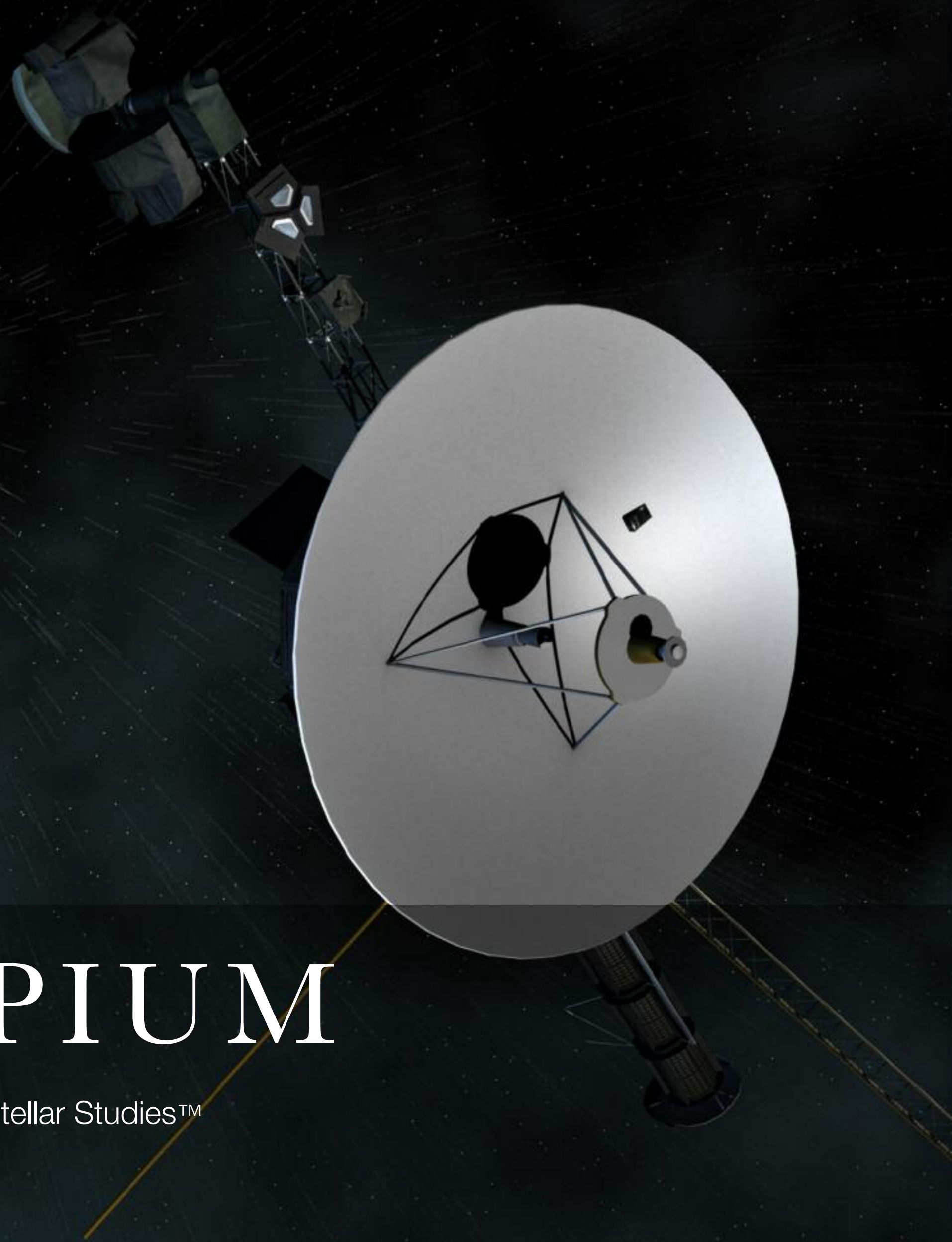


PRINCIPIUM

The Newsletter of the Institute for Interstellar Studies™

Issue 2 | January 2013

www.I4IS.org

Scientia ad sidera

Knowledge to the Stars

A letter from Rob Swinney

We do indeed live in exciting times. I remember growing up in the sixties and seventies and being totally captured by a similar spirit during the Apollo age and the later planetary missions. Sadly the dream of manned missions to Mars by the eighties and Saturn by the early twenty-first century crumbled. The promise shown by the inspirational yet fictional worlds of *Star Trek* and *Star Wars* seemed just that – fictional.

Now, once again, 'the planets are lining up'. There is a new buzz. There is a feeling that the technologies required to reach the stars are just on the horizon (at least unmanned to start with). So a few years ago, having attained the rank of squadron leader as an aerosystems engineer in the Royal Air Force, I decided to take my contractual option to leave. I was already reflecting on what great new adventure to take. Maybe you are too?

Having met the likes of the Institute's Executive Director Kelvin Long at the British Interplanetary Society's meetings, it was through Project Icarus that we came to work more closely together, starting in 2009. When Kelvin told me of his plans for the Institute I was immediately keen to get involved. I didn't realise that he had big plans for me having known that I had spent a few years as a teacher and had also been closely involved at the RAF's College, running and instructing on aerosystems engineering courses and being involved with the leadership training of young officers.

My role in the institute for Interstellar Studies will be the first Director of the Academy. We have big plans for the Academy to support the work of the Institute and have recently started with new interstellar themed MSc Projects. Our first 'customers' are based with the International Space University located in Strasbourg with four students undertaking projects as part of their Space Studies course. Recently we even had our first member travel from India to the USA to attend an international conference. We plan to develop this to support the younger members of the Institute and eventually create a full scholarship programme. We are developing a core curriculum in interstellar studies for students to provide them with the up-to-date academic training they will need to be successful in this field. In the longer term we also intend to inspire and develop students from as early as Key Stage 2 onwards and will undertake targeted public outreach events to give them an understanding of space and its many challenges.

Although the Institute's mission has a clearly defined goal, to achieve true interstellar flight, we believe that in the coming years the Academy will naturally provide a cornerstone in the Science, Technology, Engineering and Mathematics (STEM) goals of the wider society. In addition we hope to encourage all aspects of understanding, from the related social and cultural activities, the arts and fostering imagination so that our graduates will be able to work co-operatively with anyone from the global community and make a positive contribution.

One of our greatest challenges is that we are initially a group of volunteers working in our own time to build a strong foundation to the Academy and the Institute. Our rapid growth has proven to be an organisational challenge and only overcome by more hard work and time dedicated to the cause. We are fortunate that we have a growing number of people supporting our work. Perhaps you would like to be involved with the Institute too? Enthusiasts are always welcome and you can reach us via our website, www.i4is.org.

This brings me to the recent sad passing of Sir Patrick Moore, whom I first met in the 1980s. He was undoubtedly my favourite enthusiast, showing what could be achieved with great dedication and hard work. If the founders of the Institute can follow his example we can look forward to a successful future.

Thank you Patrick, RIP.

Rob Swinney
Academy and Finance Director
The Institute for Interstellar Studies™

News from the Institute

Going interstellar in Tennessee

Scientists, engineers, authors, anthropologists and sociologists will be heading to Alabama, United States in February for the Second Tennessee Valley Interstellar Workshop. It's organised by NASA space scientist and science fiction author Les Johnson – who's book *Going Interstellar* we reviewed last issue – and is being sponsored by several organisations including the Institute for Interstellar Studies™ and the British Interplanetary Society. There's going to be a strong I4IS presence at the workshop, including Kelvin Long and Claudio Maccone, as well as Centauri Dreams' Paul Gilster and Icarus Interstellar's Richard Obousy.

The aim of the workshop is to encourage discussion and debate and promote thought-provoking ideas across a wide-range of topics: spacecraft propulsion technologies and engineering; economic, social and political considerations; life support and hibernation; colonisation concepts and exoplanet studies; and SETI. With the line-up of heavy-hitting speakers and attendees it's going to be one not to miss if you're in the area. Held over 3–6 February 2013 at the Nexolve first floor auditorium at 655 Discovery Drive, Huntsville, Alabama, USA, as part of the workshop there will also be a tour of the United Launch Alliance facility where the workhorse Delta IV and Atlas V rockets used by NASA are built. Meanwhile, the results of the workshop will be published in a special issue of the *Journal of the British Interplanetary Society*.

