News Feature: Rob Swinney at the Royal Aeronautical Society

John Davies and Rob Swinney

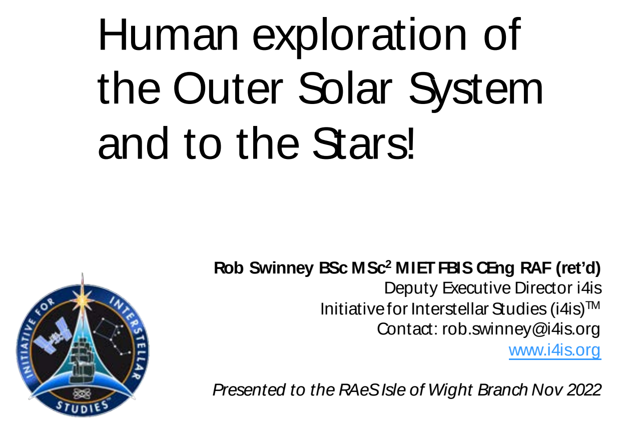
The Isle of Wight (IoW) branch of the Royal Aeronautical Society (RAeS) has an illustrious history, being founded in 1937 and originally based around the Design and Development staff of the Saunders Roe company - famous for its flying boats. For those of us old enough to recall the giant Saro Princess flying boats rusting away on the IoW shore in the fifties it's something we will never forget.

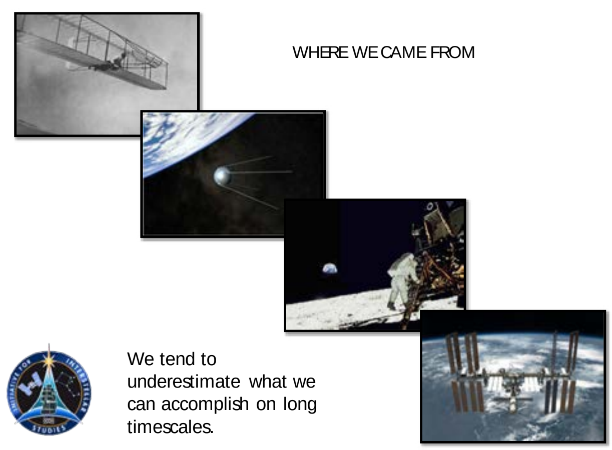
However the IoW RAeS is a forward looking outfit and they hosted a talk by Rob Swinney of i4is titled *Interstellar Human Travel* in November last year (2022). This was one of Rob's most comprehensive lectures and we thought it would be useful to review it here although this article features just a small selection of his material.

Introduction and Background

Rob covered -

- Introduction and Background
- Tipping Point?
- Long distance, close up or landers?
- The scale of the problem
- Justifications
- How might we do it?
- Projects Daedalus and Icarus
- Some alternatives
- Summary





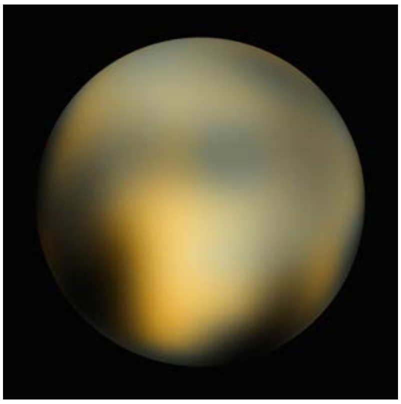
In one hundred years we have progressed from the first powered flight to Moon landing and a space station in Earth orbit - what can we achieve in another hundred years?

Cheap access to low Earth orbit can be that tipping point which will change everything. SpaceX and Blue Origin can offer this and others will come along. Since Rob's talk China has announced a launcher on a similar scale to the SpaceX Starship, featuring a reusable 10m diameter first stage[1] so we can expect a competitive market in super heavy lift launchers in the near future.

