# PRINCIPIUM

The Initiative and Institute for Interstellar Studies | Issue 49 | May 2025

SCIENTIA AD SIDERA | KNOWLEDGE TO THE STARS

**Lead Feature: Novel Technosignatures**

**Features: The Interstellar Coracle at the NIAC Symposium in Pasadena,**

**Aerographite: A Candidate Material for Interstellar Photon Sailing**

**News Features: Breakthrough Discuss 2025,**

**IAC24-The Interstellar Presentations Part 3**

**Interstellar News**

**The Journals: JBIS and Acta Astronautica**

ISSN 2397-9127 i4is.org

# EDITORIAL

Welcome to issue 49 of Principium, the quarterly magazine of i4is, the Initiative and Institute for Interstellar Studies. Our Lead Feature is *Novel Technosignatures*, an article by Al Jackson and Greg Benford breaking new ground in a key aspect of SETI. We have News Features *Breakthrough Discuss 2025* and part 3 of *IAC24-The Interstellar Presentations* and our usual, *The Journals*, the regular summary of relevant peer-reviewed papers in *The Journal of the British Interplanetary Society* (JBIS) and *Acta Astronautica*. Our Features are *The Interstellar Coracle at the NIAC Symposium in Pasadena* and *Aerographite: A Candidate Material for Interstellar Photon Sailing*.
Our cover images are an SF visualisation of a fusion spacecraft reflecting one of our News items and a visualisation of a Shkadov thruster, one of the more exotic *Novel Technosignatures* discussed in our Lead Feature. More about both in *Cover Images* inside the rear cover. And, as always, we have the i4is members' page and our regular call to action, *Become an i4is member*.
We have reluctantly cancelled the full report on the First European Interstellar Symposium but will look out for publications based upon it. Just now see some videos from the Symposium at -
https://www.youtube.com/playlist?list=PLaEYPgNFlkhZcyXmQaYYP9EtFxTxr8NsK

Next time, P50 in August 2025, will be the final issue edited by John Davies. Our new team will be lead by Editor Gill Norman and Commissioning Editor Kajol Mistry. In P50 we will introduce the new Editor, Commissioning Editor and colleagues in *Principium: The New Team*.
We will have -

- A review of *From Stars to Life - A Quantitative Approach to Astrobiology.*
- A shared world anthology about the arrival of a mission to a known star, *The Ross 248 Project.*

-both postponed from this issue. We will introduce the interstellar presentations to be expected at this year's International Astronautical Congress and present an update on the i4is *Project Hyperion* worldship competition as well as our regular *Interstellar News*.
More details on P50 in *Next Issue* at the end of this issue.
And if you would like to help with any part of ***Working towards the real Final Frontier*** then please take a look at our poster on page 34.

**John I Davies, Editor,** john.davies@i4is.org
**Patrick Mahon, Deputy Editor,** patrick.mahon@i4is.org

**After 10 years and 41 issues John Davies will be stepping down as Editor after the 50th issue, August 2025. We have now appointed a successor Editor, Gill Norman, and Commissioning Editor, Kajol Mistry. We are building a broader team, sharing responsibilities for the magazine, as we transition towards issue 51. We especially seek a Layout Editor to enhance our design and an Interstellar News team to ensure we continue to keep our readers in touch with the many advances in Interstellar Studies which are inevitably coming given the broadening work in the subject.**
**If you would like to be part of the new Principium team please get in touch with -**
**John (john.davies@i4is.org), Patrick (patrick.mahon@i4is.org) or Tam O'Neill (tam.oneill@gmail.com).**

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

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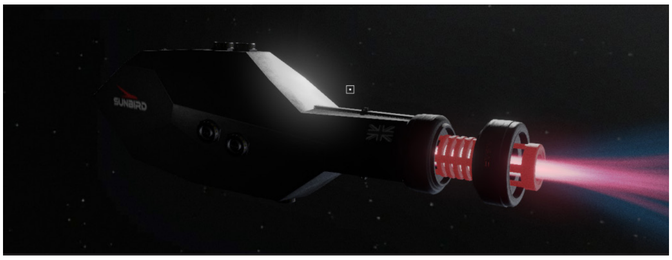

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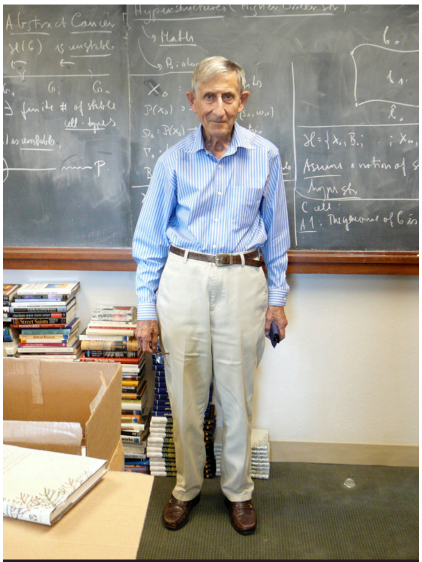
# *Novel Technosignatures*

**A A Jackson and Gregory Benford**

Al Jackson (Triton Systems LLC, Houston) and Greg Benford (UC Irvine) both have a long and distinguished track record in space technologies in general and interstellar studies in particular. This article is based on a 2020 paper with the same title, arxiv.org/abs/2009.08873.
They quote Freeman Dyson -
*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.*
They suggest widening the Search for Extraterrestrial Intelligence (SETI).
References at the end of this article.