For more details, visit http://lesjohnsonauthor.com/tviw/tviw_2013.

Evacuate Earth!

National Geographic Channel explored the possibility of interstellar travel before the end of the twenty-first century over the Christmas period with their new docu-drama, *Evacuate Earth*. With I4IS Executive Director Kelvin Long onboard as a scientific consultant, *Evacuate Earth* focused on whether it would be possible to transport humanity to another star system were Earth placed in jeopardy (in the programme, from a rogue neutron star on a collision course).

Evacuate Earth: launching a starship from a doomed planet.
Image: National Geographic.

The show garnered a fair bit of media attention, including a piece in the 21 December edition of *The Times*, where Long was interviewed about possible forms of starship propulsion and I4IS given a mention in the newspaper – hopefully it is just the beginning of raising the Institute's star in the media!

If you missed *Evacuate Earth* on the National Geographic Channel, you can catch it on YouTube at http://www.youtube.com/watch?v=vFgJ7Hss1VA

I4IS Talks

Institute for Interstellar Studies Executive Director Kelvin Long will be embarking on a lecture tour in the United States at the beginning of February. Dates announced so far include:

- Tennessee Valley Interstellar Workshop, Huntsville, Alabama (5 February)
- NASA Marshall Spaceflight Center, Huntsville, Alabama (6 February)
- NASA Glenn Research Center, Cleveland, Ohio (8 February)

Kelvin also has two European dates lined up. First he'll be at the International Space University in Strasbourg, France on 19–20 February and then on the following weekend of 23–24 February at the UKSEDS (UK Students for the Exploration & Development of Space) 2013 conference at the University of Bristol. To keep up with Kelvin you can follow him on Twitter under 'thestarshipman' [https://twitter.com/thestarshipman].

The Philosophy of the Starship

Date: May 29th 2013

Venue: BIS HQ 27/29 Lambeth Road, London

This is a symposium on the philosophy of the Starship. At some point in the future, human kind will build robotic and human carrying vessels which will go beyond the solar system, out into interstellar space and onto visit worlds around other stars. As we prepare our civilization to embark on this exciting journey to establish the new frontier, it is worth pausing to think, and consider how we should plan these bold and ambitious missions. That planning begins now.

History has shown examples of societies who built great vessels for similar purpose, such as the Portuguese Caravel sailing ships which were launched in the 1400's and used for 300 years hence to explore the coast of Africa. The Italian explorer Christopher Columbus set sail across the Atlantic Ocean in an expedition of three such ships in 1492, hoping to find a route to India to trade for spices. His mission was funded by King Ferdinand II and Queen Isabella of Spain. The result was his discovery of the New World. Similarly, HMS Challenger set out in 1872 on a three year scientific exercise to lay the foundations of oceanography, going on to discover 4,000 previously unknown species.

For the future Starships, what sort of vessels should we send and what will be their function? how should they be constructed, financed and governed? What sort of technology should such vessels contain? What are the risk/benefits for making the trip? What are the implications for the future evolution of those star faring humans that made the voyage? Who should go, why and what characteristics should these Starship humans have? What will we discover when we get there? Do we understand what is meant by the romantic phrase "Starship"? The Institute for Interstellar Studies™ has organized this symposium in collaboration with the Journal of the British Interplanetary Society. We invite innovative and thought provoking papers which explore these ideas.

All submissions should be sent to interstellarinstitute@gmail.com. All proceeds from running this symposium will go to the British Interplanetary Society.

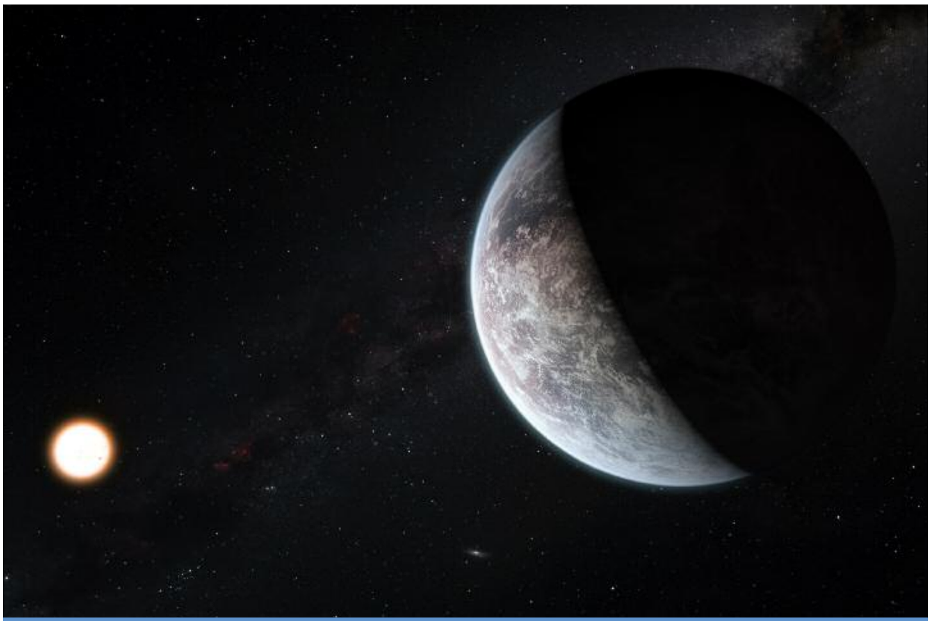
ADVANCES

Another potentially Earth-like planet?

Future interstellar explorers may have a new destination to head for: five rocky planets, including one at an equivalent distance from its star as Earth is from the Sun, just 11.9 light years away around the star tau Ceti.

The findings come from new analysis of old radial velocity data; in other words, the slight Doppler shift in the star's light as it and its planets 'wobble' around a common centre of mass. The problem for low mass terrestrial exoplanets is that they produce very small radial velocity signals that can get lost in the noise.

So a multinational team of scientists led by University of Hertfordshire astronomers have attempted to get around these limitations by coming up with a new modelling technique that they claim successfully reduces the noise in the data to reveal those tiny planetary signals. In a press release the team leader, Mikko Tuomi, describes a process of "adding artificial signals to the data and testing our recovery of the signals with a variety of different approaches. This significantly improves our noise modelling techniques and increases our ability to find low mass planets."



An artist's impression of a rocky exoplanet, perhaps like tau Ceti e.
Image: ESO/M Kornmesser.

The team applied this technique to data from the three most sensitive planet-finding spectrographs in the world – the HARPS spectrograph at the European Southern Observatory in Chile, UCLES in Australia and HIRES at the Keck Observatory in Hawaii. The most notable result indicates that planet e, with a mass 4.2 times that of Earth, orbits tau Ceti every 168 days at a distance of just over 82 million kilometres. Although tau Ceti is the closest star to share the Sun's spectral type (G), it is slightly cooler than our Sun meaning that the distance of the region where an Earth-like planet with an atmosphere can support liquid water is closer in. Additionally, planet d is on the inner edge of this zone and could perhaps resemble Venus. However, not everyone is convinced yet as to the existence of the planets.

"[Their work] does not give, with good probability, any final answer about the planetary content of the system, but only a first guess," says Stephane Udry of the University of Geneva, who works with the HARPS instrument. "In such cases our approach has always been to go back to the telescope and confirm with further observations."

After a recent flurry of unconfirmed terrestrial planets (including alpha Centauri Bb and HD 40307g, both reported on last issue) we stand either on the cusp of a new age of planetary science, or one of disappointment as the planet claims are retracted. One thing is for certain; with each new discovery of a nearby exoplanet, the clamour for an interstellar mission grows.

Did you know?

Tau Ceti was one of two stars surveyed by Frank Drake for extraterrestrial signals as part of his pioneering Project Ozma (the other star being epsilon Eridani) in 1960.

Listening Post

To the Editor,

Good science depends upon precision in the use of language. For example, physics makes important distinctions between energy and power, mass and weight, force and momentum.