[1] Long March 9 en.wikipedia.org/wiki/Long_March_9

Rob illustrated the advantages of going to the most distant objects rather than using telescopes with images of Pluto from the Hubble telescope and the New Horizons probe -

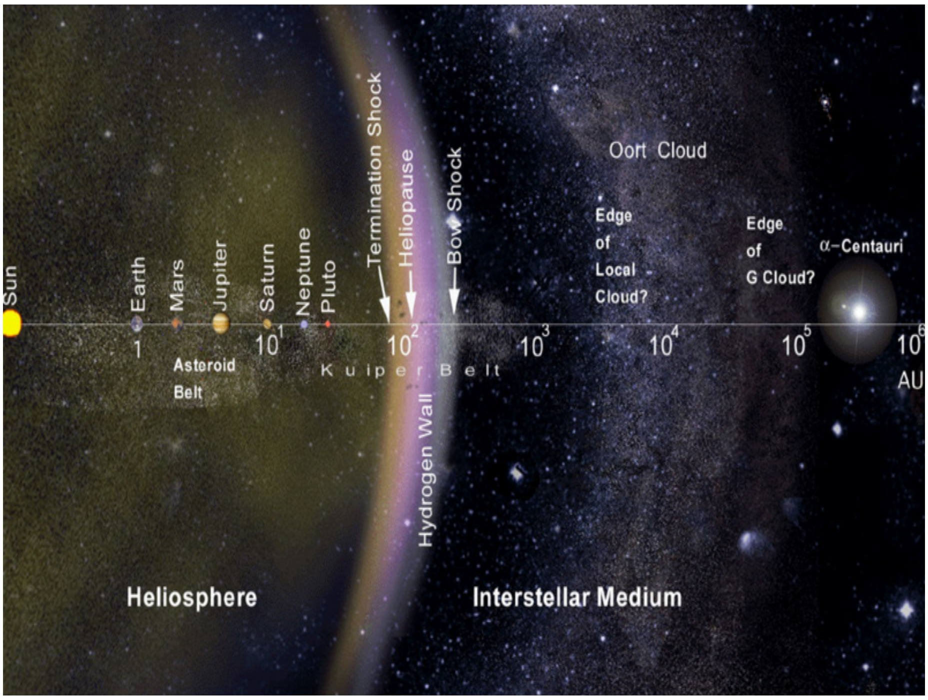
THE BEST IMAGE FROM HUBBLE..?



FROM NEW HORIZONS

- *High Resolution with Enhanced Color*

But getting to even the nearest stars needs a logarithmic scale to illustrate it, as in this image from the Johns Hopkins University Applied Physics Laboratory -



But Rob pointed out the fundamental limitation of all rocket propulsion, the Tsiolkovsky rocket equation. The velocity obtainable (Δv) is limited by our difficulty in either generating very high exhaust velocities (v_{ex}) or in practically using a very high ratio of fuel mass (m_o) to dry mass (m_f.) with only nuclear processes reaching the very high exhaust velocities required for practical travel to even the nearest stars.

$$\Delta v = v_{ex} Ln(\frac{m_o}{m_f})$$

Konstantin Tsiolkovsky
Formulated the "*aviation formula*" in 1887

However, the latest generation of serious interstellar studies, beginning about 10 years ago, is looking again at the serious possibilities for a probe.
Here's the group which met in 2014 and 2015 hosted by the California Institute of Technology (CalTech) and NASA's Jet Propulsion Laboratory (JPL) [1].

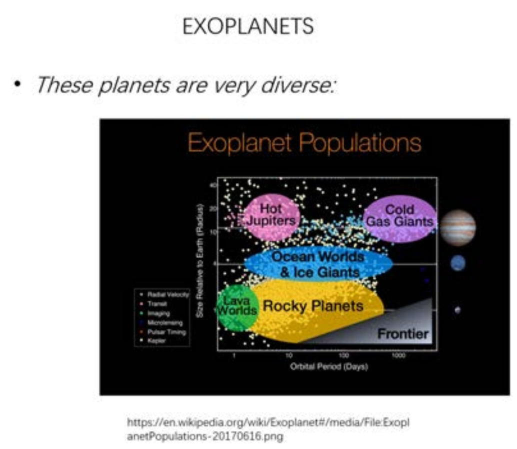
KECK INSTITUTE OF SPACE STUDIES WORKSHOPS, 2014 AND 2015

Stone, E, Alkalai L, Friedman L, 'Science and Enabling Technologies for the Exploration of the Interstellar Medium', Keck Institute of Space Studies report, 6th November 2015.