Freeman Dyson in 2007 at the Institute for Advanced Study.
Credit: Wikipedia

## Abstract

Technosignatures can represent a sign of technology that may imply  the existence of intelligent life elsewhere in the universe. This had usually meant searches for extraterrestrial intelligence using narrow-band radio signals or pulsed lasers. Back in 1960 Freeman Dyson put forward the idea that advanced civilizations may construct large structures in order to capture, for use, the energy of their local star, leading to an object with an unusual infrared signature. Later it was noted that other objects may represent the signature of very advanced instrumentalities, such as interstellar vehicles, beaming stations for propulsion, unusual beacons not using radio or laser radiation but emission of gamma rays, neutrinos or gravitational radiation. Signs may be unintentional or may be directed.  Among directed and undirected signs we present some models for signalling and by-product radiation that might be produced by extremely advanced societies not usually considered in the search for extraterrestrial intelligence.

## I. Introduction

The most studied approach to SETI is by way of the electromagnetic spectrum, mostly radio and possibly lasers, the infrared being favored. Many new methods of doing SETI are in the works [1], but one can ask the question: are there any other signatures of advanced extraterrestrial civilizations?
At almost the time of the paper by Philip Morrison and Giuseppe Cocconi [2] Freeman Dyson [3] and Nikolai Kardashev [4] noted that the works of advanced civilizations with innovative technologies could build artifacts such as Dyson Spheres or Kardashev civilizations which may have observable properties.

Briefly the Kardashev classification is:
Type I – harnesses the energy output of an entire planet, about $10^{16}$ watts.
Type II – harnesses the energy output of a star, about $10^{26}$ watts.
Type III – harnesses the energy output of a galaxy, about $10^{37}$ watts.
Roughly then a Dyson Sphere would represent the technology of a type II Kardashev civilization.

In the following Kardashev I, II and III civilizations are denoted as K1, K2 and K3. (Note: Strictly speaking Kardashev's original paper dealt with how an advanced civilization might power interstellar 'beacons'. Informally his classification has passed into a scheme of taxonomy for tagging advanced civilizations, whether that is a correct thing to do will not be debated here.)
All materials composing a Dyson sphere would radiate waste heat in the infrared (or longer wavelengths) of the electromagnetic spectrum [4a]. Searches have been made for a candidate Dyson Sphere but no definitive identification has been made [4a]. Just what kind of a technology one might look for at K3 scales has been quantified, in the case of Galaxy wide Dyson spheres but nothing seen [4a], it is not entirely clear what K3 signatures are worth looking for.
We explore other exotic possibilities of signatures by advanced civilizations in the following.

## II. Starships

Consider K1 and K2 civilizations building starships. Might these be detectable in parts of the electromagnetic spectrum not usually associated with SETI? Viewing, Horswell and Palmer [5] asked such a question in 1977. They enumerated the possibilities:
1. Innocuous - Slow interstellar flight, such as World Ships.
2. Energetic
   i. Nuclear Fission
   ii. Thermonuclear Fusion
   iii. Matter-Antimatter

Viewing et al, did not draw any particular conclusions about the quantified detectability.
Zubrin 1995 [5a] examined the same question of energetic starships and did put forward some examples of detection. His considerations are given in Table 1:

Table 1 Observable Starships

| Type | Radiated at Source | Frequency | Detection Object |
|---|---|---|---|
| Radio | 80-2,000 TW | 24 - 48 kHz | Yes – Magsails |
| Visible | 120,000 TW | IR | Yes – Nuclear 300 ly |
| X-Rays | 40,000 TW | 2 - 80 KeV | Nuclear and Antimatter-Ships ~10 ly-1,000 ly |
| Gamma Rays | 1 – 32 MeV | 20-200 MeV | Antimatter Ships |

Assumptions were made about mass and acceleration of the vehicle; consult the paper [5a].

Consider beaming stations which propel sails or similar arrays. Civilizations using beamed radiation, a straight forward and technologically attractive way of implementing interstellar travel.

In this case we would be looking for the transmitter stations attenuated at whatever distance they are at. Many varieties of radiation may be involved; laser beam power and microwaves have received great attention, Figure 1.

