reception Night	28/06/2019
FISW 2019 – Living in Deep Space	29/06/2019
FISW 2019 – Advanced Propulsion Technology & Missions	1/7/2019
FISW 2019 – Building Architectural Megastructures	3/7/2019
Member Newsletter #3	30/08/2019
Another interstellar visitor!	13/09/2019
2I/Borisov Updates	14/10/2019
Happy New Year from the Initiative for Interstellar Studies	3/1/2020
Newsletter: Could electric sails be better than light sails? + Membership Survey	2/2/2020

We would appreciate as many responses as possible to the Membership Survey so that we can improve the membership scheme to better meet your needs and interests.

Principium preprints

These are collections of articles due to be published in upcoming issues of our quarterly, Principium. The articles you find here are made available exclusively to our members before they are made freely available when Principium is published. These are late drafts so may not be exactly what appears in Principium (i4is.org/members/preprints/). We also hope they also form an archive of content which is easy to search. Here is a recent selection -

We listed preprints up to 17 November in the last Principium Members Page

Here are the new ones since then -

Title	Author	Added
News Feature: TVIW's 6th Interstellar Symposium and Advanced Interstellar Propulsion Workshop	Meany, J.	2020-01-12
The Equation used in the Benkoski Paper: A Derivation	Hibberd, A	2020-01-12
What Do We Really Know About The Outer Solar System?	Sutton, P.	2020-01-12

You can find them all at i4is.org/members/preprints/ (logon with your i4is identity).

Become active in i4is

We need all your talents - maths & physics are important but many other talents are needed. The time and the unique skills of our members and, especially, our active volunteers are vital to all we do.

We listed just a few of the major contributors of time, brains and effort in the last Principium Members page. Here are some more - the diversity of occupations and talents should again be apparent!

- Tam O'Neill, systems administrator at M & Co and at i4is - Project Manager for the Membership Scheme
- Satinder Shergill. PhD student at Cranfield University - subject 'Adaptive In-Situ Resource Utilisation (ISRU) for Long-Term Space Exploration' - and at i4is - major contributor to educational outreach and founder member of the Royal Institution Skateboards to Starships team
- Paul Campbell. Software Engineer at Verint Systems - and at i4is - Lead Technologist for the i4is website and membership system
- John Davies, retired software engineer and mobile telecomms consultant and at i4is - Editor of Principium, requirements analyst for the Membership Scheme, lead for schools outreach in i4is Education and founder member of the Royal Institution Skateboards to Starships team

All of our members have skills and all have an interest in our work and in interstellar studies in general. We would love to hear from you if you can offer some of your time and talent. You will find us a friendly and welcoming bunch! Contact us via info@i4is.org and we'll get back to you.

Help us to grow!

Print the general poster on pages 25 & 39 (black and white background) and the student poster on page 13 (black background). All four posters are at i4is.org/i4is-membership-posters-and-video/ And tell your friends and colleagues!

i4is membership launch: A word from Andreas Hein, our Executive Director

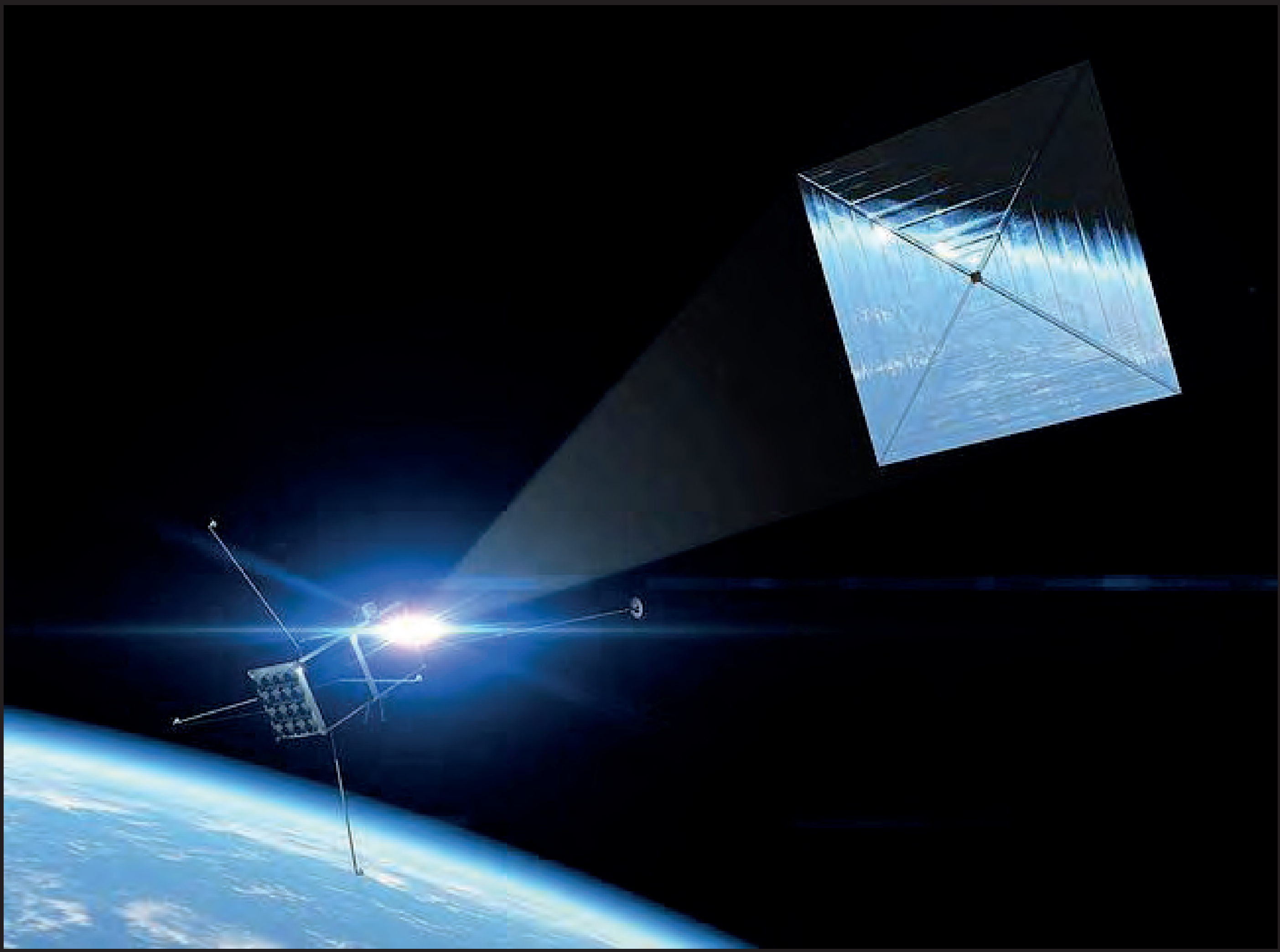
Here is Andreas' launch video - please share widely!

www.facebook.com/InterstellarInstitute/videos/562925214131758/

JOIN I4IS ON A JOURNEY TO THE STARS!

Do you think humanity should aim for the stars?

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



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

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

Join us and get:

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

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

Become an i4is member

Patrick J Mahon

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

The Initiative and Institute for Interstellar Studies (i4is.org) is a growing community of enthusiasts who are passionate about taking the first steps on the path toward interstellar travel now.

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

In addition to supporting the programme, members have access to privileged content. This includes exclusive reports from the Second Foundations of Interstellar Studies Workshop last June, selected papers from which have just appeared in the Journal of the British Interplanetary Society, presentations, including those given by i4is members at the Royal Institution in London last August, and at the Astronomical Society of Edinburgh in October, and 'The Interstellar Minimum', a test paper to explore your knowledge of starship engineering.

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

More details are on the *The i4is Members Page*, page 23 in this issue of Principium. You will get access to all this content, and much more, if you choose to join.

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

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

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

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

News Feature: 70th International Astronautical Congress 2019

The Interstellar Papers - Part 2

Reported by John I Davies

Here is a second brisk trot through what we saw and heard at the 70th IAC in Washington DC 21-25 October. We distributed print issues of Principium 26 at the event including the timetable in that issue. More from this massive event in the last issue P27, November 2019.

The quoted links to papers and presentations are accessible to all IAC 2019 participants. I have looked for versions of the papers on open access and quoted links where I found them. Please get in touch via Principium@i4is.org if you find more.

We must again thank the IAF Media Office for press access to the Congress. Delegate fees would have been a significant expense in addition to the travel and accommodation overheads, which we donated personally, our normal practice since the foundation of i4is. We are and will remain a low-overhead organisation.

Tuesday 22 October	**SETI 1: SETI Science and Technology**	**IAC reference: IAC-19/A4/1/**	**iafastro.directory/iac/browse/IAC-19/A4/1/**

Co-Chair: Prof. Michael Albert Garrett, University of Manchester, United Kingdom;

Co-Chair: Mr. Bill Diamond, SETI Institute, United States

New Limits on the Presence of Technological Civilizations in the Universe from Breakthrough Listen

Dr. Andrew Siemion University of California USA

IAC paper: not available - abstract at - iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/manuscripts/IAC-19,A4,1,1,x54207.pdf

IAC presentation: not available - nearest equivalent - www.jodrellbank.manchester.ac.uk/media/eps/jodrell-bank-centre-for-astrophysics/news-and-events/2018/wide-field-seti/presentations/SIEMEON---PRESENTATION.pdf

Open paper: none found

Dr Siemion's paper has 10 co-authors, most from UC-Berkeley. Others are from Breakthrough itself, NASA, University of Manchester and Radboud University, Nijmegen. The array of telescopes doing the listening is much wider - including partners they are the veteran dishes at Parkes in Australia and Jodrell Bank in UK , the Automated Planet Finder telescope in California, MeerKAT in the South Africa, the VERITAS Cherenkov Array in Arizona, the Murchison Widefield Array in Australia, the International Low Frequency Array Stations in Birr, Ireland and Chilbolton, UK, and China's massive 500m FAST telescope with, under development, Sardinia Radio Telescope, the Nancay Radio Observatory in France, the Nobeyama dish in Japan and the Cherenkov Telescope Array in Spain and Chile. The SETI endeavour now extends across the world and across the spectrum from gamma rays to low radio frequencies as illustrated here.

Large Sized Cherenkov Telescope
Credit:Siemion / UC Berkeley

UK LOFAR antenna field - the European LOFAR system detects frequencies around 100MHz, roughly FM radio range. Thousands of simple dipole antennas, bit like old-style car radio aerials, feed into a centre in Groningen, Netherlands, where an IBM high-performance computer system combines and analyses the signals.

image credit Roger Dingley/STFC

The Cherenkov array is named after the radiation it detects from incoming gamma ray photons. From the very shortest end of the spectrum these photons collide with atomic nuclei to produce electrons and positrons which are themselves travelling so fast that they produce the quantum equivalent of the "sonic boom" produced by supersonic aircraft. It is this "boom" in the form of Cherenkov radiation at the shortest end of the visible spectrum which these telescopes detect (more on this at en.wikipedia.org/wiki/IACT).

Dr Siemion presented the status of the Breakthrough Listen program, its observational facilities and data processing systems. He discussed the current limits on detecting presence of technologically capable life in the universe and how those limits are expected to improve as Breakthrough Listen advances. Both technological phenomena and biosignature are being sought. Naturally biosignature research targets exoplanets.