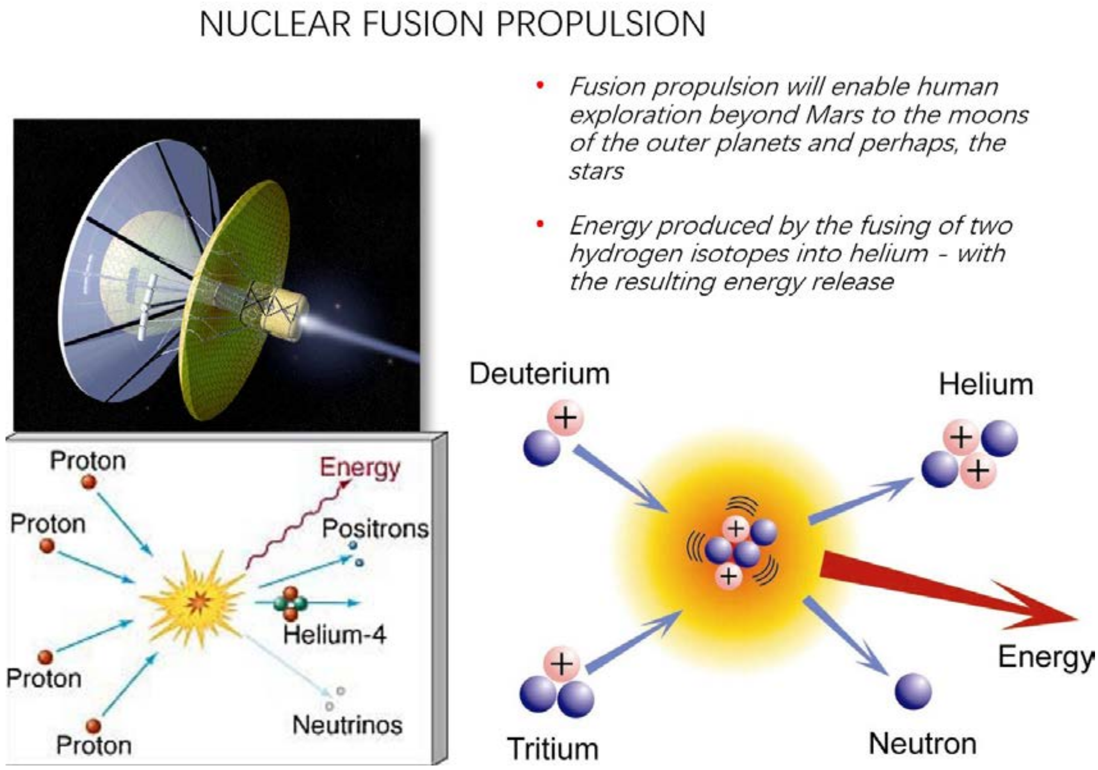
Prominent here are Ralph McNutt (Johns Hopkins University - Applied Physics Laboratory - JHU-APL) on the far left and next to him on the front row Philip Lubin (University of California at San Diego - UCSD) and on the far right Claudio Maccone (chair of the SETI Permanent Committee of the International Academy of Astronautics). McNutt represents the source of some of the most advanced thinking for upcoming missions beyond our solar system. Lubin leads a team which has pioneered the detailed study of laser propulsion for very high speed missions to interstellar space. Maccone is a founding father of the serious study of how to find extraterrestrial intelligences. Others here are many of the people active in the current wave of interstellar studies. When the history of our outreach to the stars is written these will be many of the people who will be credited.
In the short term we can reach the nearest parts of interstellar space using conventional rocket propulsion and various slingshotting techniques around planets (notably Jupiter) and even the Sun. McNutt's team at JHU-APL propose a mission to the interstellar medium, a "pragmatic interstellar probe" for the next round of major NASA funding. There are even objects in our system which may have an interstellar origin including centaurs amongst the outer planets and Jupiter's distant Trojan companions. And of course we have now found at least two interstellar objects (ISOs) entering our system, 1I/'Oumuamua and 2I/Borisov. i4is Project Lyra includes mission planning studies to reach them.

[1] the Keck Institute of Sapce Stdies report (KISS) studies resulted in a probe to go to 200 AU, the JHU-APL Pragmatic Interstellar Probe is the latest design now targetting 1,000 AU.