If the scientific community is adopting populist expressions that are scientifically inaccurate, I propose that the I4IS should lead the way in promoting a more precise use of language. This is especially important in such an exotic subject as interstellar studies, whose concepts are often remote from popular understanding, even to the point that, in his 10 December posting on Centauri Dreams, Paul Gilster commented: “I still find myself having to explain the difference between ‘interplanetary’ and ‘interstellar’ at the oddest moments.”

We are seeing increasing use of the term ‘habitable zone’ around a star, and ‘habitable planet’ within that zone, as for example in *Principium*, issue one, page six.

The obvious implication of the adjective ‘habitable’ is that on such a planet or within such a zone, life may be found; outside such a zone, life may not be found. This is quite clear, and also highly misleading.

At the present state of scientific knowledge, the limits on the possible locations of living organisms are simply not known. It may in fact be the case that the life which has evolved in the Universe so far only occurs on and near the surfaces of Earth-analogue planets that have Earth-analogue orbits around Sun-like stars. In such a case, the current use of the term ‘habitable’ would indeed be justified. But it may also be the case that life, even life as we know it, is found in underground environments on any world with sub-surface liquid water.

We thus have the ironic situation that while interstellar researchers focus their attention on the supposed habitable zones around nearby stars, Solar System researchers are getting excited about the possibility of finding subterranean life on worlds such as Europa, Enceladus or Titan, worlds which orbit well outside that supposed zone in our own planetary system. Obviously, if bodies such as these are habitable to living organisms, then the zone of habitability is essentially coextensive with the entire astronomical Universe. A terrestrial-type world, generating internal heat for billions of years through radioactive decay of uranium, thorium and potassium, could then support sub-surface life wherever that world might happen to be located in interplanetary, interstellar or even intergalactic space. Many such worlds must have been ejected from their parent planetary system during the chaotic processes of planetary formation.

What makes a planet ‘habitable’? Image: NASA/JPL–Caltech/R Hurt (SSC/Caltech).

Further, the focus on habitable zones completely ignores any possibility of life being based on anything other than carbon chemistry with water as a solvent. Such unconventional life may exist, or it may not; it is much too early to close our eyes to the possibility. The book *Evolving the Alien* [a.k.a *What Does a Martian look Like?: The Science of Extraterrestrial Life* – Ed] by Jack Cohen and Ian Stewart (Ebury Press, 2002) contains a lively exploration of some mind-bending alternatives to life as we know it, while stating, “the astrobiological concept of a habitable zone is largely useless,” (page 10).

Leading researchers such as Seth Shostak and Paul Davies have argued in their recent publications that life at our stage of development naturally goes on to produce civilisations consisting purely of autonomous computerised machinery. Regardless of one’s views as to whether this is a likely outcome or not, it remains another possibility that as yet cannot be excluded. Such systems would both answer a general definition of life and be totally independent of Earth-like surface conditions.

Given that the terms ‘habitable zone’ and ‘habitable planet’ are therefore grossly misleading at our current state of knowledge, I would suggest that the I4IS lead the way in using terms that reflect more accurately what is actually meant. ‘Earth-analogue’ planet/zone would seem to be the most precise. Life may inhabit an Earth-analogue planet in the Earth-analogue zone around its star, or it may inhabit somewhere else, such as a sub-surface region of a world like Europa or Titan, or a temperate zone in the atmosphere of a gas giant planet, or a completely manufactured artificial world. Any of these alternatives could be found at different distances from a star. ‘Surface liquid water zone’ would also convey the intended meaning with vastly more precision than at present.

Such terms would allow one to draw the parallel with our own planet, while leaving open the possibilities that carbon-based, water-solvent, surface-dwelling, non-technological life may not be the only type of life that may be encountered in our exploration of the Galaxy in which we live.

Stephen Ashworth
Researcher, I4IS

***Principium* welcomes letters and dialogue from our readers on all interstellar related topics.**

E-mail us at principium@I4IS.org.

Please provide your full name with any correspondence. The Editor reserves the right to edit or shorten letters.

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Also check out the I4IS’ blog, the Interstellar Index, for more discussion and comments!
☛ http://www.interstellarindex.com/blog/

Follow Kelvin F Long and the I4IS on Twitter at
☛ https://twitter.com/thestarshipman

Meet the Neighbours

Before deciding where to send an interstellar space probe it will be necessary to perform a detailed inventory of the nearest stars to the Sun and characterise, to the best extent that we can, any planetary systems they may have, writes Ian Crawford.

Cataloguing nearby star systems is going to be crucial for maximising both the scientific returns and the design of such a mission. Clearly we would wish to send our first interstellar probe to a scientifically interesting target but the more distant the target the longer the mission will take, the greater the challenges to be faced by the hardware and software on board will be, and the higher the risk of damage by collision with interstellar dust particles. It follows that the designers of the probe will need to know the destination well in advance.

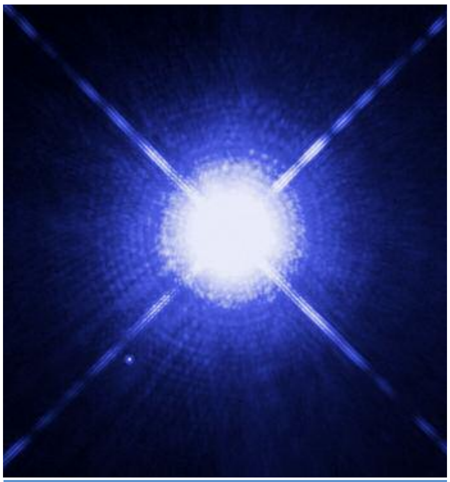
Given realistic propulsion options it seems likely that the maximum range of humanity's first interstellar mission would be of the order of 15 light years. This would imply a journey time of 150 years at 10 percent of the speed of light – a hugely challenging undertaking but certainly not physically impossible. If we wanted journey times of the order of a human lifetime then, almost certainly, we would be restricted to targets within just a few light years. Within 15 light years of the Sun there are approximately 58 stars in 38 separate stellar systems. Probably the most authoritative recent compilation, and the one on which my number of 58 stars is based, is that published by the Research Consortium on Nearby Stars.

Closest exoplanets

Based on the detection rate of extra-solar planets to date and allowing for the known biases in the detection methods, it has been estimated that at least 30 percent of main sequence (i.e. Sun-like stars) stars will have planets of one sort or another (see Astronomical Considerations Relating to the Choice of Target Star). Thus, we might expect at least 17 of the 58 stars within 15 light years to be accompanied by planets and, given the current lack of data on very low mass planets, it could easily be many more. However, as things currently stand only four of these stars are actually known to have planets. These are alpha Centauri B (a member of the alpha Centauri triple system at a distance of 4.4 light-years, and thus one of the very closest stars to the Sun); epsilon Eridani (a single K-type star at a distance of 10.5 light years), tau Ceti (a G-type star spectrally similar to the Sun, 11.9 light years away and home to five planetary candidates – see the *Advances* section this issue for more) and the red dwarf GJ 674 at a distance of 14.8 light years. As noted above, the statistics imply that many more stars within 15 light years of the Sun will have planets, but they are currently below the detection thresholds of existing search methods. An excellent summary of all known extra-solar planets (currently more than 850) can be found in the Extrasolar Planet Encyclopedia maintained by Jean Schneider at the Paris Observatory.

Alpha Centauri – the closest star system to the Solar System. A triple star, one of its members hosts a planet.
Image: ESO/Digitised Sky Survey II.

Owing to its relative proximity, the planet orbiting alpha Centauri B (provided the recently reported detection is confirmed by further work) is of particular interest from the point-of-view of planning interstellar space missions. This planet has approximately the same mass as Earth but is in a very tight (0.04 astronomical units, AU) orbit about the star. At this orbital distance the planet's daytime hemisphere will have a surface temperature well in excess of 1,000 degrees Celsius and is most unlikely to be habitable. However, the presence of one planet implies that others may exist in the system and, given that alpha Centauri is the closest possible target for an interstellar probe, it is very important to determine whether other planets are indeed present. Although alpha Centauri is a multiple star system, dynamical calculations indicate that planets should have stable orbits within about two astronomical units of both alpha Centauri A and B, so habitable planets in the system are certainly possible in principle.