Breakthrough Listen on the Murchison Widefield Array

Dr. Steve Croft University California (UC) Berkeley USA

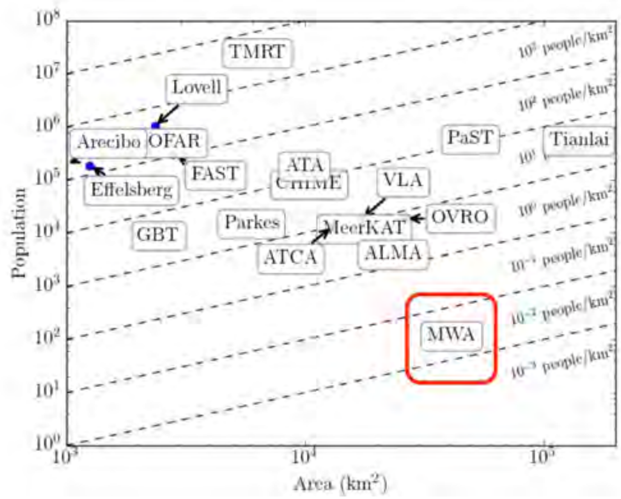
IAC paper: not available

IAC presentation: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/presentations/IAC-19,A4,1,2,x52457.show.pptx

Open paper: none found

Dr Croft's paper has 8 co-authors, four from UC-Berkeley. Others are from Swinburne University of Technology and Curtin University, both Australia.

Breakthrough Listen has provided new back end hardware to the Murchison Widefield Array (MWA), the low-frequency precursor to the upcoming Square Kilometre Array telescope in Western Australia (en.wikipedia.org/wiki/Murchison_Widefield_Array#Project_partners). This is a very radio quiet part of outback Australia.



Area versus Population for comparable radio telescopes
Credit: Steve Croft, D Kaplan , UC Berkeley

The instrument has a 20 degree field of view (FOV) and is steerable by delay between "tiles" which comprise it. It also allows multiple simultaneous users. A 100Gbit link to Perth is coming soon. Dr Croft told us that the TurboSETI software (see seti.berkeley.edu/listen2019/ and github.com/UCBerkeleySETI/turbo_seti for more details) would be going live in weeks (this old systems programmer wishes the team luck!). Capacity is currently back end systems limited. The plans for evolution towards the Square Kilometre Array (SKA) are illustrated by the transport and processing load presented by Dr Croft.

	MWA I & II	MWA III	SKA1 Low
Antennas correlated (x2 pol'ns)	128	256	512
Instantaneous BW (MHz)	30.72	~100	300
Bits/sample	4+4	8+8	8+8
Oversampling factor	1	1.25	1.25
Data rate per antenna (Mbps)	491.52	4000	12,000
Data rate into correlator (Gbps)	62.91	1024	6144
Number of processing units	24	32	~200
Data rate per correlator box (Gbps)	2.62	32.00	30.72

He points out that "MWA Phase III is only a factor of 2 in stations and a factor of 3 in bandwidth from SKA Low". This is truly "big science" and, as always for science on this scale, the engineering challenges are substantial.

On the Breakthrough Listen search for signs of intelligent life near the Galactic center

Ms. Karen Perez   Columbia University USA (main author: Dr. Vishal Gajjar, UC Berkeley)

IAC paper: not available - abstract at - iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/manuscripts/IAC-19,A4,1,3,x53288.pdf

IAC presentation: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/presentations/IAC-19,A4,1,3,x53288.show.pptx

Open paper: none found

Breakthrough Listen looks towards the galactic centre since there are more stars in that direction and therefore potentially more civilisations. The frequency bands covered will be from 0.7 GHz (700 MHz) to 93 GHz using the dishes at Parkes, Australia, 350 hours planned, 0.7 - 4 GHz and at Green Bank, Maryland, 280 hours planned, 4 - 93 GHz with analysis via the Breakthrough Listen extraterrestrial intelligence signal search pipeline using the turboSETI software mentioned in the account of Steve Croft's presentation above. Pulsars and Fast Radio Bursts (FRBs - en.wikipedia.org/wiki/Fast_radio_burst) are both potential interferers and objects of scientific interest. They and the pulsar "cousins", magnetars (en.wikipedia.org/wiki/Magnetar) will also be analysed. The Green Bank C band observations 3.95 - 8 GHz are almost complete and other bands will follow but analysis is just beginning.

The BL Search for Intelligent Life: Public Data, Formats, Reduction and Archiving

Mr. Matt Lebofsky   UC Berkeley USA

IAC paper: no paper, abstract only iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/manuscripts/IAC-19,A4,1,4,x54978.pdf

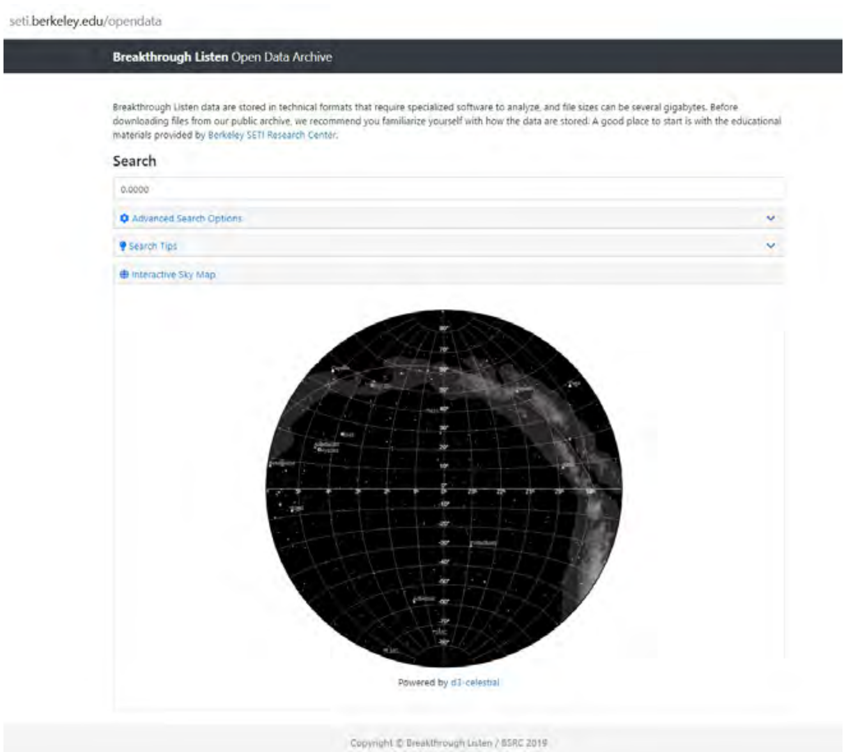
IAC presentation: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/presentations/IAC-19,A4,1,4,x54978.show.pdf

Open paper: arxiv.org/abs/1906.07391

Matt Lebofsky is the Lead sysadmin (system administrator* for Breakthrough Listen at the University of California Berkeley.

The BL database requires very substantial hardware. Lebofsky's paper (see Open paper above) offers a "deep dive" into data formats, pipelines, and analysis tools. At the time of reporting the Green Bank telescope data alone is 10 petabytes (one million Gigabytes or about 100,000 times my biggest backup drive). The Parkes telescope data will add substantially to this. The data is reachable via seti.berkeley.edu/opendata.

Lebofsky's UC Berkeley team are aiming to create a "Sandbox" and provide citizen science access to the database. As of this presentation bandwidth limitations between Berkeley and Parkes mean that data is physically transferred by courier - providing the required bandwidth (en.wikipedia.org/wiki/Sneakernet#Theory).



The home page of the Breakthrough Listen Open Data Archive

*system administrator - en.wikipedia.org/wiki/System_administrator

SUCCESS STORIES	
FRB121102 C-band detection led to publications of 3 Astrophysical Journal papers and 1 Nature paper.	Michili D. et al. 2018, Nature, Gajjar et al. 2018, ApJ, Zhang et al. 2018, ApJ, Hessels et al. 2019, ApJ
Downloaded data from FRB121102 was used for a recent publication to verify central Network classifier to detect Fast Radio Burst.	Agarwal et al. 2019, arvix.org/pdf/1902.06343.pdf
High school student David Lipman downloaded APF data, went on to write a paper on laser line emission from Boyajian's Star	Lipman et al. 2019, PASP
- and - • Breakthrough Listen data collected at the Parkes telescope are currently being used to search for pulsars in collaboration with a team at CSIRO. • Pulsar data collected from the GBT are currently being used to find extreme scattering events in collaboration with Prof. Assaf Horesh and Sapir Parnes from the Hebrew University. Credit: Matt Lebofsky, UC Berkeley, Breakthrough Listen	

Opportunities for Radio Technosignature Searches with the Allen Telescope Array and Very Large Array

Dr. Andrew Siemion (presented by Dr. Alexander Pollak) University of California USA

IAC paper: Abstract only - iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/manuscripts/IAC-19,A4,1,5,x54307.pdf

IAC presentation: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/presentations/IAC-19,A4,1,5,x54307.show.pptx

Open paper: none found

The Allen Telescope Array (ATA) is in northern California, It consists of 42 6.1 m antennas. Its mission is specific to detecting Fast Radio Bursts (FRBs). It is supported via private foundation funding (Mount Cuba Foundation and Franklin Antonio). The team (UC Berkley, Caltech and SETI Institute) are investigating how the ATA can be extended to SETI via upgraded backend processing, do an initial follow-up observing survey of sources identified elsewhere and provide a testbed for technosignature search for upgrading the Jansky Very Large Array (JVLA) in New Mexico, the Next Generation VLA (ngVLA) and similar capabilities at the Meerkat array, see Siemion paper mentioned above. Technology includes software defined radio based on GNURadio (en.wikipedia.org/wiki/GNU_Radio)

Towards a UK SETI capability with e-MERLIN/EVN

Prof Mike Garrett University of Manchester United Kingdom

IAC paper: not available

IAC presentation: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/presentations/IAC-19,A4,1,6,x50637.show.pdf (titled: SETI using Long Baseline Interferometry)

Open paper: not found

Prof. Garrett discussed moving beyond single site telescopes, especially noting MeerKAT - using multiple smaller dishes. Two approaches are -

Beam forming - which has the disadvantage that the field of view (FOV) becomes smaller

Interferometry yields images and FOV set by the dimensions of the small antennas

If antennas are well separated, say at least 100 km (VLBI), local interference is reduced

Prof Garrett summarised the advantages of interferometry -
- Suppression of Interference (citing. Rampadarath 2012*) .
- Field-of-view of individual antennas retained.
- Ability to specifically target thousands of individual sources (e.g. stellar systems) in the sky.
- Unique signal detections on each baseline improve confidence of results (false positives).
- Spatial invariance (on short time scales) expected of a SETI signal also improves confidence of results.
- Milliarcsecond positions can pin-point the location of a potential SETI signal.
- Sensitivity - combining the largest telescopes across the planet.
- VLBI can even resolve planetary sources
- and even very large telescopes can be included in the VLBI

The great disadvantage is data size - scaling as N squared versus single-dish or beam-formed arrays where N is the number of antennas.