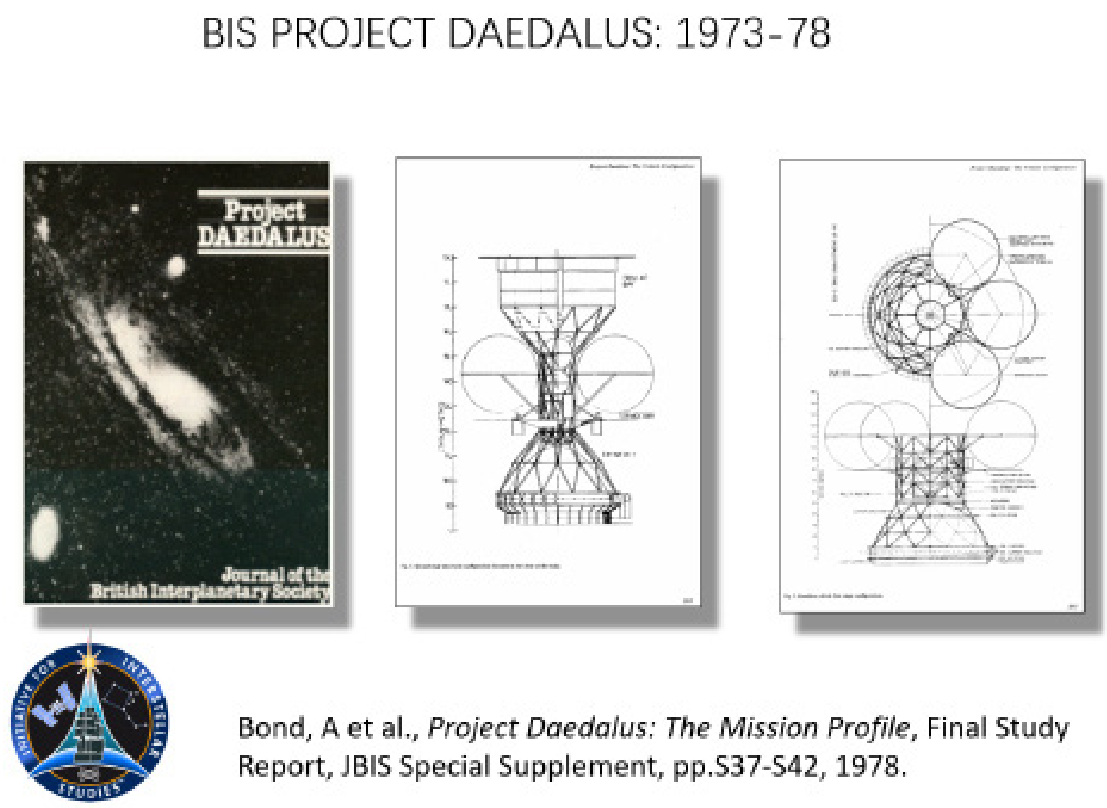
Better telescopes and techniques have now shown us that almost all other star systems have planets so our own solar system is again shown to be just a normal sort of place - distinguished mainly by our presence.



So what are the more efficient ways of propelling our probes? They must be enormously more efficient than our current rockets if we are to reach even the nearest stars in human timescales.
Electric propulsion uses charged particles expelled by an electric field to provide thrust. It is very fuel efficient but does not provide the large thrust required.
VASIMR (Variable Specific Impulse Magnetoplasma Rocket) is an electrothermal mechanism to provide greater thrust at similar fuel efficiencies but it also has thrust limitations.



Nuclear fission, as in our power stations, may be enough to get us efficiently to the outer solar system but we need to go further! Nuclear fusion is our most plausible technology for a rocket both efficient and powerful enough to get us to the nearest stars in just a few decades.
Here we see two fusion mechanisms - four protons at very high velocity fuse to produces a Helium4 nucleus, a lot of energy, some much lighter positrons and the "almost not there" particle, neutrinos. This is the mechanism which Robert W Bussard proposed to yield a rocket propelled by protons from the interstellar medium itself. The other mechanism uses propellants we would have to supply, Deuterium and Tritium, to propel our rocket via a magnetic nozzle controlling the ionised Helium produced. Sadly there seem to be fundamental reasons why the Bussard idea, the Bussard ramjet, would not work.



The other mechanism is the foundation of many of our fusion rocket ideas and as far as we can tell it would work.