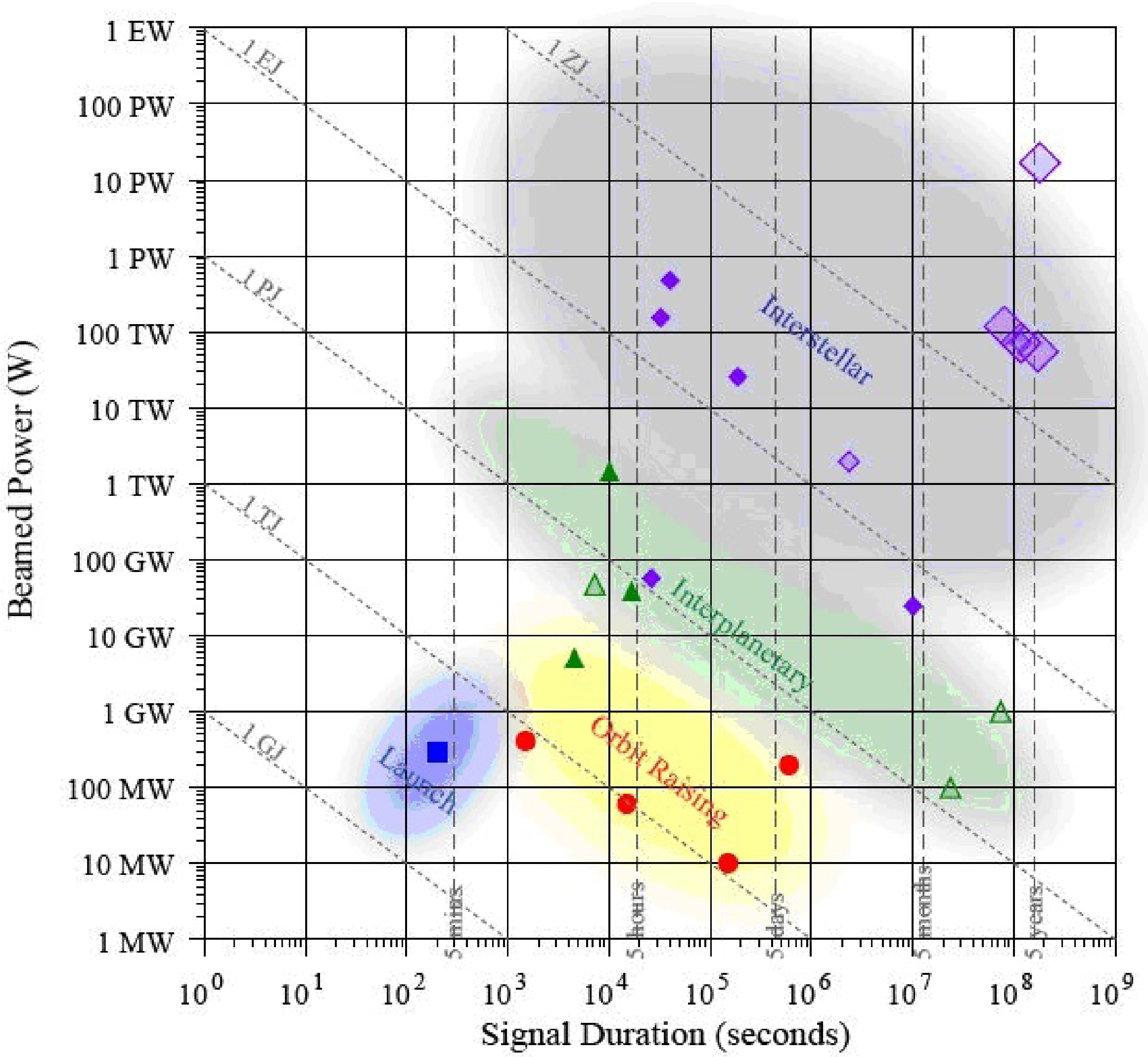



Figure 1: Candidate Beaming Stations
Benford and Benford (Astrophysical Journal, Volume 825, Number 2, 2016)
(By authors permission.)

A caveat: in most of the starships the observer has to be inside the transmitter cone of an energy beam. In general this stream of energy will be narrow. If one compares this with the full sky which would be four pi steradians the ratio of beam diameter to the expanse of the sky implies rather small observational probabilities.

## II.1 Relativistic Ships

Following the lead of Freeman Dyson and Nikolai Kardashev we extrapolate.
Take the civilization to be Kardashev 2, or K2, these ships will be taken to be relativistic starships.