The European VLBI Network first results are expected in the coming August - to be followed by telescopes in China and South Africa. Calibration against Kepler exoplanet results has already begun.

Involvement of the Sardinia Radio Telescope in the BL Initiatives: first results and ongoing activities

Dr. Andrea Melis INAF - Istituto Nazionale di AstroFisica Italy

IAC paper: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/manuscripts/IAC-19,A4,1,7,x49722.pdf

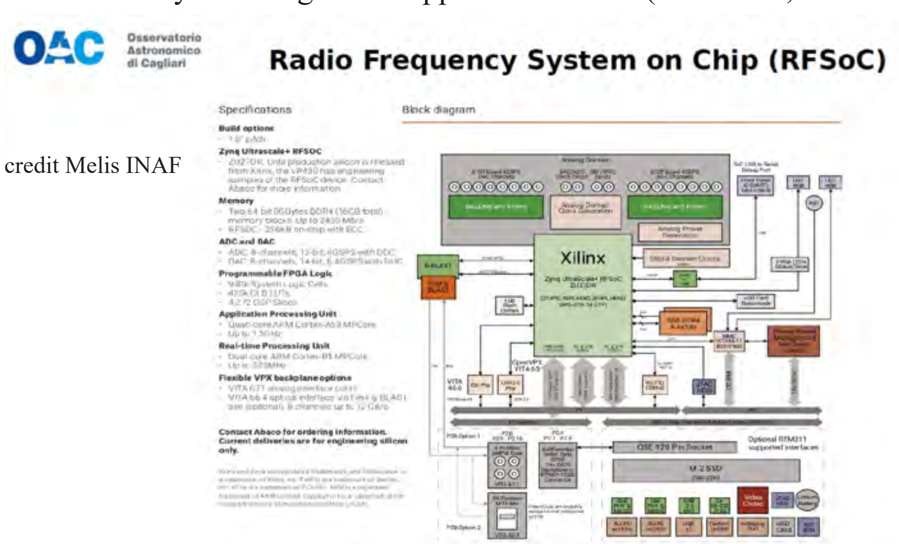
IAC presentation: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/presentations/IAC-19,A4,1,7,x49722.show.pdf

Open paper: (related) sait.oat.ts.astro.it/MSAIt890318/PDF/2018MmSAI..89..352M.pdf

The Sardinia Radio Telescope (SRT) is a 64-m steerable dish operating 300 MHz – 115 GHz. SETI activities are -
- Implementation of the Kahrnunen-Loeve Transform (KLT en.wikipedia.org/wiki/Karhunen–Loève_theorem#Properties_of_the_Karhunen–Loève_transform)
- Involvement of the SRT in the Breakthrough Listen Initiatives

The team will use the SRT's unique high energy capabilities to conduct targeted searches of the Galactic Centre at high radio frequencies (C-band, K-band) for SETI sources, pulsars and FRBs.

Backend hardware is based on existing ROACH (Reconfigurable Open Architecture and Computing Hardware) , now moving to Square Kilometre Array Reconfigurable Application Board (SKARAB, alias ROACH3) hardware. The central component used is a Xilinx Inc processor Radio Frequency System on Chip (RFSoC)



credit Melis INAF

Analysis of data using the Kahruen-Loeve Transform may eventually be extended to SETIatHome (en.wikipedia.org/wiki/SETI@home). The team believes that KLT is the best way to find signals that are unintentionally transmitted by possible alien civilizations (using a wide-band approach). But the major issue for such a KLT engine is the computational demand.

* The First Very Long Baseline Interferometric Seti Experiment, H. Rampadarath et al, ICRAR, Curtin University, Perth, Australia - iopscience.iop.org/article/10.1088/0004-6256/144/2/38/pdf

Searching for Low Frequency Optical SETI Signals buried in Atmospheric Scintillation

Dr. Richard Stanton Jet Propulsion Laboratory USA

IAC paper: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/manuscripts/IAC-19,A4,1,8,x49439.pdf

IAC presentation: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/presentations/IAC-19,A4,1,8,x49439.show.pptx

Open paper: not found

Atmospheric Scintillation is that charming twinkling so beloved of song writers but so annoying to astronomers. But counting photons in the twinkles could reveal non-natural sources and hence SETI. For example, if we built a "Global Cooling Reflector" at Lagrangian Point L1 to mitigate global warming then how would our ETI neighbours see this? Megastructures and deliberate optical signalling might be even easier to spot. The paper reports experiments using four photomultiplier modules at the prime focus of the 30 inch reflector at the Shay Meadow Observatory and injecting test signals (as well as detecting optical "RFI" from things like aircraft navigation lights, meteors, etc). Autocorrelation reveals repeating phenomena. Power Spectrum analysis can use the Fast Fourier Transform.

The possibility of detecting a sunshade should perhaps make us wary that we are being looked at as while we are looking!

Time Markers for SETI in Binary Systems

Dr. Jacob Haqq-Misra Blue Marble Space Institute of Science USA

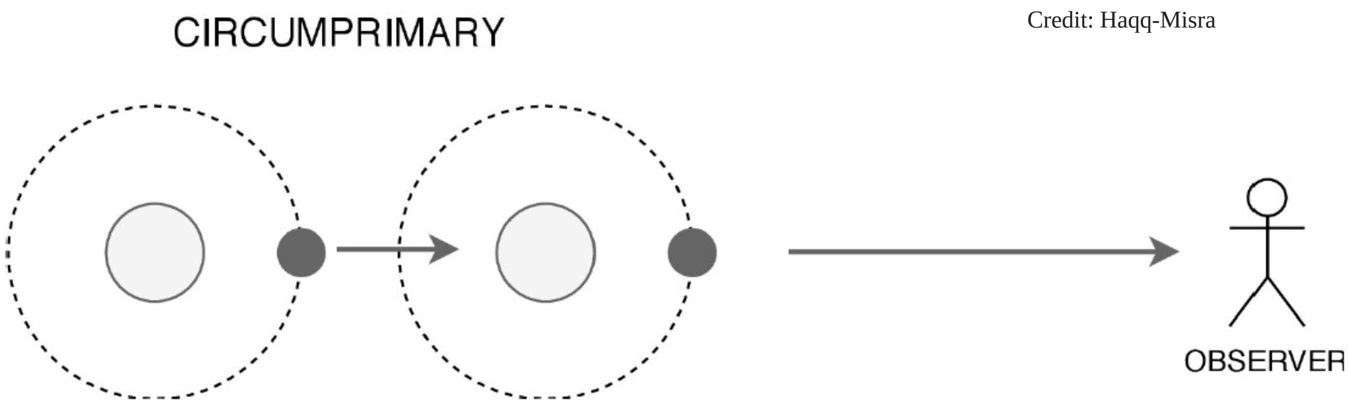
IAC paper: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/manuscripts/IAC-19,A4,1,9,x49704.pdf

IAC presentation: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/presentations/IAC-19,A4,1,9,x49704.show.pdf

Open paper: none found

Blue Marble Space ([www.bmsis.org)](www.bmsis.org) is a Seattle-based non-profit with a name inspired by Sagan's famous pale blue dot. In this paper they ask not just where we should look for SETI evidence, but when. ETIs in binary systems might choose to signal when one star eclipses the other - if they had guessed roughly were we are. Two planets signalling to each other with a beamed transfer would be detectable when they were in alignment in our direction.

Credit: Haqq-Misra



Exoplanets for binary eavesdropping

Haqq-Misra cited earlier work *Supernovae as Time Markers in Interstellar Communication* (Tang, JBIS, 1976) and *Time markers in interstellar communication* (Pace and Walker, Nature, 1975) - "Single star civilisations would logically transmit signals to binaries at the observation of periastron and apastron. Binary star civilisations would scan single stars at a time 2T after periastron and apastron, where 2T is twice the signal propagation time between the stars."

KLT for an expanding universe with SETI applications.

Dr. Nicolò Antonietti Italy

IAC paper: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/manuscripts/IAC-19,A4,1,12,x49250.pdf

IAC presentation: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/presentations/IAC-19,A4,1,12,x49250.show.pptx

Open paper: none found

Dr Antonietti is a co-author of the paper above by Dr. Andrea Melis on the Involvement of the Sardinia Radio Telescope in the BL Initiatives which introduces the Kahrnunen-Loeve Transform (KLT - see paper by Dr Andrea Melis above). This paper, co-authored by an long-time friend of i4is and a member of the Advisory Council of the Initiative for Interstellar Studies, Dr Claudio Maccone. This paper builds on 1981 work by Dr Maccone. He has also covered this in *Deep Space Flight and Communications* (2009).

The mathematics here is somewhat beyond the abilities of your humble reporter. However it's noteworthy that the computational demands of KLT are now more tractable than they were in 1981!

Dr Antonietti's table of advantage ↑ versus disadvantage ↓ for Kahrnunen-Loeve Transform (KLT) compared with Fast Fourier Transform (FFT) -

KLT		FFT	
↑	Works well for both wide and narrow band signals	Practically true for narrow band signals only (Nyquist criterion)	↓
↑	Works for both stationary and non-stationary input stochastic processes	Works OK for stationary input stochastic processes only (Wiener-Khinchine theorem)	↓
↑	Is defined for any finite time interval	Is plagued by the “windowing” problems and the Gibbs phenomenon	↓
↓	Needs high computational burden: no “fast” KLT	Fast algorithm FFT	↑

See also -

en.wikipedia.org/wiki/Karhunen–Loève_theorem#Properties_of_the_Karhunen–Loève_transform

en.wikipedia.org/wiki/Fast_Fourier_transform

Hyper-SETI – A New Way of Searching for Extraterrestrial Intelligence

Prof. Hakan Kayal University of Wuerzburg Germany

IAC paper: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/manuscripts/IAC-19,A4,1,13,x48686.pdf

IAC presentation: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/presentations/IAC-19,A4,1,13,x48686.show.pdf

Open paper: www.uni-wuerzburg.de/fileadmin/ifex/2019/IAC-19_A4_1_13_x48686_full_paper.pdf

Hyper-SETI assumes the hypothesis that there is already extraterrestrial communication, but using more advanced physics and technology, overcoming the speed of light constraint. So we should search for anomalies in our environment.

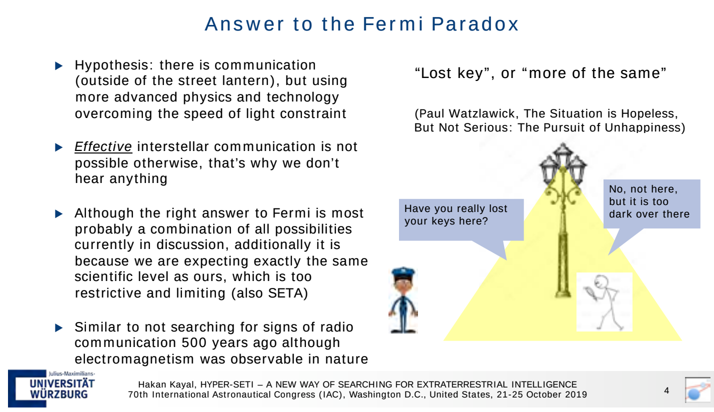
What might we find -

- Unusual geometric forms

- Unusual strong signals at any wavelength and anywhere

- Unusual concentrations

- Short, transient illuminous events



The Answer to the Fermi Paradox? from Kayal, Hyper-SETI – A New Way of Searching for Extraterrestrial Intelligence

Self-replicating - the Hart-Tipler argument against the existence of extraterrestrial intelligence

Prof. Alex Ellery Space Exploration & Engineering Group, Carleton University Canada

IAC paper: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/manuscripts/IAC-19,A4,1,14,x49645.pdf

IAC presentation: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/presentations/IAC-19,A4,1,14,x49645.show.ppt

Open paper: none found

The dear old Fermi paradox runs into the anthropic principle (en.wikipedia.org/wiki/Anthropic_principle).