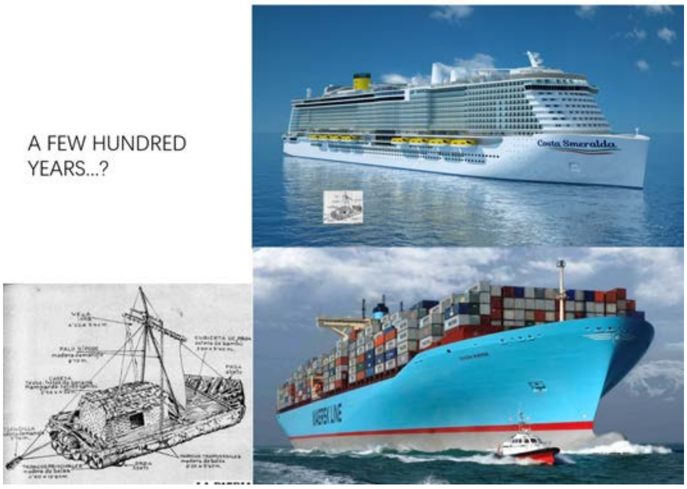
The most detailed study so far of a fusion propelled probe remains the 1970s work of the British Interplanetary Society (BIS) team led by Alan Bond and Tony Martin, Project Daedalus. All the papers from Project Daedalus are available in a BIS book obtainable via bis-space.com/shop/product/project-daedalus-demonstrating-the-engineering-feasibility-of-interstellar-travel/. This was a one-way fly-through mission travelling at 12% of the speed of light so if you do the calculation 0.12*300 thousand = 36,000 km/sec. So if our own system were the target then the transit time across the whole diameter of the Earth's orbit, 300 million km, would be only 300 million/36 thousand = 300/36 thousand seconds = 8,333 seconds = about 2.5 hours. Not long after a journey of around 40 years!

In the past 10 years Project Icarus has aimed to revise the Daedalus design and several teams have worked on different propulsion approaches. The most fully developed of these has been Icarus Firefly which suggests use of a Z-Pinch fusion rocket. Here's how a z-pinch works -

If the powerful current from a lightning strike finds its way to earth via a hollow conductor like this copper tube then the inward force produced by any current will be enough to squeeze the conductor. If a current flows through a plasma then the plasma will be squeezed. Given a strong enough current in a plasma with the right elements the squeezing will lead to fusion. Since the plasma is confined by the squeezing the resultant very high velocity particles have only one way out - in the direction of the plasma flow.

This is an extremely powerful long thin rocket which looks like it has a glowing tail - hence the label Firefly. Robert Freeland and Michel Lamontagne led a small team which envisioned this resulting in a proposed probe which would not only reach the nearest stars but also decelerate so that observation of the target system can be extended, probably to months or years. Here is the most recent visualisation of the probe -
The z-pinch beam is unshielded and the fuel and payload occupy the long vehicle body ahead of a shadow shield to protect them. It would not be wise to be, quite literally, "within a million miles" of this vehicle! More about Firefly in a review paper by Patrick Mahaon in Principium 22 [1].
Advances in all forms of fusion technology have been substantial in recent years and both magnetic confinement and inertial confinement fusion have approached the break even point where they start to produce more energy than they demand to drive them,

Once we learn to build our vehicles in space then there is no practical limit to their size. The issue is more like the marine case -
And look what our species has achieved from the balsa rafts and multi-hull canoes with which we settled the Pacific islands about 1,000 years ago to the cruise and container behemoths which now carry us across the same ocean. In space the 50,000 tons of Daedalus or the 25,000 tons of the Icarus Firefly can be just the beginning of vehicle and structures which will make our largest ocean ships look as small as the Kon Tiki raft that took Thor Heyerdahl and his crew across the Pacific just to prove that this way of populating our largest ocean really was possible.



But we are not there yet with in-space construction or mature fusion propulsion technology so how can we send probes using what we already have and know? And the answer is photon propulsion. We have already shown how photons from the Sun can provide small but usable amounts of thrust - Japan's Ikaros probe and the Planetary Society Lightsail-2 have shown this can work. But to reach the nearest stars our light source must be much brighter than the Sun. In 2014 i4is sponsored a student competition to design a vehicle to be propelled by very powerful lasers, Project Dragonfly, and teams from UK, Germany, USA and Egypt submitted designs.

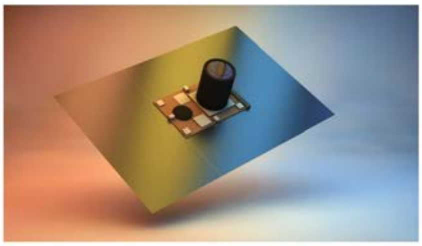
[1] *Reaching the Stars in a Century using Fusion Propulsion - A Review Paper based on the 'Firefly Icarus' Design,* Patrick J Mahon, Principium 22 August 2018 (i4is.org/reaching-the-stars-in-a-century-using-fusion-propulsion/).