The Dog Star Sirius, which is the brightest star in the sky, is a double star with a white dwarf partner (nicknamed 'the Pup') both located 8.6 light years from the Sun. However no planets have yet been found in the Sirius system.
Image: NASA/ESA/H Bond (STScI)/M Barstow (University of Leicester).

Imaging our near neighbours

Unfortunately finding them will not be easy. The radial velocity technique used to discover the alpha Centauri B planet was really pushed to its limit for this discovery and finding an Earth-mass planet in an Earth-like (1 AU) orbit using the same technique is at present impossible because the radial velocity signature decreases with increasing orbital distance. The prospects are not much better for the transiting technique that has recently been employed by the Kepler spacecraft to identify large numbers of planet candidates: the probability that an Earth-sized planet in an Earth-like orbit around either alpha Centauri A or B will undergo transits as seen from Earth is only about one percent. It therefore seems likely that direct imaging, probably with large space telescopes specially designed to detect the

An artist's impression of the planetary system, including an asteroid belt, around the star epsilon Eridani, 10.5 light years away. Image: NASA/JPL–Caltech/T Pyle (SSC).

faint light from planets orbiting nearby stars, will be the most efficient means of characterising planets around alpha Centauri and other nearby stars. Direct imaging has the great advantage that, having obtained the light from an extra-solar planet, it will be possible to analyse it spectroscopically to search for biomarker molecules in its atmosphere.

Although it may be possible to make a start with currently planned instruments, such as the 6.5-metre James Webb Space Telescope to really make progress in the characterisation of nearby planetary systems will probably require a dedicated infrared space interferometer such as the European Space Agency's proposed Darwin mission. Although ESA has decided not to proceed with the Darwin study at the present time, something like this ambitious space-based instrument will almost certainly be required if we are ever to characterise nearby planetary systems in sufficient detail to plan interstellar missions to visit them. Fortunately, it seems likely that that the recent discovery of the alpha Centauri B planet will stimulate thinking along these lines.

The bottom line is that only further observational work will reveal how common planets actually are around the nearest stars and what those planets are like. The good news is that, long before we will be in a position to build an interstellar spacecraft, astronomical technology will have reached the point where we will probably have a complete census of planetary systems within 15 light years of the Sun. Not only will these instruments be able to identify which stars have planets and calculate their orbital parameters, they will be able to make basic spectroscopic searches for biosignatures in their atmospheres. Thus, although we currently cannot identify an obvious specific target for humanity's first interstellar space probe, when the time comes to build one we are likely to have a very good idea where to send it!

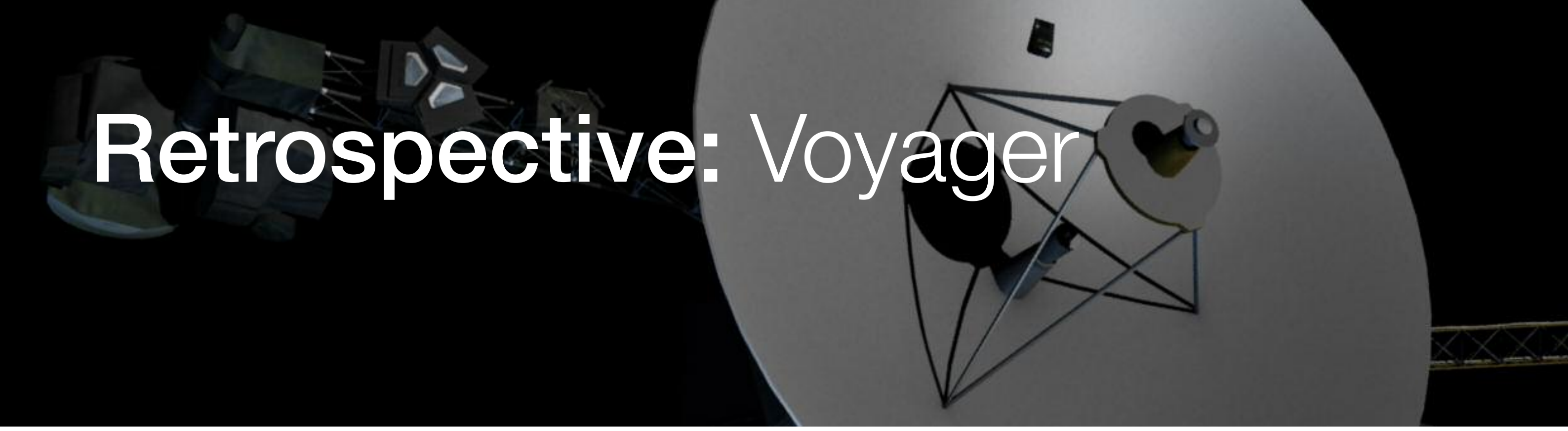
About the author

Ian Crawford is Professor of Planetary Science and Astrobiology at Birkbeck College, University of London (http://www.bbk.ac.uk/es/staff/Ian_Crawford), is Lead Designer for the Project Icarus 'Astronomical Target' module and is a member of the I4IS Advisory Council.

Jargon Buster

Astronomical Unit

An astronomical unit (AU) is the average distance between Earth and the Sun, which is 149.6 million kilometres. This unit of measurement is used as the standard distance scale for planetary systems, while light years are used for distances between one star and another. There are 63,338 astronomical units in a light year. Our most distant probes, Voyager 1 and 2 (see our retrospective this issue) are by comparison only a mere 122 and 100 AU from the Sun after 36 years of travel.



Retrospective: Voyager

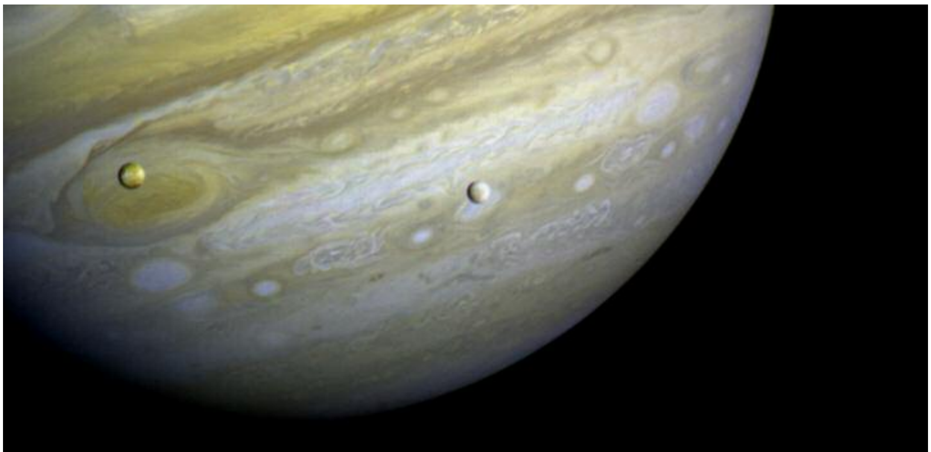
NASA's veteran Voyager probes have been true pioneers, from exploring the outer planets to becoming the first to venture to the edge of the heliosphere. Here is their story.

Our interstellar adventure has already begun, blasting off 36 years ago with the launch of twin science probes on missions of discovery. They were the Voyagers, spindly sets of booms and arms arranged under the iconic shapes of their antenna dishes, which toured the outer Solar System and now venture boldly towards interstellar space, still operating and conducting scientific operations after all this time. Within the next decade they are expected to cross the boundary between where the Sun's magnetic influence ends and that of interstellar space begins. When that happens, the Voyagers will become our first interstellar craft.

Their story begins almost five decades ago, in 1960s California. Amidst the decade of hippies, free love and war protests, at Pasadena's Jet Propulsion Laboratory an aerospace engineer by the name of Gary Flandro noted that the outer planets were aligned in such a way that by making use of gravitational assists – effectively using the gravity well of a planet as a slingshot to speed up a spacecraft and alter its trajectory – pairs of probes could be sent to all of the outer planets, including Pluto. It was going to be a once in a lifetime opportunity: the alignment neatly set itself up during the late 1970s and wouldn't happen again for another 175 years. That the Space Age had dawned when it did was fortuitous indeed.