Prof Ellery started by labelling -

- Carl Sagan (the good) co-opted Martin Rees' comment "Absence of evidence is not evidence of absence" in relation to the existence of black holes to the ETI issue
- Michael Hart's (the bad) Fact A states that absence of evidence IS evidence of absence by the Occam's razor principle
- Frank Tipler (the ugly) - self-replicating probes render Hart's argument more compelling

Tipler (with John D Barrow) suggests a "final Anthropic principle" (FAP) (en.wikipedia.org/wiki/Frank_J._Tipler) in the 1986 book *The Anthropic Cosmological Principle*. Ellery summarises the Hart-Tipler argument thus -

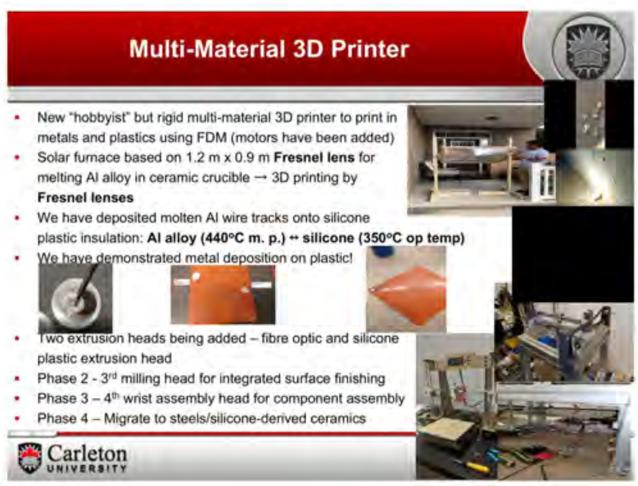
> A self-replicating spacecraft would be sent to any neighbouring star system and use the raw materials available therein to manufacture copies of itself to be sent thenceforth to other star systems ad infinitum. Taking r=number of offspring per generation and m=number of generations the population of these Von Neuman probes (en.wikipedia.org/wiki/Self-replicating_spacecraft#Von_Neumann_probes) would be -
>
> $$N = \sum_{i=1}^{m}(1+r)^i$$
>
> Which is enough to colonise the Galaxy in one million years assuming probes travelling at 10% of the speed of light.

Given that we already have most of the means to create crude self-reproducing machines we are driven back to Fermi's question - Where are they?

Ellery's team decided to see what obstacles exist to developing such a self-reproducing machine. 3D printers can already reproduce many of their own plastic parts, create simple Turing machine-like computers and the team have even been able to 3D print simple electric motors. Using materials known to be available on the Moon and some asteroids the team are making good progress towards basic self-reproduction.

Given all of this, Ellery concludes that the absence of technosignatures may just mean humanity has first mover advantage!

See also the report on the paper - *Steps toward self-assembly of lunar structures from modules of 3D-printed in-situ resources* - by the same author in Principium Issue 27 November 2019 page 19.



Multi-Material 3D Printer.
credit Ellery Carleton University

Novel Technosignatures

Dr. Albert Jackson   Triton Systems LLC   USA

IAC paper: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/manuscripts/IAC-19,A4,1,15,x52501.pdf

IAC presentation: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/presentations/IAC-19,A4,1,15,x52501.show.pdf

Open paper: None found

Dr Jackson, began with a quote from Freeman Dyson (who is a member of i4is Advisory Council) -

"My rule is there is nothing so big nor so crazy that one out of a million technological societies may not feel itself driven to do, provided it is physically possible."

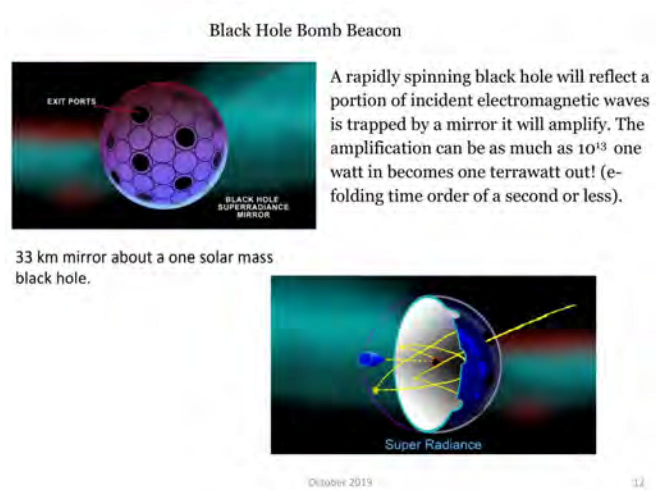
One possible source of technosignature is starships and he quoted Zubrin's table -

Type	Radiated at Source	Frequency	Detection Object
Radio	80-2000 TW	24 – 48 kHz	Yes- Magsails
Visible	120000 TW	IR	Yes – Nuclear 300 ly
X-Rays	40000 TW	2 - 80 KeV	Nuclear and Antimatter- Ships ~10 ly-1000ly
Gamma Rays	1 – 32 MeV	20-200 Mev	Antimatter Ships

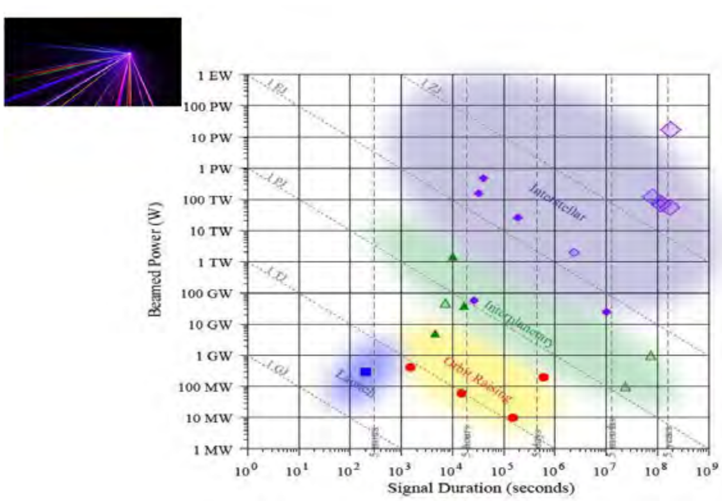
- from Zubrin 1995 *Detection of Extraterrestrial Civilizations via the Spectral Signature of Advanced Interstellar Spacecraft* - adsabs.harvard.edu/full/1995ASPC...74..487Z

Jackson considered the characteristics of relativistic starships (emissivity, Lorentz factor at fractions of c). Gravitational machines (Oberth effect and related), surfing black holes, bow shocks from decelerating mag sails, black holes (lensing and beamed propulsion). He also considered very advanced signalling methods including zero rest mass or near zero rest mass carriers such as neutrinos, beacons using black holes, neutron stars, gravitational waves and even a beacon using a mirror around a black hole - producing a black hole bomb!

Naturally when considering very advanced civilisations, megastructures are a possibility. More exotic still Shkadov thrusters (focusing a star's emissions for propulsion) and ultimately perhaps traversable wormholes which, if they exist, would likely produce effects we could observe.



ack - Hole Bomb Beacon, Credit: Jackson



Candidate Beaming Stations

Beamed power in watts (megawatts to petawatts) versus duration of beaming in seconds - log-log scale

- with lines of constant total energy in joules (gigajoules to zettajoules)

Credit: Jackson and Benford

(Benford and Benford - Astrophysical Journal, Volume 825, Number 2, 2016)

Lunar Opportunities for SETI

Mr. Eric Michaud UC Berkeley USA

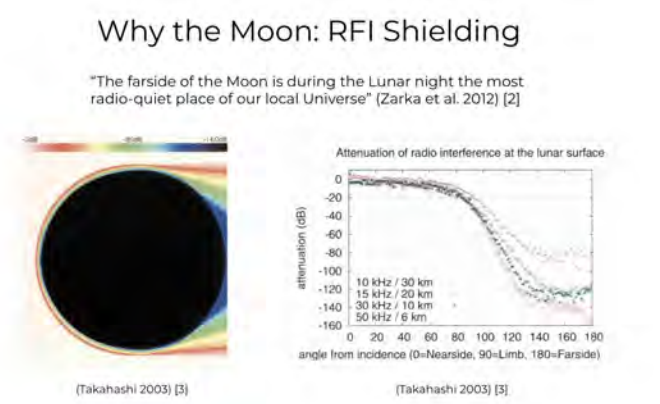
IAC paper:iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/manuscripts/IAC-19,A4,1,16,x54535.pdf

IAC presentation: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/presentations/IAC-19,A4,1,16,x54535.show.pdf

Open paper: none found

Dr Michaud showed us the concept of "lunarcibo" - by analogy with the Puerto Rico Arecibo dish.

He quoted that “The farside of the Moon is during the Lunar night the most radio-quiet place of our local Universe”. RFI from human technology is a clear source of "false positives" in SETI meaning that this is a very attractive location for this purpose.



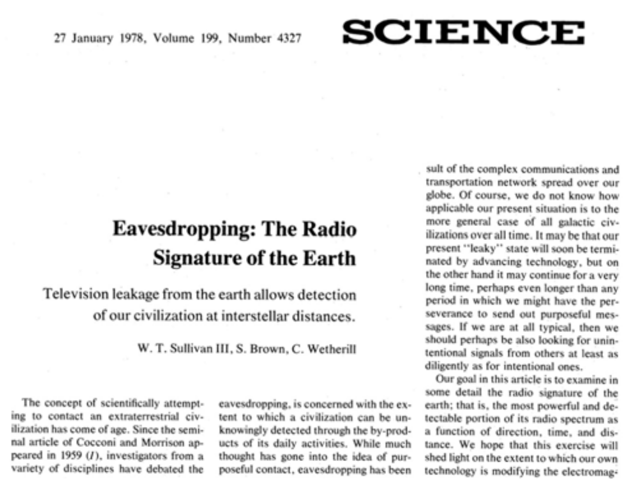
Credit; Micahaud / UC Berkeley

Terrestrial astronomy at all points of the electromagnetic spectrum is also threatened by the current rush to provide universal internet service using large numbers of very low orbit communications satellites.

An Arecibo type dish in a crater is clearly structurally attractive. However the lunar night means that no solar power would be available so the battery requirement would be substantial. But a relay similar to the Chinese Queqiao at the Earth–Moon Lagrange 2 point would be required.

Interest in our cosmic audibility is not new

Credit: Demarines/Science magazine



27 January 1978, Volume 199, Number 4327 **SCIENCE**

Eavesdropping: The Radio Signature of the Earth

Television leakage from the earth allows detection of our civilization at interstellar distances.