In early 2016 an (almost) chance encounter with a recently retired senior NASA administrator led to a request to design a probe to reach Alpha Centauri. The time available was three days and the entire resources of i4is produced the Project Andromeda design in that time.

I4IS ANDROMEDA PROBE

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

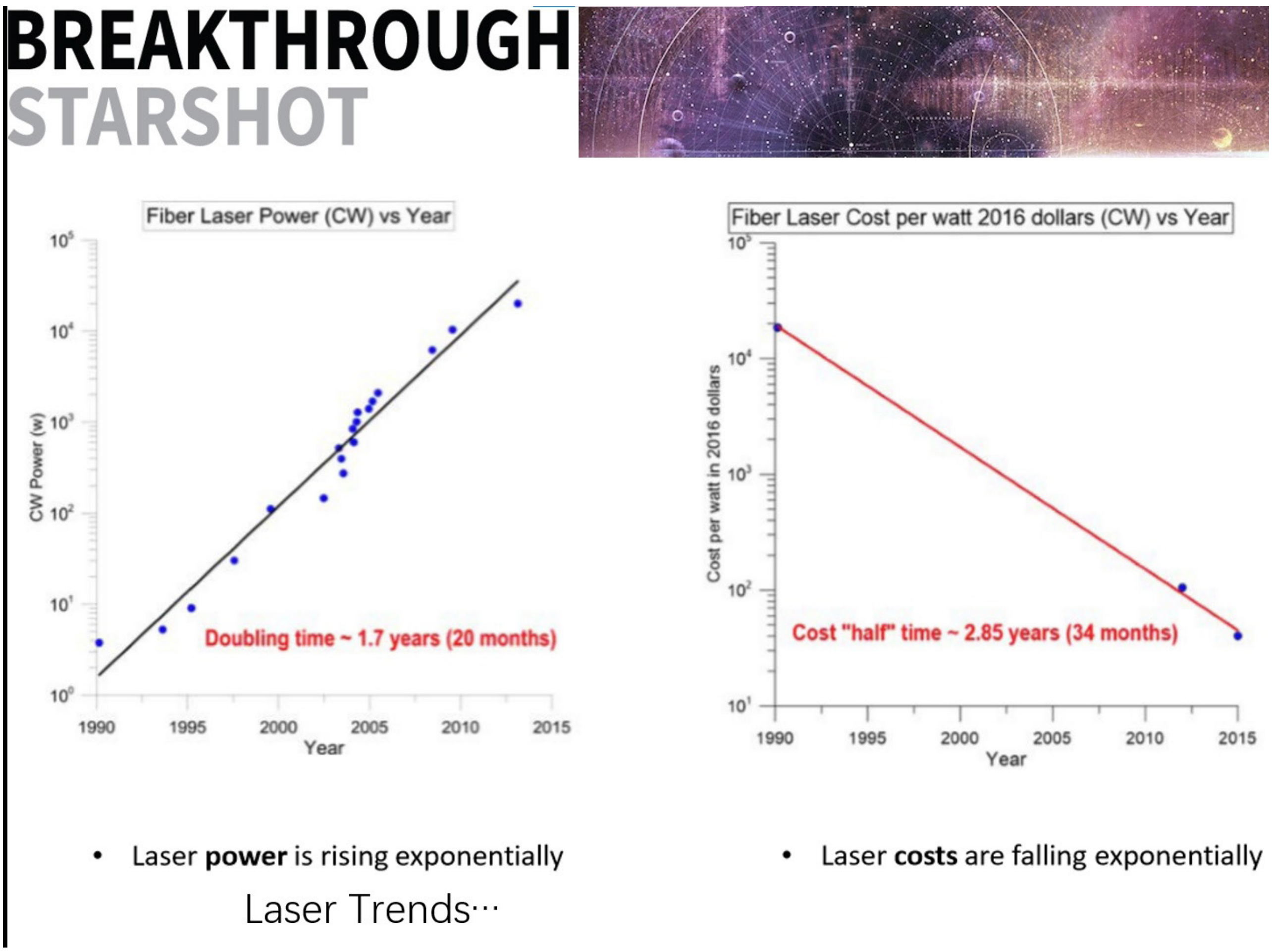
Spacecraft subsystem	**Technology**	**[g]**
Payload	MEMS camera + aperture, various MEMS sensors	2,4
OBDH	FPGA-based microcomputer	1
Power	Graphene supercapacitors (storage) and electromagnetic tethers (power generation)	6.5
Structure	Rigid Graphene matrix	0,1
Communications RF	Foldable phased-array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



The left hand table was our first attempt which came back with the comment 'too heavy'at 420 g, so it was redesigned in to the version on the right at only 23 g.