It wasn't to be. Ambition on this scale costs money and, with the United States embroiled in a war in Vietnam, Congress simply wasn't willing to part with the billions of dollars that such a 'Grand Tour' would have gobbled up. So the programme was scaled back to just two robotic probes, namely Voyager 1 and 2, which would both fly past Jupiter and Saturn with the option to carry onwards to Uranus and Neptune – should they survive the hazardous journey past the first two planets. Unfortunately little Pluto would miss out, although this has since been rectified by NASA's New Horizons probe, scheduled to encounter the diminutive dwarf planet in 2015.

The ringed world Saturn photographed by Voyager 2. The two dots below are the moons Rhea and Dione.



Jupiter imaged by Voyager 1, with moons Io (left) and Europa (right) in the foreground, and the Great Red Spot looming behind them. All images: NASA/JPL–Caltech.

Braving the radiation belts

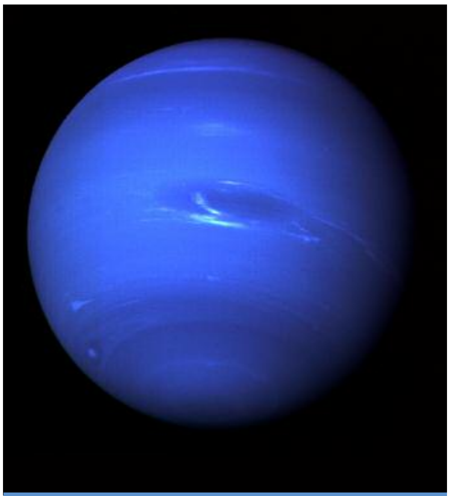
The Voyagers launched weeks apart in August and September 1977 (Voyager 2 actually launched first, on 20 August, but was quickly overtaken by its sibling). Designed to function for at least five years, their most severe test would be to navigate the harsh radiation belts of Jupiter, which could fry their circuitry and shut them down. Voyager 1 was first to enter the danger zone on 5 March 1979, flying within 277,500 kilometres of Jupiter's cloud tops and making its main observations of the Jovian system over a short 48-hour period. Voyager 2 repeated the fly-by on 9 July 1979 and both emerged unscathed, discovering in the process volcanoes on Io, new rings around Jupiter, numerous tiny new satellites and producing astonishing imagery of the tumultuous atmospheric bands that encircle the planet and the giant maelstrom that is the Great Red Spot – the biggest storm in the Solar System, large enough to engulf the Earth several times over.

Fly-bys of the beautiful ringed planet Saturn followed in November 1980 and August 1981, with equally wide-ranging discoveries, but here is where the fates of the two spacecraft separated. Voyager 1, upon reaching Saturn first, was tasked with two important objectives at the ringed planet: one, to fly behind the rings and analyse the particles that make up their gossamer framework and two, get a closer look at Saturn's enigmatic moon Titan. But this meant Voyager 1 had to fly past Saturn in its equatorial plane, which was tilted with respect to the plane of the Solar System and the other planets. This trajectory would take it up and out of the Solar System – there would be no Grand Tour for this spacecraft.

Voyager 2, on the other hand, would plough onwards, gaining a gravity assist from Saturn to speed it towards Uranus in January 1986 and Neptune in August 1989. Prior to these encounters the ice giants, as they are termed, had appeared through telescopic eyepieces as little more than pale blobs. Voyager 2 brought them to life, the bland turquoise features of Uranus and its menagerie of odd moons (especially patchwork-quilt Miranda) and dim rings, and the azure blue of Neptune with its white atmospheric 'scooters', the antithesis of Jupiter's Great Red Spot in the form of a Great Dark Spot, plus more new moons and a close look at Triton and its towering eight-kilometre high geysers of nitrogen gas laced with black dust.

And then the Grand Tour was over, with Voyager 2 likely to remain the only visitor to the ice giants until at least the mid twenty-first century, even in the best case scenario. In 1990 Carl Sagan requested that Voyager 2 be turned to look back at

During its fly-by of Uranus in January 1986 Voyager 2 imaged its odd moon Miranda with its chaotic terrain.



Brilliant, azure blue Neptune – the last planet on the Grand Tour.

the Solar System and snap a group shot of all the distant planets, leading to the famous Pale Blue Dot photograph of Earth. The jaw-dropping vista hints at how extraterrestrial observers may view our planet from faraway.

Interstellar component

As Voyager 2 slid away into the darkness, it was only the end of the beginning. Now Voyager scientists scrambled into a new mode of exploration – an interstellar mission, one that was to be shared by both Voyager craft on their separate trajectories out of the Solar System. Out there, in those deep, icy realms, the Sun still wields influence, even at a distance of 18 billion kilometres from the Solar System's warm heart. The further the Voyagers push into space, however, the weaker that influence becomes until one day they will reach the point where the Sun reigns no longer and the spacecraft will find themselves in the space between the stars.

Think of the majority of the Solar System – the planets, asteroids and the icy bodies of the Kuiper Belt – as being encompassed within a giant magnetic bubble, blown on the supersonic gusts of the solar wind emanating from the Sun. This bubble is known as the heliosphere; its outer boundary buffets against the magnetic fields of interstellar space, creating a turbulent region known as the heliosheath on the inside of the boundary where the speed of the solar wind drops below supersonic. Voyager 1, careening through space at 61,000 kilometres per hour, crossed this 'termination shock' in December 2004, but it wasn't a clean crossing. Since the solar wind is not steady, but varies in response to solar activity, the termination shock moves inwards and outwards on the gusts of the solar wind like the ebb and flow of a tide washing up on a distant shore. Voyager 2, moving slightly slower at 56,000 kilometres per hour after its two extra planetary encounters, passed the termination shock in September 2007. Interestingly, both did so at different distances from the Sun (Voyager 1 crossed at 94 astronomical units, i.e. 94 times further from the Sun than Earth, while Voyager 2 crossed at 84 astronomical units), showing that, despite its name, the heliosphere is not a sphere centred on the Sun, but an elongated, teardrop shape streamlined by resistance to the Solar System's motion through the interstellar medium and inflating and deflating on the solar wind.

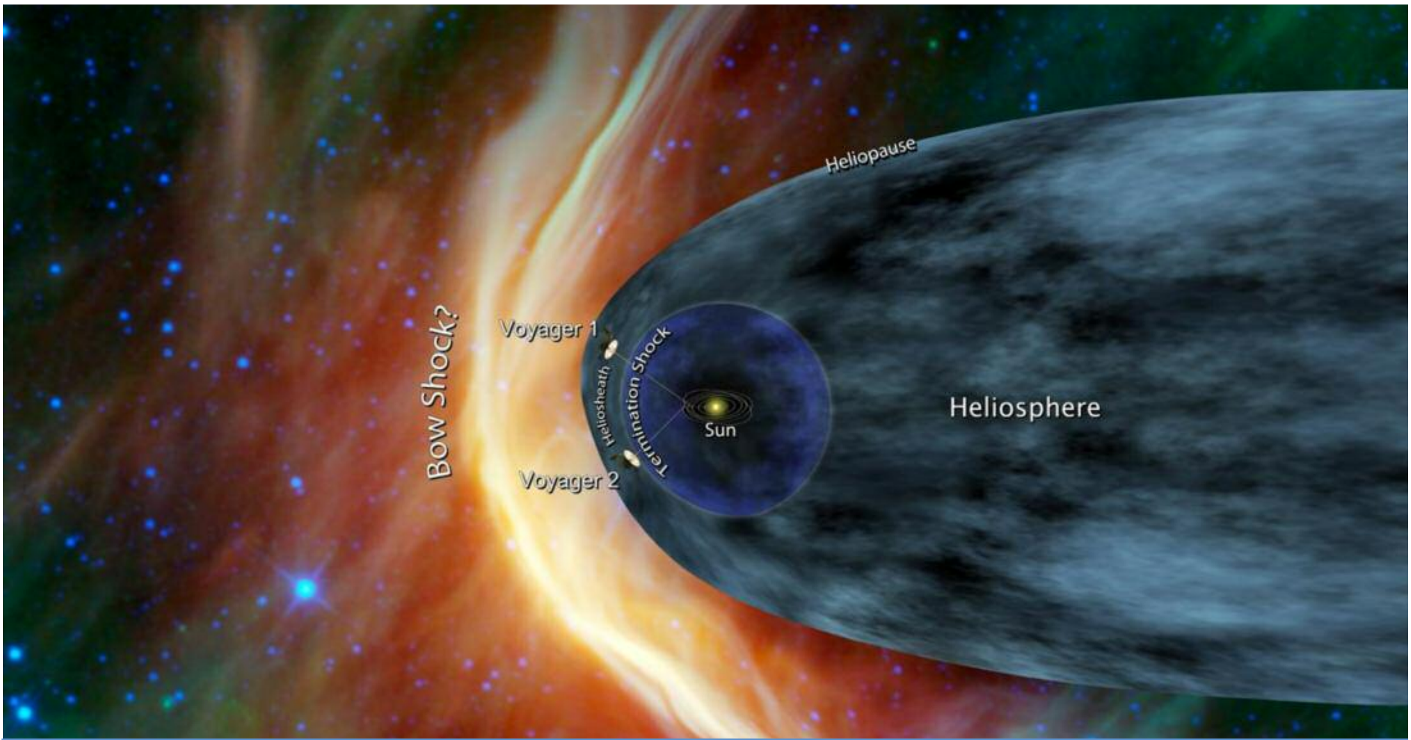
Since crossing the termination shock, the Low Energy Charged Particle (LECP) instruments on both Voyagers have monitored the speed of the solar wind slowing gradually from 241,000 kilometres per hour to zilch. It doesn't mean that the solar wind has dissipated, however; Voyager scientists merely suspect it has 'turned a corner' and the charged particles of the solar wind – electrons, protons, ions, that kind of thing – riding along the chaotic magnetic field lines in the heliosheath have simply begun moving perpendicular to the Voyager's direction of travel.