W. T. Sullivan III, S. Brown, C. Wetherill

The concept of scientifically attempting to contact an extraterrestrial civilization has come of age. Since the seminal article of Cocconi and Morrison appeared in 1959 (*1*), investigators from a variety of disciplines have debated the eavesdropping, is concerned with the extent to which a civilization can be unknowingly detected through the by-products of its daily activities. While much thought has gone into the idea of purposeful contact, eavesdropping has been sult of the complex communications and transportation network spread over our globe. Of course, we do not know how applicable our present situation is to the more general case of all galactic civilizations over all time. It may be that our present "leaky" state will soon be terminated by advancing technology, but on the other hand it may continue for a very long time, perhaps even longer than any period in which we might have the perseverance to send out purposeful messages. If we are at all typical, then we should perhaps be also looking for unintentional signals from others at least as diligently as for intentional ones.

Our goal in this article is to examine in some detail the radio signature of the earth; that is, the most powerful and detectable portion of its radio spectrum as a function of direction, time, and distance. We hope that this exercise will shed light on the extent to which our own technology is modifying the electromag-

The Moonbounce Project: Observing the Earth as a Communicating Exoplanet

Ms. Julia DeMarines UC Berkeley USA

IAC paper: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/manuscripts/IAC-19,A4,1,17,x55025.pdf

IAC presentation: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/presentations/IAC-19,A4,1,17,x55025.show.pptx

Open paper: (similar paper) pdfs.semanticscholar.org/9b48/0662bdf74fc636b273ca7e1742674a7e64aa.pdf

Julia DeMarines asked - What does our own biosignature and technosignature look like? Blue Marble (mentioned above), UC Berkeley and Breakthrough Listen are examining our own reflections from the Moon to investigate these. Observing through the Green Bank Telescope (GBT) for RF and the Automated Planet Finder (APF) at Lick Observatory (arranged by Breakthrough Listen) to measure in visible wavelengths.

SETI Space Missions

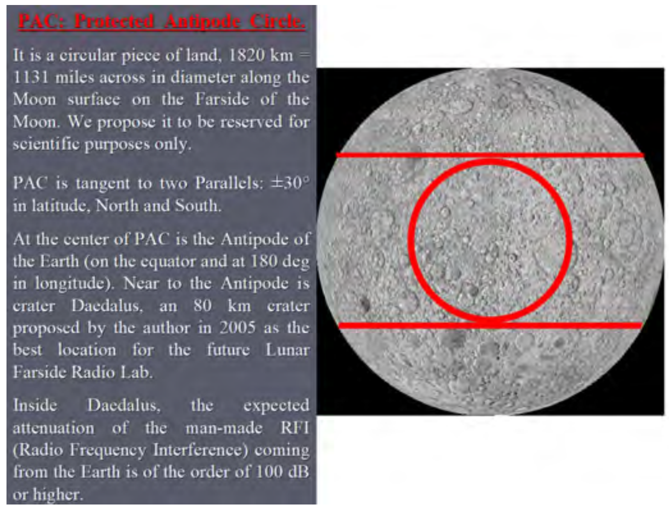
Dr. Claudio Maccone International Academy of Astronautics (IAA) & Istituto Nazionale di Astrofisica (INAF) Italy

IAC paper: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/manuscripts/IAC-19,A4,1,18,x49763.pdf

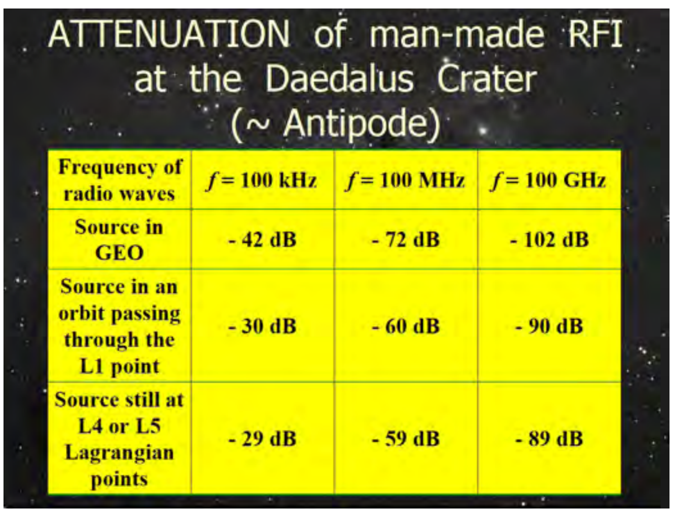
IAC presentation: iafastro.directory/iac/proceedings/IAC-19/IAC-19/A4/1/presentations/IAC-19,A4,1,18,x49763.show.ppt

Open paper: none found

Dr Maccone presented a review paper about over his more than thirty years of activity promoting missions enabling SETI searches from space. He has long been an advocate of keeping the far side of the Moon as radio-quiet as possible. Specifically the PAC, the Protected Antipode Circle, a large circular area about 1820 km in diameter, centred around the antipode of the Earth on the Farside subtending a conic angle of 60 deg at the centre of the Moon.



Proposed Protected Antipode Circle
Credit: Maccone



ATTENUATION of man-made RFI at the Daedalus Crater (~ Antipode)

Frequency of radio waves	f = 100 kHz	f = 100 MHz	f = 100 GHz
Source in GEO	- 42 dB	- 72 dB	- 102 dB
Source in an orbit passing through the L1 point	- 30 dB	- 60 dB	- 90 dB
Source still at L4 or L5 Lagrangian points	- 29 dB	- 59 dB	- 89 dB

In this part of space you can hear ETI not just screaming but maybe just thinking!

- attenuation of man-made RFI at the Daedalus Crater at the lunar antipode from the Earth

Credit: Maccone

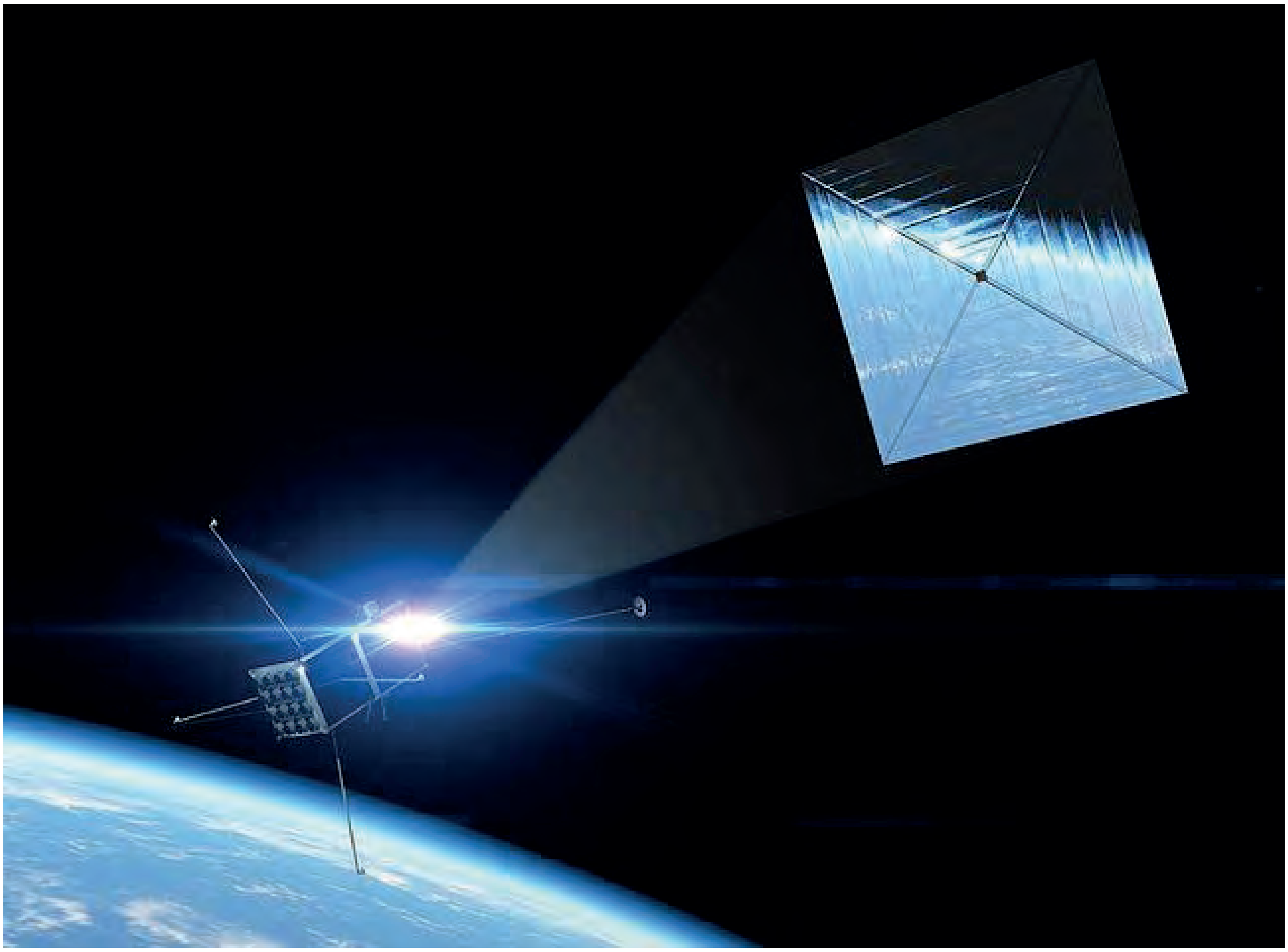
The Lagrange points, both Earth-Moon and Earth Sun, are also attractive locations for missions and thus possible sources of technological RFI. Dr Maccone's paper is a detailed technical analysis of this issue and a plea for electromagnetic quiet on the Moon's farside as our best site for SETI in the future.

See also Dr Maccone's book *Mathematical SETI: Statistics, Signal Processing, Space Missions*, Springer Science & Business Media, 2012

JOIN I4IS ON A JOURNEY TO THE STARS!

Do you think humanity should aim for the stars?

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



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

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

Join us and get:

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

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

The Equation used in the Benkoski Paper

A Derivation

Adam Hibberd

In the last issue of Principium. P27, Adam described how he joined the i4is Project Lyra team and became the main author of the orbit calculations required to send probes to the two interstellar objects found so far, 1I/'Oumuamua and 2I/Borisov. His piece *How to reach Interstellar Visitors - Optimum Interplanetary Trajectory Software* **was complemented by a discussion of the equation used by Dr Jason Benkoski, Johns Hopkins University Applied Physics Laboratory (JHU-APL) in his presentation at IAC2019 -** *The Physics of Heat Shielding During an Oberth Manoeuvre*. **Dr Benkoski used this to calculate how the velocity increment, DeltaV, required by such missions can be achieved by firing a rocket at perihelion in an Oberth manoeuvre. Adam asked** *How low can you go? - The Benkowski equation* **in P27. As promised, here is Adam's derivation of this extremely useful equation.**

Dr Benkoski's equation as quoted in P27 is -

$$V_{escape} = 7.4142 \frac{\Delta V^{1/2}}{r^{1/4}}$$

Vescape in AU/yr, perihelion altitude above the Sun in solar radii, and DeltaV in km/s

For the derivation we need -

Parameters	
V_∞	The Velocity relative to the Sun at Infinity after the Solar Oberth (the hyperbolic Excess).
V_{SOA}	The Velocity relative to Sun at the Solar Oberth after application of the burn ΔV
μ	The Gravitational Mass of the Sun = 1.327×10^{20} m³/s²
r	The Radial Distance from Centre of the Sun at Solar Oberth initiation
V_{SOB}	The Velocity relative to Sun at the Solar Oberth before application of the burn ΔV
ΔV	The impulsive change in velocity at the Solar Oberth.