The request had been somewhat mysterious but all was revealed when Internet entrepreneur Yuri Milner announced Breakthrough Starshot, a $100m investment in design effort to achieve such a probe.

Trends in maximum achievable laser power and costs support the conclusion that this will soon be feasible -

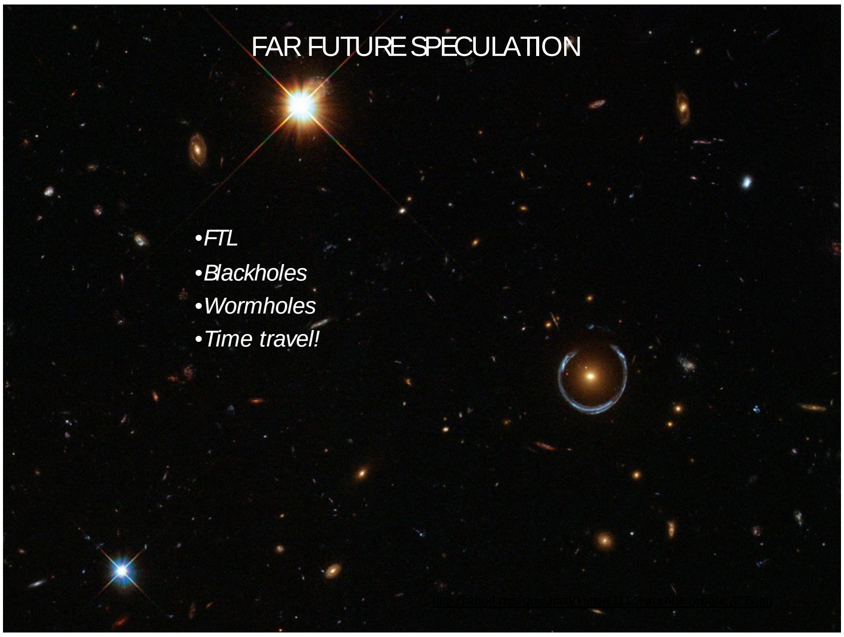


Early requirement values for the Starshot probe included -
• Mass of nanocraft 1 gram
• Acceleration time 2 minutes
• Launch distance 60,000 km
• Speed 60,000 km/s
• Launches per day 1

Among many challenges to build such are craft are the sheer acceleration demands of reaching 60,000 km/s in 2 minutes = 60,000,000 /120 = 0.5 million metres per second per second. The acceleration due to gravity at the Earth's surface is about 10 metres per second per second so our tiny probe will experience 0.5/10 million metres per second per second which is 50 thousand million g. The only places to find this naturally are close to neutron stars or black holes so the materials science challenge is considerable.

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

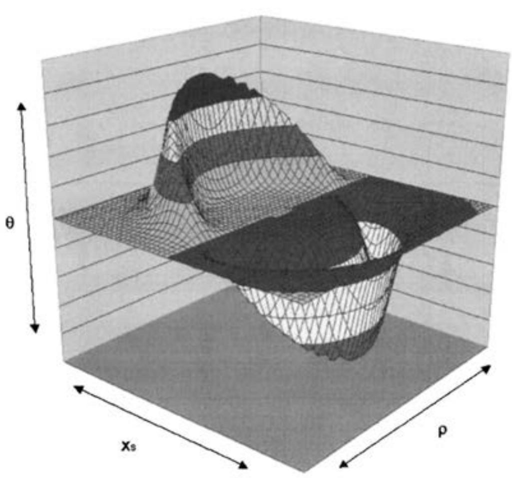
Of these the only one we have achieved (although for two much larger craft) is number 11 - since the Voyager craft are still operating despite having been launched in 1977, 46 years ago [1].
This sort of technology can get tens of thousands of tiny probes to the nearest stars in about 20 years but can we go further?