There have been more dramatic occurrences recently. An increase in high-energy cosmic rays coming in from beyond the Solar System over the past few years was to be expected. What wasn't expected was a sudden five percent increase in cosmic rays detected by the LECP on 14 May 2012. A similar increase followed on 28 July but this time it was accompanied by a five-fold decrease in the number of lower energy particles originating from within the heliosphere. Then on 25 August Voyager 1 experienced the largest increase in cosmic rays yet, bringing the total increase from March 2012 to 30 percent. Something strange was happening.

Signposts

We'll know when the Voyagers pass the signpost that states 'you are now leaving the heliosphere', from which point on lies interstellar space, when three key conditions are met. First is that the density of high-energy cosmic rays from beyond the Solar System jumps up. Second is that the density of low energy particles from the heliosphere drops off. That's two boxes ticked. Crucially, however, the third and final criteria is that the magnetic field will suddenly change direction as the interstellar field takes over.

"Had we been looking at the particle data alone, we would have said we're out,

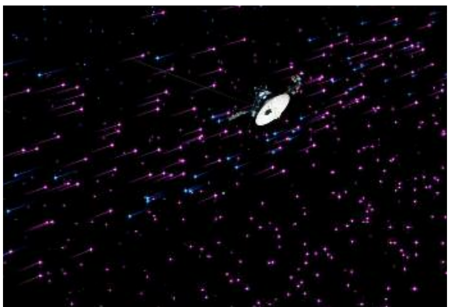


A diagram showing the different parts of the heliosphere, including the termination shock, heliosheath and bow shock, as well as the relative positions of the Voyager probes.

out of the Solar System," Stamatios Krimigis of Johns Hopkins University, who is LECP's lead scientist, told a NASA press conference in December 2012. Yet the onboard magnetometer indicated no change in the magnetic field direction – Voyager was still within the heliosphere.

Instead, it is believed that Voyager 1, which is currently around 18 billion kilometres away (Voyager 2 lags behind, 15 billion kilometres from the Sun), has now hit the fast lane along a magnetic highway that is driving low-energy particles out of the Solar System and allowing cosmic rays to race in. It is completely unexpected. "It's as though somebody opened the floodgates and the water all moved downriver," says Krimigis.

This is likely the last, unexplored layer of the heliosheath before Voyager 1 reaches the heliopause – that aforementioned signpost at the outer boundary – and interstellar space beyond. Yet Ed Stone, Voyager's Project Scientist at JPL who has been with the mission since the very beginning, reckons it may be another five years before Voyager 1 marks that major milestone and becomes humanity's first ever interstellar emissary, swiftly followed by Voyager 2. Still, that's not bad for a pair of spacecraft that, on 13 August 2012, became the longest operating mission, surpassing Pioneer 6's record of 12,758 days.



Voyager 1 is now in a new region of the heliosheath, a magnetic highway that is allowing low-energy particles out of the heliosphere and high-energy cosmic rays in.

Long-duration missions are a good habit to get into if one wishes to truly go interstellar one day – even under the most powerful engines that we can realistically think of, it will still take decades to reach the nearest star. Thus the Voyagers are true pathfinders in this regard. That they still produce useful science is a testament to the skill and quality that went into their construction.

"[Voyager's] instruments still do a remarkable job of returning high quality science data after over 35 years of space travel," says Arik Posner, the Voyager Program Scientist for NASA's Heliospheric Division. Yet 1970s technology does have its limitations, he tells *Principium*. "Voyager's main limitation that could be improved with today's technology is onboard data storage."

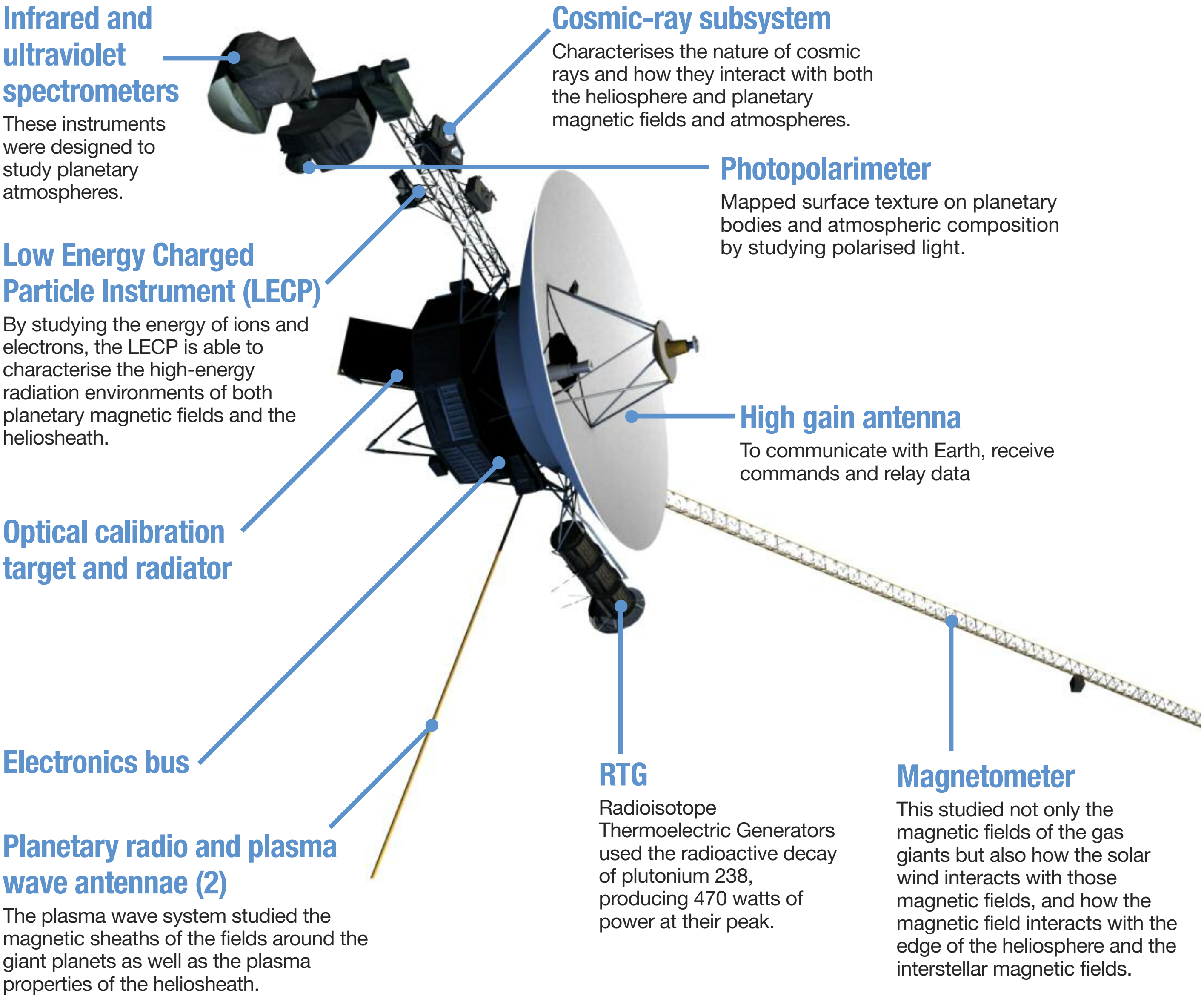
Remember, it is only relatively recently that computer memory has become cheap; in the 1970s you were lucky to get a few bits of data storage. Instead, Voyager relays everything that it observes and measures in real time (or as much in real time as the light delay will allow) only when commanded to do so at times when the Deep Space Network (DSN) of radio dishes across the globe is pointed towards it. Nothing is stored onboard the spacecraft. Given that the DSN is a shared resource, being utilised for communicating with the likes of probes at Mars, Dawn in the Asteroid Belt, Juno on the way to Jupiter, Cassini, New Horizons as well as the twin Voyagers, then opportunities for communication are limited.