By conservation of energy, we have the following, after the Solar Oberth:

$$V_\infty^2 = V_{SOA}^2 - \frac{2\mu}{r} \qquad (1)$$

Assuming the incoming orbit is parabolic, again by conservation of energy, we have the following, before the Solar Oberth:

$$V_{SOB}^2 = \frac{2\mu}{r} \qquad (2)$$

The following relationship holds:

$$V_{SOA} = V_{SOB} + \boldsymbol{\Delta} V \qquad (3)$$

Inserting (2) into (3) and then (3) into (1) we have:

$$V_\infty^2 = \left(\sqrt{\frac{2\mu}{r}} + \boldsymbol{\Delta} V\right)^2 - \frac{2\mu}{r} \qquad (4)$$

After some manipulation:

$$V_\infty = \Delta V^{\frac{1}{2}} \left(2\sqrt{\frac{2\mu}{r}} + \Delta V \right)^{\frac{1}{2}} \qquad (5)$$

Assuming ΔV is small compared to 2√(2μ/r):

$$V_\infty \approx \frac{\Delta V^{\frac{1}{2}}}{r^{\frac{1}{4}}} \sqrt{2\sqrt{2\mu}} \qquad (6)$$

The Gravitational mass of the Sun is $\mu = 1.327 \times 10^{20}\ m^3/s^2$ so:

$$V_\infty \approx \left(180505 \frac{\Delta V^{\frac{1}{2}}}{r^{\frac{1}{4}}} \right) {}^{m}/_{s} \qquad (7)$$

Changing units:

$$V_\infty \approx \left(38.0769 \frac{\Delta V^{\frac{1}{2}}}{r^{\frac{1}{4}}} \right) {}^{AU}/_{yr} \qquad (8)$$

This assumes ΔV is in m/s and r is in metres . If we want ΔV to be km/s we need to multiply by the factor $1000^{1/2}$ and furthermore if we want r in Solar Radii (1SR = 695510000m) than we need to divide by $(695510000)^{1/4}$ Thus we get:

$$V_\infty \approx \frac{1000^{\frac{1}{2}}}{695510000^{\frac{1}{4}}} \left(38.0769 \frac{\Delta V^{\frac{1}{2}}}{r^{\frac{1}{4}}} \right) {}^{AU}/_{yr} \qquad (9)$$

$$V_\infty \approx \left(7.414 \frac{\Delta V^{\frac{1}{2}}}{r^{\frac{1}{4}}} \right) {}^{AU}/_{yr} \qquad (10)$$

Where ΔV is in km/s and r is in Solar Radii, as required.

See the account of Benkoski's IAC 2019 presentation *The Physics of Heat Shielding During an Oberth Manoeuvre* in Principium Issue 27 November 2019 pages 26-27 including references to paper and presentation.

News Feature: TVIW's 6th Interstellar Symposium and Advanced Interstellar Propulsion Workshop

Joe Meany

Principium is pleased publish this report by Joe Meany with some edits from Martha Knowles. Its based on a report for the newsletter of the Tennessee Valley Interstellar Workshop (TVIW tviw.us), *Have Starship, Will Travel* (HSWT). Principium and HSWT have often worked together and we have recently strengthened ties through Pauli Laine (TVIW, Finland) and Douglas Loss (President, TVIW).

The conference assembled. All picture credits Martha Knowles /TVIW Originals at - piwigo.tviw.us/index.php?/category/8

The 6th Interstellar Symposium and Advanced Interstellar Propulsion Workshop—presented by the Tennessee Valley Interstellar Workshop (TVIW) in collaboration with the National Aeronautics and Space Administration (NASA) and hosted jointly by Wichita State University and Ad Astra Kansas Foundation—was held in Wichita, KS on November 10-15, 2019. We heard incredible talks and held productive round-table discussions regarding multiple aspects of interstellar exploration.

The Sunday Seminars returned this year. We were lucky to include new sessions on In-Space Manufacturing (presented by Tracie Prater and Matthew Moraguez) and Space Law (presented by Laura Montgomery). Dr. Rob Hampson gave a seminar on Life in Space. The First Contact seminar/working group discussion was chaired by Ken Wisian, Ken Roy, and John Traphagan. This seminar/working group will likely evolve into an ongoing working group with a presentation to be given at the next TVIW symposium. All of the seminars were well attended, and we will absolutely bring them back for the next symposium.

The Monday morning keynote speech, given by Professor Greg Matloff of City University of New York (CUNY), reviewed the range of options for achieving interstellar flight. That was followed by Marc Millis, Ohio Aerospace Institute*, who provided the attendees a refresher on the challenges of interstellar flight, and then an update on the NASA grant for assessing the research options to achieve it. The afternoon keynote

* and founder of the Tau Zero Foundation

Alexander Cohen, UCSB, presents on *Damage to Relativistic Interstellar Spacecraft by ISM Impact Gas Accumulation*


Al Jackson and Ken Roy. In the interstellar business for a long time!

by Engineering Director Pete Klupar from Breakthrough Starshot gave us a glimpse into the state of the project. This was especially helpful since we had so many presentations from Prof. Phil Lubin's group at University of California Santa Barbara (UCSB), covering the progress they've made on high-power laser propulsion.

Tuesday morning featured a particularly outstanding presentation by Dr. Joel Mozer, Chief Scientist at the US Air Force Space Command. Dr. Mozer presented a summary of recent Air Force "space futures" plans, which posited the most optimistic and pessimistic outlooks for space development in the next 30 years and how each might affect the goal of advancing interstellar flight.


Pete Klupar, Engineering Director, Breakthrough Starshot

Throughout the event, presentations took more detailed looks at a broad range of specific topics, such as minimum-mass power supplies, and the implications of humans in space (culturally, biologically, etc.). Presenters Dr. Deana Weibel, Professor of Anthropology at Grand Valley State University (GVSU) and Dr. Kelly Smith, Professor of Philosophy & Biological Sciences at Clemson University attended at the invitation of Organizing Committee member Dr. James Schwartz. The philosophical and ethical implications of space exploration and colonization are not negligible, and each presentation raised considerable discussion during the question-and-answer period after each talk.

All three presenters were joined by Dr. John Traphagan, Professor of Religious Studies and Anthropology, University of Texas at Austin, and Dr. Sheri Wells-Jensen, Professor of English at Bowling Green State University, at the Sagan Meeting on Tuesday evening. The Sagan meeting, a two hour panel discussion, focused on the questions: "What is the most ethically salient roadblock to space settlement, the most important issue or problem that must be resolved in advance of initiating space settlement?"

TVIW was proud to begin a new tradition this year. Dr. Greg Matloff and two TVIW volunteers (John Trieber and Matthew Johnson) were presented with the first-ever Eridani Awards. Matloff was recognized with the first Eridani Professional award for his

C Bangs (artist), Doug Loss (TVIW President) and Dr Greg Matloff


decades of contributions to the interstellar community. Trieber and Johnson were recognized for their continuing dedication to TVIW operations. Trieber has been an invaluable resource running the AV systems at the past four Interstellar Symposia; Johnson is a talented and careful IT administrator.

Our team also introduced a new experiment this year, live-streaming the sessions for free to those who could not attend the meeting in person. We felt that our impact could be increased by making the information as widely available as possible, in real time. People tuned in from the United States, Europe, and South America! The talks will be edited for audio balance, and will be uploaded to the TVIW YouTube Channel. We also plan to host them on the TVIW website as they become available.

Andrew Higgins, McGill University, on -
Strategies for Mitigation of Dust and Charged Ion Impact on Laser-Driven Lightsails

The bus trip to the Cosmosphere Space Museum (cosmo.org) was a popular evening activity on Wednesday night. The experience was a worthy addition to the tours we have offered at past TVIW symposia, which have included Oak Ridge National Lab tour and the US Space and Rocket Center in Huntsville. Participants were treated to a private dinner adjacent to a replica of Space Shuttle Endeavour and an SR-71 Blackbird, as well as the original Apollo 13 capsule. After dinner the museum was open for browsing, offering exhibits on the planets, rovers, and the Space Race (even featuring sections of the Berlin Wall). The evening ended with a viewing of *Apollo 11: First Steps Edition* (apollo11firststeps.com) in the museum's planetarium.

Geoffrey Landis expands on *The Physics of Negative Mass: Applications for Propulsion and Interstellar Travel*

Thursday evening provided a chance for participants to relax and dream with a panel of science fiction authors discussing their work and how it is informed by real science and feasible engineering. The panel was moderated by Baen Books Publisher, Toni Weisskopf, and included authors Dan Hoyt, Sarah Hoyt, Les Johnson, Geoff Landis, and Robert Hampson.

In addition to the normal three-day symposium topics, from broad science advances important to interstellar development, the meeting included a special two-and-a-half-day NASA Advanced Propulsion Workshop focusing on Directed Energy Propulsion and Highly Energetic Nuclear Processes for Propulsion (Fusion and Antimatter). The NASA Advanced Interstellar Propulsion Workshop started Wednesday afternoon with keynote talks by Andrew Higgins (Directed Energy Propulsion) and Jason Cassibry (Highly Energetic Nuclear Processes). This was a new addition to our regular sessions and served to inform NASA's requirement to deliver to the US Congress a notional plan for launching a true interstellar mission (with a spacecraft traveling at least 0.1 c) no later than the 100th anniversary of the Apollo 11 moon landing in 2069. The two technology communities (of discipline experts) met in parallel sessions and developed near- and mid-term technical milestones necessary to advance their specific technologies and meet the 2069 goal. The Directed Energy group outlined a five-year-plan for answering open questions regarding the phased-array lasers and fundamental sail materials. The Highly Energetic Nuclear Processes group outlined five-year goals for fission, fusion, and antimatter propulsion missions.

We at the TVIW would like to thank our collaborators at NASA, Wichita State, and Ad Astra Kansas for their efforts in making this such a successful meeting.

During the meeting, Stephen Fleming and TVIW President Doug Loss jointly announced that TVIW will be partnering with The University of Arizona to host the 7th Interstellar Symposium in the fall of 2021. While it is too early to release any further details, we look forward to seeing all the Wichita and previous symposia participants, as well as any other interested attendees, at the next TVIW symposium, to be held in Tucson!