[1] A literature search on the above list to 19 challenges will be featured in the next issue of Principium - unless of course some one does this first.(please let us know!).
Breakthrough published papers and discussion (breakthroughinitiatives.org/challenges/3).

In 1994 Miguel Alcubierre published a paper, *The Warp Drive: Hyper-fast travel within general relativity* (but of course Star Trek fans knew about this back in the sixties...)

THE ALCUBIERRE WARP DRIVE

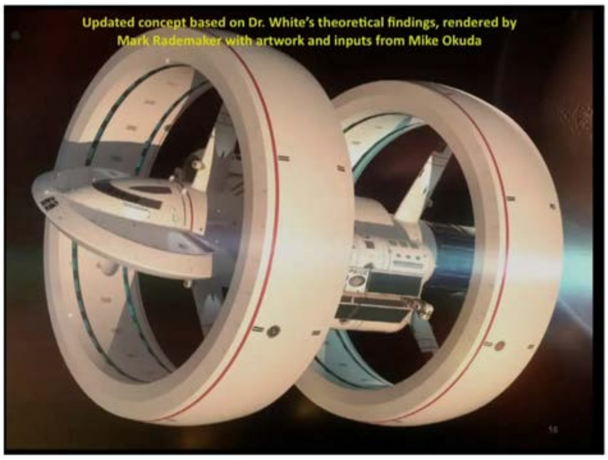


- First figure is York time visualization of spacetime distortion
- Second figure is resulting required distribution of mass
- *f*- shape function: includes wall thickness, radius of warp bubble
- r_s is Euclidian distance in local reference frame
- Reduce mass requirements: (still need between Jupiter and Voyager 1 mass amount)
  - Thicker torus
  - Oscillate York time magnitude
- Examples of negative energy:
  - Casimir effect
  - Gravitationally squeezed electromagnetic zero-point fluctuations (close to black hole event horizon)
  - Certain electric/magnetic field configurations
  Dark matter surrogates

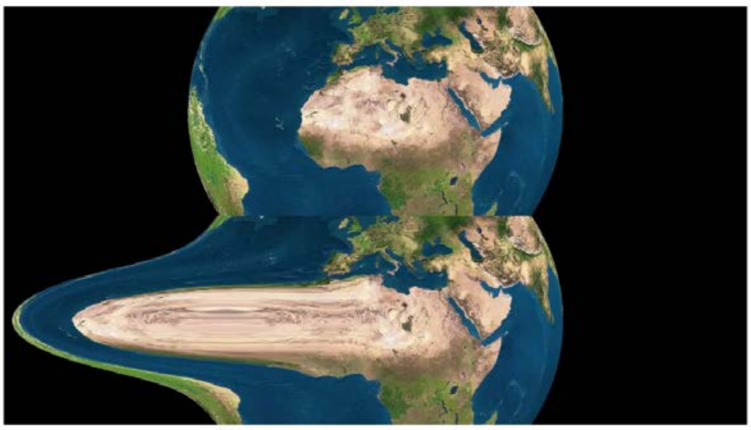
We need a Minkowski diagram - a two-dimensional depiction of a portion of Minkowski space (en.wikipedia.org/wiki/Minkowski_space).
Ship outraces its own photons: so at some point they arrive from two "directions" which looks like time travel but we can still infer that ship travels forward in time.

Here is a conception of the required vehicle. I4is Deputy Technical Director, Dr Dan Fries, will be discussing the current "state of the art" in FTL in the next issue of Principium.

The Alcubierre Warp Drive



What happens at FTL?



https://www.youtube.com/watch?v=JP7oleafg0U

In SUMMARY -
There is a long history of people thinking about extreme deep space travel - and a lot of ideas.
A major tipping point has been reached with low cost to orbit arriving.
Major technology advances are foreseen.
The problems seem challenging but will be conquered given time - there are no physical barriers.
The i4is team is dedicated : ***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.***
Find out more in our quarterly free magazine, *Principium*. Access and subscription at i4is.org/publications/principium/.

Frant cover of Principium 39 (P39) celebrating our tenth anniversary

And we do work with universities, schools, astronomical societies, science societies, engineering societies and others to raise awareness of the potential for interstellar.
Here we are at the UK Royal Institution - as they say "Science lives here!"

SUMMER SCHOOL AT THE ROYAL INSTITUTION - LONDON