Each Voyager is energised by a trio of radioisotope thermoelectric generators (RTGs), which produce power from the radioactive decay of plutonium-238. With a half-life of 87 years we know that the plutonium power sources will decrease in output to the point that in 2020 scientists will have to begin switching instruments off and, by 2025, there won't be enough energy for the spacecraft to function. The Voyager mission will be at an end.

An interstellar journey

Suppose, however, the Voyagers were able to continue and, just suppose, they were able to reach another star. Can we take what we have learned from the Voyagers about the interface between the heliosphere and interstellar space and apply it to what a future interstellar probe could expect to find upon entering an 'astrosphere' around another star?

We know that other stars traverse the Galaxy embedded within their own magnetic bubbles because we can see



them. Take Mira, for example, also known as omicron Ceti, the prototype for a class of variable red giant stars. This star is speeding through space, ploughing through the diffuse gas of the interstellar medium. Like the white froth in the waves riding ahead of a boat, Mira's astrosphere is also creating a bow shock in the interstellar medium, leaving a long tail that in ultraviolet light is reminiscent of a comet's tail. This is a more extreme example, but many other stars have quieter astrospheres much like the Sun's heliosphere.

"Our knowledge about the more benign astrospheres of stars that are similar in their interaction to ours is rather limited due to the lack of observational signatures," says Posner. "Nonetheless, we will learn a lot from Voyager that will apply elsewhere as well and it is interesting to think through a scenario of entering an astrosphere from the outside, whether technically possible or not."

Posner points out that the first data to be gleaned upon approach to another star would be the conditions of the interstellar medium buffeting the astrosphere – in the case of Mira the environment would be quite severe. However, he points out that the Sun is able to create a 'neutral' wind though the exchange of charge between the solar wind and the neutral interstellar gas. The resulting neutral wind, which passes through magnetic fields like they are not there, could extend quite deep into the interstellar medium.

"Therefore, approaching another star could allow us to analyse this neutral stellar wind and infer properties of the charged stellar wind before we would get immersed in it," he says. This wind could tell us about conditions deep within the system, on the star itself.

So how do the Voyagers stand as testbeds for a true interstellar mission of discovery? After reaching a significant percentage of the speed of light, a subsequent interstellar probe is probably not going to be able to slow down, but rather whiz through any planetary systems they come across. Voyager has prepared us for this kind of hasty science, squeezing out every last drop of science possible during fly-bys of the outer planets that only lasted 48 hours.

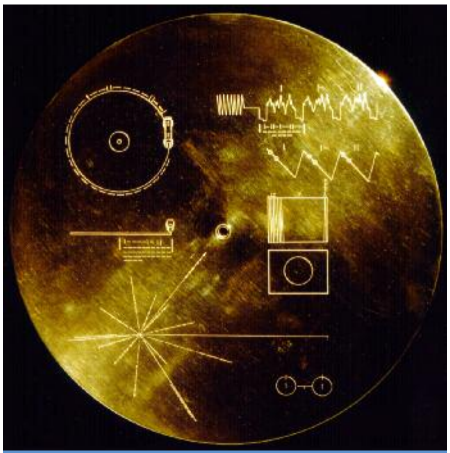
Furthermore, as good as they have been the Voyagers have taught us how we could do an interstellar mission better. "It is certainly clear that both energetic particle instruments and neutral atom imagers would be emphasised [on a future mission]," says Ralph McNutt of the Johns Hopkins University Applied Physics Laboratory, who is co-investigator of Voyagers' LECP and plasma science (PLS) instruments. McNutt should know; he was on the science definition team for a NASA study of a dedicated mission to the stars, the Innovative Interstellar Explorer, in the early 2000s. In addition, Arik Posner proposes that an interstellar dust detector would also be an advantage.

> ***This record represents our hope and determination and our goodwill in a vast and awesome Universe.***
> ***— President Carter***

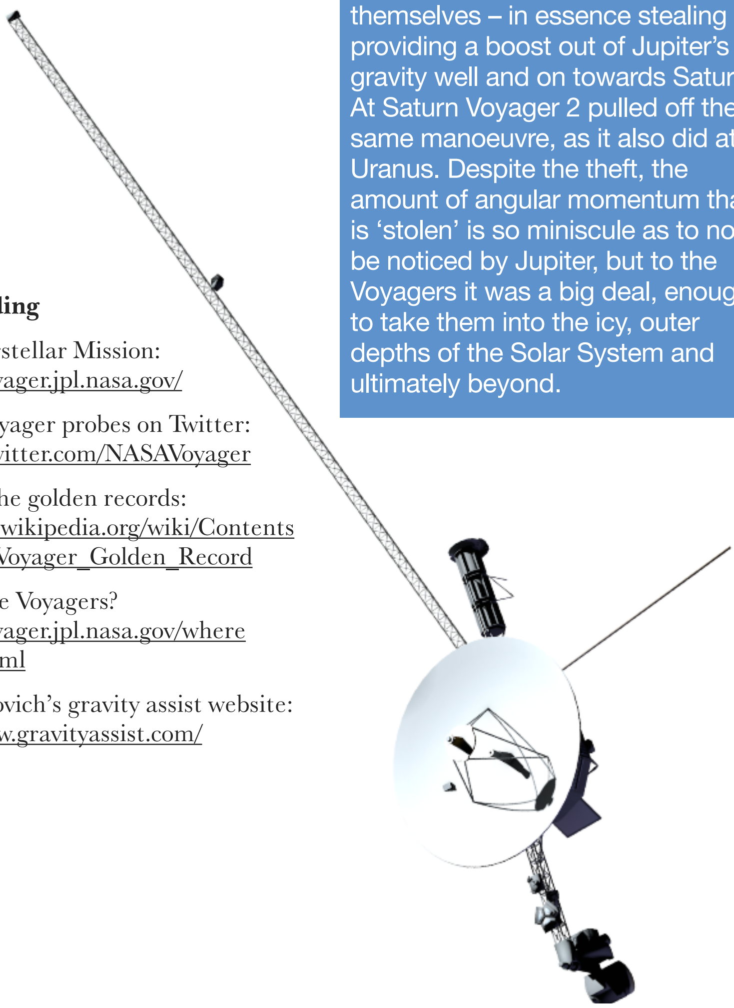
Now into their thirty-sixth year, it would be nice if the Voyagers could last half a century. Alas, it seems they will fall just short. When they do shut down, they'll just be a light day from Earth, a far cry from the several light years to the nearest stars. They won't truly be out of the Solar System either. Although they will have departed the heliosphere, the Sun's gravity will still reign supreme in the Oort Cloud of comets which is speculated to extend up to a light year away, possibly further. One day, however, the Voyagers will reach the stars. In the year 40,272, Voyager 1 will come within 1.7 light years of the star AC+79 3888 (also known as Gliese 445, the star is currently 17.6 light years away but within forty millennia will have moved much closer to us). Around the same time, Voyager 1 will fly within 1.7 light years of the red dwarf star Ross 248 in the constellation of Andromeda.