A convivial group - left to tight - Al Jackson, Cissa Fleming, Stephen Fleming , and Timothy Swindle

Two of the real pioneers of Interstellar Studies

Marc Millis (left) and Les Johnson (right)

Respectively Senior Scientist at Ohio Aerospace Institute and Principal Investigator at NASA for the Near Earth Asteroid Scout solar sail project

News Feature: Interstellar Objects (ISOs)- Oumuamua, Borisov and objects in between

A note and two quotes

John I Davies

A recent paper by Julie C Castillo-Rogez of NASA Jet Propulsion Labs and colleagues prompts some thoughts on these mysterious high-eccentricity objects and what is known and conjectured about them.

Our colleague Marshall Eubanks noticed the paper, *Approach to exploring interstellar objects and long-period comets**. Principium readers will be aware of the two Interstellar Objects (ISOs) found so far. i4is Project Lyra has investigated the feasibility of missions to such objects - i4is.org/what-we-do/technical/project-lyra/

The Project has published three papers so far (see box on next page) and numerous articles in Principium.

Others, notably Darryl Seligman and Gregory Laughlin of Yale University have also examined how and why we might visit ISOs**.

Now NASA JPL researchers are considering missions. The paper by Castillo-Rogez et al aims to identify the best approaches for exploring planetary bodies with very long orbital periods, see their abstract and links below, Annex 1. However there is no open publication so far.

Manx comets have no tails

The JPL paper abstract mentions the concept of Manx comets. This deserves an introduction in Principium. Clearly the controversy about the nature of Oumuamua (mysterious) and Borisov (a comet from beyond the Solar System) has caused renewed interest in Manx comets which, like the cats of that small island, have no tails. There is a survey article summarised in the Annex 2 below - *Manx comets - a Royal Society review.*

Asteroids and comets are useful classifications of celestial bodies but nature seems to love to confound human attempts to classify it. Perhaps this is part of the reason why science is such an endlessly fascinating endeavour!

1902 photograph of Manx cat

**** Approach to exploring interstellar objects and long-period comets***

Castillo-Rogez, Julie C. and Landau, Damon and Chung, Soon-Jo and Meech, Karen (2019) Approach to exploring interstellar objects and long-period comets. In: Spaceflight Mechanics 2019. Advances in the Astronautical Sciences. No.168. American Astronautical Society , San Diego, CA, pp. 2115-2128. ISBN 9780877036593. resolver.caltech.edu/Caltech AUTHORS:20191205-094833503/authors.library.caltech.edu/100202/

***** The Feasibility and Benefits of In Situ Exploration of 'Oumuamua-like Object***

Darryl Seligman and Gregory Laughlin (Department of Astronomy, Yale University)

Published 2018 April 30 • © 2018. The American Astronomical Society. All rights reserved.

The Astronomical Journal, Volume 155, Number 5, Focus on the First Interstellar Small Body `Oumuamua

iopscience.iop.org/article/10.3847/1538-3881/aabd37/meta

Annex 1 - Abstract of *Approach to exploring interstellar objects and long-period comets*

authors.library.caltech.edu/100202/

Castillo-Rogez, Julie C and Landau, Damon and Chung, Soon-Jo and Meech, Karen (2019)

Abstract

This paper aims to identify the best approaches for exploring planetary bodies with very long orbital periods, i.e., bodies that approach Earth only once in a lifetime. This includes long-period comets (LPCs), and the newly discovered classes of Manx comets and interstellar objects (ISOs). Long-period comets are high scientific value targets, as indicated in the current Planetary Science Decadal Survey. Interstellar objects open the fascinating possibility to sample exoplanetary systems. Manxes hold the key to resolving long-time questions about the early history of our solar system. Specific strategies need to be implemented in order to approach bodies whose orbital properties are at the same time extreme and unpredictable. As ground-based telescope capabilities are greatly improving, it will soon become possible to detect LPCs more than ten years before they reach perihelion. On the other hand, the non- or weakly active Manx comets and ISOs require reactive exploration strategies. All of these bodies offer many challenges for close proximity observations that can be addressed by the deployment of multi-spacecraft architectures. We describe several concepts that leverage the many advantages offered by distributed sensors, fractionated payload, and various mother-daughter configurations to achieve high impact science within the reach of low-cost missions.

Project Lyra papers - most recent first

Hibberd, A., Perakis, N., Hein, A.M. 2019. *Sending a Spacecraft to Interstellar Comet C/2019 Q4 (Borisov).* arXiv:1909.06348 - arxiv.org/abs/1909.06348

Project Lyra: Catching 1I/'Oumuamua – Mission opportunities after 2024

Acta Astronautica Volume 170, May 2020, Pages 136-144

Adam Hibberd(i4is), Andreas M Hein(i4is), T Marshall Eubanks(i4is and Space Initiatives Inc)

- preceded by -

Hibberd, A., Hein, A.M., Eubanks, T.M., 2019. *Project Lyra: Catching 1I/'Oumuamua - Mission Opportunities After 2024.* arXiv preprint arXiv:1902.04935. - arxiv.org/abs/1902.04935

Project Lyra: Sending a spacecraft to 1I/'Oumuamua (former A/2017 U1), the interstellar asteroid

Andreas M Hein(i4is), Nikolaos Perakis(i4is), T. Marshall Eubanks(i4is and Space Initiatives Inc), Adam Hibberd(i4is), Adam Crowl(i4is), Kieran Hayward(i4is), Robert G KennedyIII(i4is), Richard Osborne(i4is)

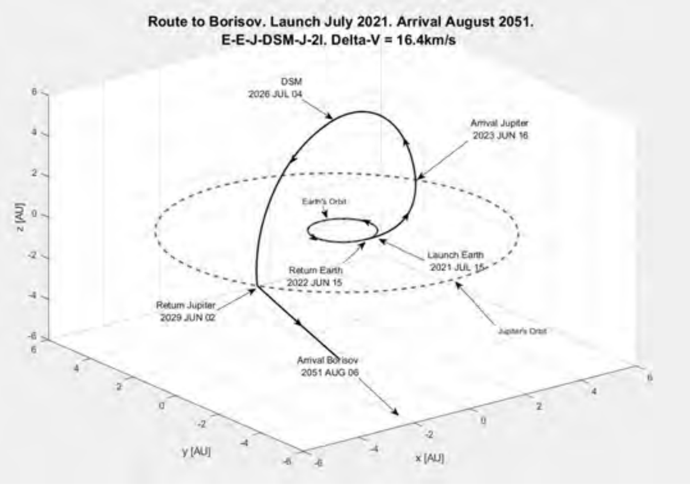
Acta Astronautica, Volume 161, August 2019, Pages 552-561

doi.org/10.1016/j.actaastro.2018.12.042

/www.sciencedirect.com/science/article/abs/pii/S0094576518317004

- preceded by -

Hein, A. M., Perakis, N., Long, K. F., Crowl, A., Eubanks, M., Kennedy III, R. G., & Osborne, R. (2017). Project Lyra: Sending a Spacecraft to 1I/'Oumuamua (former A/2017 U1), the Interstellar Asteroid. arXiv preprint arXiv:1711.03155. - arxiv.org/abs/1711.03155



An illustration of Project Lyra work in progress: This is an alternative method of getting to 2I/Borisov which does not require a solar Oberth, chractised as E-E-J-DSM-J-2I.

DSM = Deep Space Manoeuvre. A user-specified point in space where a further DeltaV is applied. The polar angles of Longitude and Latitude of this point are optimised to require the minimum DeltaV for the overall trajectory. In this case approximately one Jupiter radial distance from the Sun and a high latitude, well out of the ecliptic plane, giving a leveraging manoeuvre to yield a propitious velocity vector approach to Jupiter delivering a more effective Jupiter sling-shot effect (Jupiter Oberth) and thus a high heliocentric speed. However, the long mission duration and the near-future launch date (2021) are problematic.

Credit: Adam Hibberd / i4is

Annex 2 - *Manx comets - a Royal Society review*

royalsocietypublishing.org/doi/full/10.1098/rsta.2016.0259

The original is a 15 page article with 134 references. Principium readers who find this brief set of excerpts interesting are referred to the Royal Society link above. All [references] are to that paper.

Excerpts with (my **emphasis**) follow -

Review article-Asteroid–comet continuum objects in the solar system

Henry H. Hsieh - Published:29 May 2017

doi.org/10.1098/rsta.2016.0259

Abstract

In this review presented at the Royal Society meeting, ‘Cometary science after Rosetta’, I present an overview of studies of small solar system objects that exhibit properties of both asteroids and comets (with a focus on so-called active asteroids). Sometimes referred to as ‘transition objects’, these bodies are perhaps more appropriately described as ‘continuum objects’, to reflect the notion that rather than necessarily representing actual transitional evolutionary states between asteroids and comets, they simply belong to the general population of small solar system bodies that happen to exhibit a continuous range of observational, physical and dynamical properties. Continuum objects are intriguing because they possess many of the properties that make classical comets interesting to study (e.g. relatively primitive compositions, ejection of surface and subsurface material into space where it can be more easily studied, and orbital properties that allow us to sample material from distant parts of the solar system that would otherwise be inaccessible), while allowing us to study regions of the solar system that are not sampled by classical comets.

...

1. Background

Asteroids are classically understood to be essentially inert objects composed primarily of non-volatile material. They are mostly found in the inner solar system (inside the orbit of Jupiter) where they are believed to have formed. Meanwhile, comets are classically thought of as ice-rich bodies originally from the outer solar system (beyond the orbit of Neptune, in the Kuiper Belt, scattered disc or Oort Cloud) that have been perturbed onto orbits passing through the inner solar system. While in the inner solar system, when they are sufficiently close to the Sun and therefore sufficiently heated, sublimation of their volatile contents drives the release of gas and dust, producing cometary activity in the form of comae, tails or both.

...

In this review presented at the Royal Society meeting, ‘Cometary science after Rosetta’, I present **a broad overview of studies of small solar system objects that exhibit properties of both asteroids and comets (with a particular focus on so-called active asteroids)**. Sometimes referred to as ‘transition objects’, these bodies are perhaps more appropriately described as ‘continuum objects’. In other words, rather than necessarily representing transitional evolutionary states via which comets evolve into asteroids or vice versa, these objects simply belong to the general population of small solar system bodies that happen to exhibit a continuous range of observational, physical and dynamical properties of both asteroids and comets. For additional perspectives, the reader is also referred to previous reviews in the literature [14,15].

...

2. Types of continuum objects

(a) Dormant and extinct comets

Astronomers have long recognized the potential for inactive comets to be mistaken for asteroids. By 1970, several authors had already noted the **dynamical similarities between apparently inactive asteroids, such as the Apollo and Amor asteroids, and short-period comets**, as well as the potential for previously known comets to appear completely inactive over certain portions of their orbits [16,17]. . A hypothesis was put forth that these objects, as well as low-activity comets like 28P/Neujmin 1 and 49P/Arend-Rigaux, could represent transitional phases between comets and minor planets (i.e. asteroids). It was noted, though, that the cometary origins of such objects could still be identified via dynamical criteria, such as their dynamical lifetimes [17]. A more clearly defined dynamical criterion for distinguishing the orbits of asteroids and comets was eventually adopted in the form of the Tisserand invariant (TJ), or Tisserand parameter, which is a mostly conserved quantity in the restricted circular three-body problem*

...