Epilogue

In that far distant future, any intelligent being that stumbles across either of the Voyagers will find a gift attached to the spacecraft. A golden disc – a gold-plated copper phonographic record – containing sounds and pictures from Earth and of humans, including greetings in 55 languages, classical music and Chuck Berry's Johnny B Goode. As the disc's recorded message from President Jimmy Carter says, "This record represents our hope and determination and our goodwill in a vast and awesome Universe." The hopeful intention of the disc's originators, including Carl Sagan, Jon Lomberg, Frank Drake, Timothy Ferris, Linda Salzman and Ann Druyan, was that any intelligent extraterrestrials that found the Voyager probes could learn of its origins, but in the vastness of space such an encounter would be unlikely. Rather the golden records are a symbol, a statement of humanity reaching out into space. Perhaps in the future human interstellar explorers will chance upon the lost Voyager probes, the greatest time capsules of all, showing our ancestors a glimpse into a world that was, a world at the dawn of an interstellar future.



The cover to the golden disc carried onboard both Voyager spacecraft includes information on where to find Earth relative to local pulsars (bottom left) and how to play the record (top left and right). At bottom right is a depiction of a hydrogen molecule.



Further reading

Voyager Interstellar Mission:
☞ http://voyager.jpl.nasa.gov/

Follow the Voyager probes on Twitter:
☞ https://twitter.com/NASAVoyager

Contents of the golden records:
☞ http://en.wikipedia.org/wiki/Contents_of_the_Voyager_Golden_Record

Where are the Voyagers?
☞ http://voyager.jpl.nasa.gov/where/index.html

Michael Minovich's gravity assist website:
☞ http://www.gravityassist.com/

How gravity assists works

Despite being only tiny pebbles compared to the vastness of the mighty, mythologically-tinged outer planets, the Voyagers dared to steal from the gods. The alignment of the planets that enabled the Grand Tour wasn't simply a case of permitting quicker travel times; it was an essential necessity for the success of the mission.

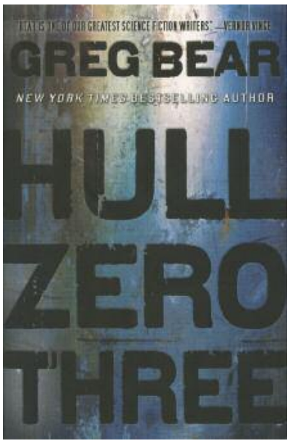
Launched on Titan III/Centaur rockets, the Voyagers were only able to build up enough speed to reach Jupiter – the Sun's gravity well would otherwise trap them in an elliptical orbit with aphelion out at Jupiter's orbit and perihelion near Earth's orbit. The answer was a gravity assist off Jupiter itself.

Gravity assists, first developed in 1961 by JPL engineer Michael Minovich, work on the basis of momentum. As each of the Voyagers plunged into Jupiter's gravity well, they were carried along by the planet's angular momentum. Because they have mass, the Voyagers were able to transfer some of Jupiter's angular momentum to themselves – in essence stealing it, providing a boost out of Jupiter's gravity well and on towards Saturn. At Saturn Voyager 2 pulled off the same manoeuvre, as it also did at Uranus. Despite the theft, the amount of angular momentum that is 'stolen' is so miniscule as to not be noticed by Jupiter, but to the Voyagers it was a big deal, enough to take them into the icy, outer depths of the Solar System and ultimately beyond.

Reviews

Hull Zero Three

Author: Greg Bear



A staple of science fiction is the alien invasion that aims to wipe human life from Earth so that the aliens can claim our world as their own. But what if the boot were on the other foot?

This science fiction novel from Hugo Award winner Greg Bear takes our ideas of interstellar colonisation and turns them on their head. It is a subtle read but, without giving too much away, it manages to integrate genetic seed banks, sleeper ships, the necessity for a moral conscience in the face of contact with alien life and the possibility that an interstellar mission will be subsequently overtaken by missions with more sophisticated technology (what Marc Millis describes as the 'incessant obsolescence postulate').

Notable for interstellar enthusiasts is the design of the ship, which is definitely more hard SF than 'sci-fi'. As the title indicates, there are three hulls – long, cylindrical structures each 12 kilometres long – atop pylons that attach to a central icy comet taken from the Oort Cloud. Water is mined from this comet to be used as a reaction mass for a fusion-based engine that drives the ship at 20 percent of the speed of light. The illusion of gravity is provided by the hulls rotating. One neat scene comes when the deflection shield that protects the hulls is turned off by what the main characters believe to be their unseen foe, and Hull Zero Three becomes in danger of being scraped off the ship as it rams into interstellar detritus at 0.2c.

What about the story? The novel begins when a dream of hope is shattered by a living nightmare as the main character stumbles about a cold, dark ship with only intermittent gravity and no answers to his many questions. Bear permeates the opening 100 pages with an atmosphere of terror that almost drips from the page as horrific monsters stalk the ship's empty corridors, but nothing really develops for those first 100 pages. Thankfully the chapters are reasonably short, which helps the first half of the book pass quicker than it otherwise would. As more survivors on the ship are encountered, the mystery begins to unfold and, given that for most of the bleak tale the character's situation seems hopeless, the ending is filled with two quintessential ingredients of good SF: hope and wonder. Recommended, but you have to be patient with it to get the rewards at the end.

Hull Zero Three

Author: Greg Bear

Published by Gollancz (paperback, 307pp)

ISBN: 978-0-575-10096-1

Find this book on Amazon via our Interstellar Index website.

Pandorum

Dennis Quaid, Ben Foster

This 2009 science fiction movie bears striking resemblances to Greg Bear's *Hull Zero Three*. An interstellar voyage onboard a gothic-looking sleeper ship named Elysium is transporting colonists from a dying Earth to the newly discovered world of Tanis. However, something has gone very wrong with the mission.

Like *Hull Zero Three*, the film begins with the main character, Corporal Bower (Foster) awaking from hibernation, confused and alone, with wires and tubes embedded in his ooze-covered skin. Slowly Bower begins to unravel the mystery of the ship along with a crewmate, Payton (Quaid) and assorted other survivors he finds scattered around the ship, while avoiding bouts of space madness ('pandorum') and the cannibal-like creatures that threaten everybody onboard.

The workings of the ship are not as detailed or realistic as we might expect from a novel, but there are still some concepts worth discussing. Bower has to stabilise the ship's reactor; it is not said what type of reactor it is, but we can assume it's fusion (despite not looking anything like a fusion reactor). The journey to Tanis is quoted in the film as taking 123 years, again implying sub-light speed propulsion

More interesting is the concept of a sleeper ship, wherein the journey takes so long that the crew are placed in hibernation for the duration. Although hypersleep is not a new concept, it is an area of real ongoing medical research and something we'll explore more in an upcoming issue. Meanwhile, the idea of 'space madness', while completely fictional, is driven by underlying psychological issues that may or may not go hand-in-hand with such deep space voyages.

Overall *Pandorum* is an interesting film that, despite being somewhat derivative, does have a neat twist to the eventual outcome of their voyage and does attempt to bring the cinematic depiction of interstellar travel a little closer to what it may be in reality.

Pandorum

Starring: Dennis Quaid, Ben Foster

Directed by: Christian Alvart

Script by: Travis Malloy & Christian Alvart

Find this movie on Amazon via our Interstellar Index website.

Planetary nebula NGC 5189. Image: NASA/ESA/Hubble Heritage Team (STScI/AURA).

We'd love to hear from you, our readers, about your thoughts on Principium, the Institute or interstellar flight in general.

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