Objects with TJ<3 are essentially dynamically coupled with Jupiter and are commonly considered to have ‘comet-like’ orbits, while objects with TJ>3 do not have close encounters with Jupiter and are commonly considered to have ‘asteroid-like’ orbits [16,18,19]. Other more sophisticated sets of dynamical classification criteria have been devised and tested [20,21], but it is probably fair to say that **TJ remains the most commonly used criterion for dynamically classifying objects as ‘comet-like’ and ‘asteroid-like’, due to its simplicity as well as its long history of use for this purpose**.

...

These so-called asteroids on cometary orbits (i.e. orbits with TJ<3), or ACOs, have been the subjects of various observational studies aimed at confirming the cometary nature of these objects [25,26]and estimating the contribution of these objects to the near-Earth object (NEO) population.

...

(b) Active asteroids

(i) Overview

In contrast with ACOs, which are observationally asteroidal and dynamically cometary (i.e. have TJ<3), active asteroids are observationally cometary and dynamically asteroidal (i.e. have TJ>3) [43]. The first type of active asteroids to come to light were the main-belt comets (MBCs), which orbit completely within the main asteroid belt yet exhibit comet-like mass loss due (at least in part) to the sublimation of volatile ices [44,45]. In recent years, however, it has become increasingly clear that comet-like mass loss events due to a unexpectedly broad range of effects or combinations of effects are possible for objects on asteroid-like orbits (leading Bauer et al. [46] to suggest the more general term of active main-belt objects, or AMBOs). **In addition to sublimation, two of the more common activity generation mechanisms that have been inferred are impact disruption and rotational destabilization.** Active asteroids for which comet-like activity is not at least partially attributed to sublimation, and instead appears to be due to impacts, rotation or other disruptive effects, are **often referred to as disrupted asteroids [47].** For detailed discussions of these objects, interested readers are referred to recent reviews of MBCs [45,48] and of active asteroids in general [43], though I will highlight key aspects of these objects here.

(ii) Main-belt comets

First recognized as a new class of cometary objects in 2006 [44], MBCs have attracted interest because the unexpected present-day ice (given their location in the warm inner solar system) implied by their apparently sublimation-driven activity means that they could potentially be used as compositional probes of inner solar system ice and also as a means of testing hypotheses that icy objects from the main-belt region of the solar system could have played a significant role in the primordial delivery of water to the terrestrial planets [49–52].

...

(iii) Disrupted asteroids

The first two suspected collisionally disrupted objects in the main asteroid belt, P/2010 A2 (LINEAR) and (596) Scheila, were both first discovered to be active in 2010 [73–76]. Dust modelling showed fairly unequivocally that the dust emission event that took place on (596) Scheila was due to an oblique impact that caused an asymmetric ejecta cone that then evolved under the influence of radiation pressure [77], though an additional numerical modelling analysis later suggested that P/2010 A2’s dust emission might instead have been due to rotational destabilization [78], though this interpretation remains controversial. While not commonly considered before, rotational destabilization has since gained increasing acceptance as a plausible cause of observed mass shedding by asteroids, notably in cases where an asteroid may already be rotating at close to its disruption limit and is then accelerated past that limit by radiative torques (e.g. the Yarkovsky–O’Keefe–Radzievskii–Paddack, or YORP, effect) [79,80].

...

* Editors footnote -en.wikipedia.org/wiki/Tisserand%27s_criterion#Tisserand's_relation

(iv) Other active asteroids

While all MBCs (by definition) and most known disrupted asteroids orbit in the main asteroid belt, a few active objects (or suspected active objects) do not reside in the asteroid belt, yet have orbits with TJ>3 (implying that they at least originated in the main asteroid belt) and so, therefore, satisfy the definition of active asteroids. Notable examples of such objects include asteroids (2201) Oljato and (3200) Phaethon, and Comet 107P/Wilson-Harrington (also known as (4015) Wilson-Harrington).

...

(v) Activity generation mechanisms in active asteroids

While this section on active asteroids has focused on sublimation, impact disruption and rotational destabilization, there are other mechanisms that could potentially produce comet-like mass loss on asteroids, including thermal fracturing (see Phaethon, above, or the case of 322P/SOHO 1 [108]), radiation pressure sweeping and electrostatic levitation [43].

...

(c) Other continuum objects

There are many other types of continuum objects for which there is not enough space in this brief review to discuss in detail, but which are worth at least mentioning. For instance, cometary activity has long been linked to the production of debris streams which cause regular meteor showers on the Earth [112,113].

...

Recently, low-activity comets on LPC-like orbits, or so-called 'Manx comets', have gained attention as possible probes of early planetary migration models. Related to the class of solar system objects known as Damocloids, which are inactive objects with TJ≤2 and may be inactive HTCs and LPCs [124], **Manx comets have been hypothesized to be objects from the inner solar system, some of which might be made of distinctly un-comet-like, mostly non-icy material, that were ejected into the Oort Cloud during the era of planetary migration but have recently been perturbed onto orbits bringing them back into the inner solar system [125]**.

Could 1I/Oumuamua be an interstellar example of such a body? If 2I/Borisov is an interstellar comet then 1I/ might be the asteroid equivalent. Its still a funny shape with a funny acceleration curve though!

....

3. Dynamics

I wish to conclude this review with a brief discussion of various dynamical issues related to asteroids and comets. Traditionally, the Kuiper Belt has been regarded as the source of the JFCs while the Oort Cloud has been regarded as the source of HTCs and LPCs [118,126,127]. As discussed above (§2a), the use of TJ also provides a simple but generally effective means for determining whether an object possesses a 'comet-like' orbit (TJ<3) or an 'asteroid-like' orbit (TJ>3). Recent dynamical analyses as well as the discovery of the MBCs, which demonstrate that main-belt objects can and do contain sufficient volatile material to drive present-day cometary activity, however, have complicated these neat dynamical principles.

....

4. Conclusion

In summary, the population of small bodies in our solar system today, including both minor planets and classical comets, is far less well-delineated into distinct groups of objects than the classical paradigm might have led one to believe in the past. These objects instead appear to occupy a continuum spanning the full range of observational, physical and dynamical properties classically attributed solely either to asteroids or comets.

NEXT ISSUE

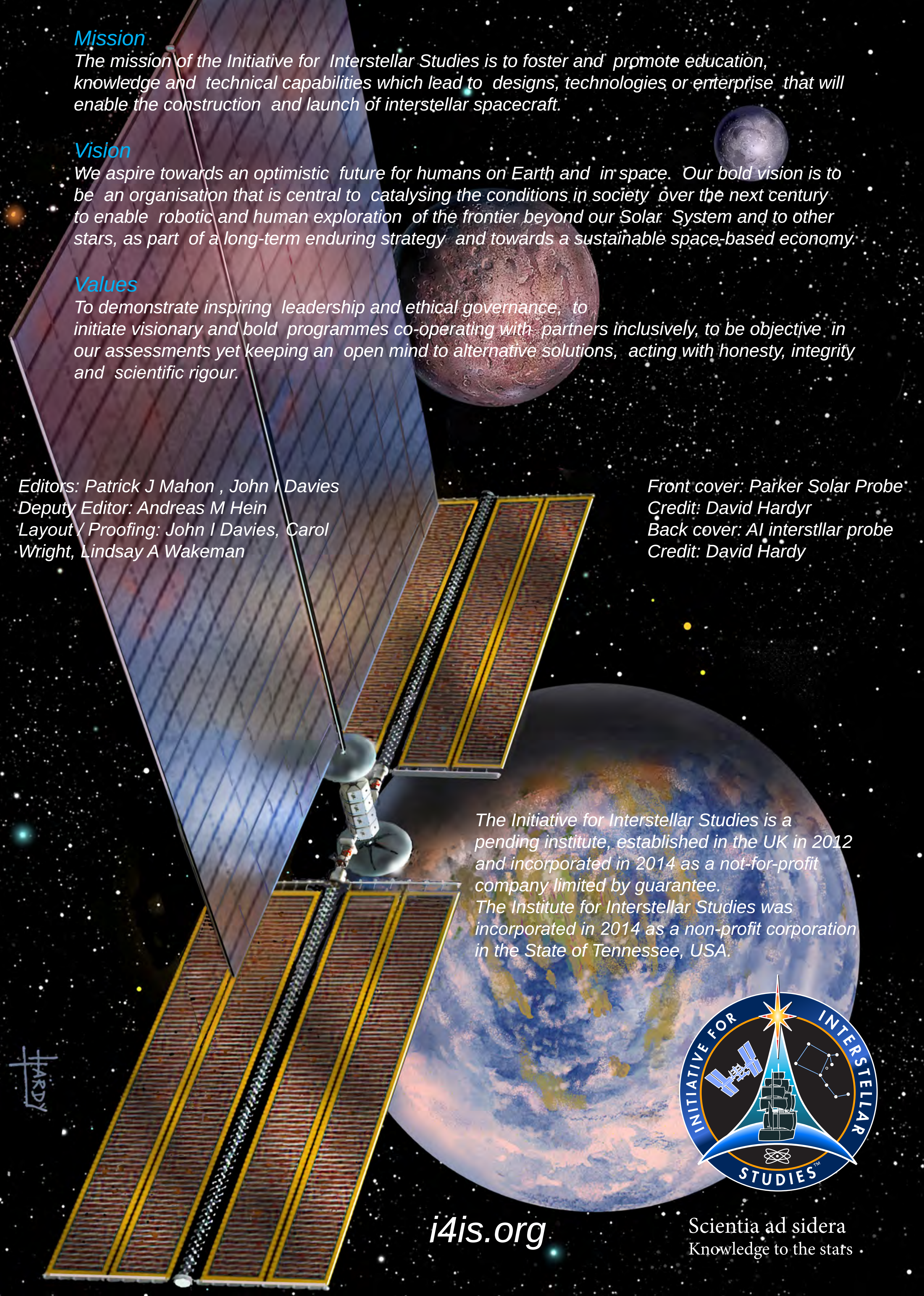
IAC 2019 Report - part 3
News Feature - the i4is Education Team
and more!

Cover Images

Both covers of Principium 28 feature the work of our long-established collaborator, space artist David Hardy (www.astroart.org).

The front cover is a vision of the Parker Solar Probe (www.nasa.gov/content/goddard/parker-solar-probe). This probe will produce much new input to solar research but the heat shield technology it uses is a benchmark yielding input to the design of similar protection for high velocity probes using the Oberth Manoeuvre to speed them on the way to interstellar objects (ISOs) like many of the proposals coming from i4is Project Lyra and to exploration of the outer reaches of the solar system like the Johns Hopkins Applied Physics Laboratory (JHU-APL) proposal, *Interstellar Probe* (interstellarprobe.jhuapl.edu). More about this in Principium 27 *How low can you go?* and JHU-APL *An Interstellar Probe for the next Heliophysics Decadal Survey* reported from IAC 2019 in the same issue.

The back cover image is one of two paintings by David Hardy commissioned by Andreas Hein illustrating his work on AI probes and based on an earlier image by Adrian Mann. See *Artificial Intelligence for Interstellar Travel*, Andreas M Hein and Stephen Baxter (arxiv.org/pdf/1811.06526.pdf and outlined in Principium 23, November 2018).



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.

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

Front cover: Parker Solar Probe
Credit: David Hardyr
Back cover: AI interstllar probe
Credit: David Hardy

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.

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