1) They can run 'hot' ... ship construction materials that can come into thermal equilibrium with temperatures as high as 5,000 K (this is close to the melting point of graphene).
2) Material structural strength limits have been overcome, that is there is support for Lorentz factors of up to at least 500 or 0.999998 speed of light. This means stress transmitted by drag due to interacting electromagnetic fields or the support of very large magnetic flux densities have been solved.
3) K2 civilizations fly 1g, maybe higher g, ships.
4) Disintegration due to relativistic dust or gas impact or drag in the interstellar medium.... solved.
5) K2 guidance, navigation and control, almost magic but still distinguishable.
6) Whatever the technical problem. Likely a K2 civilization can solve it.

Postulate a generic K2 ship, a high Lorentz factor ship (that is a large gamma).
Note a Lorentz factor (gamma) of 10 is equivalent to a ship speed of 0.995 the speed of light.
Take a hypothetical numerical example. Postulate a K2 ship with gamma of 500 (yes that's a 'super science' ship) 0.999998 the speed of light. This hypothetical K2 will be taken to be as hot as 5,000 degrees K (carbon like materials have upper limit thermal properties such as this).
Suppose such a star ship is making an interstellar trip, what might we see? While the ships engine is running and even after propulsion is off there will be waste heat. It can be modeled as isotropic radiation in the rest frame of the ship. If $\varepsilon$ is the emissivity (1 for a black body) and $\sigma$ is the Stefan-Boltzman constant then the energy flux density is $j=\varepsilon\sigma T^4$ (watts/meter$^2$), in the rest frame of the vehicle. If v is the ship velocity and c the speed of light then $\gamma=1/\sqrt{(1-\beta^2)}$, where $\beta = v/c$, $\gamma$ is the Lorentz factor.

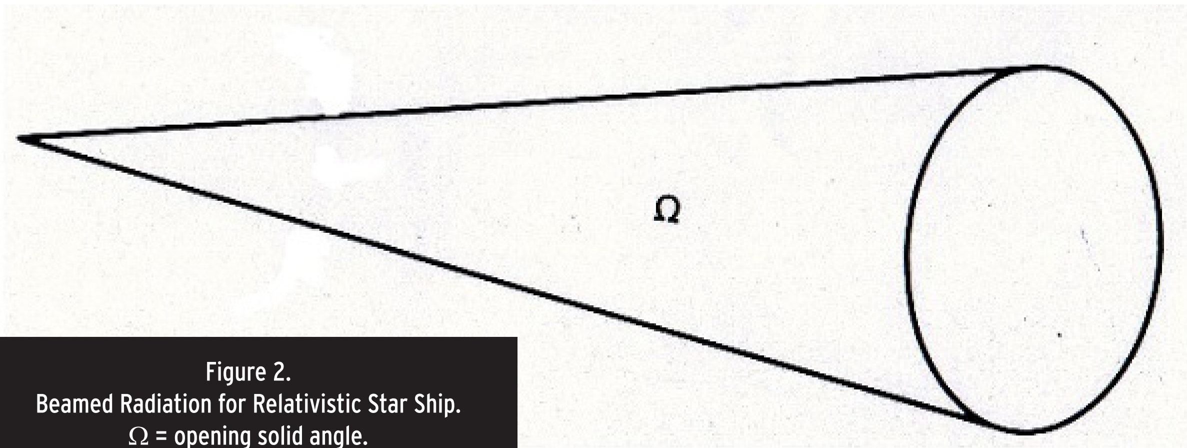



Figure 2.
Beamed Radiation for Relativistic Star Ship.
$\Omega$ = opening solid angle.

To an observer in another inertial frame the radiation will be beamed, the relativistic 'headlight' effect, see figure 2. The flux density j in the proper frame will be 'Doppler Boosted', to $j_o$ an observer's frame [6]

$$j_o = j\delta^4 \text{ watts/meter}^2 \quad [1]$$

$$\delta = \left(\frac{1+\beta}{1-\beta}\right)^{1/2} \quad [2]$$

Considering a modest ship of size and mass, a K2 ship accelerating at one gravity up to a $\gamma$ = 500. For instance a ship 1000 meters long and 50 meters in diameter radiating black body waste heat will be generating 11,402 terawatts in its rest frame, Doppler boosting [7] will generate = $2 \times 10^{16}$ terawatts beamed into the forward direction! However unless the ship is headed straight at the observer it will be almost impossible to see.

The opening solid angle is $\Omega \sim 1/\gamma$ (steradians) thus the probability of observation is $\Omega/4\varpi$ or about 0.002. The probability of observation will be difficult.

This example is very extreme, comparable to x-ray buster EXO 0531-66 [7a]. The effect is interesting, consider that 1 watt of black body radiation in a ship's rest frame is Doppler boosted by the observer's frame by $\gamma^4$ this would be a large flux in the frame of an observer.

For this case if one takes into account the Doppler shifting of the characteristic wavelength, from near green in the rest frame of the ship to soft x-rays in the observer's frame one may have to rely on satellite observatories in Earth orbit.

Thus one might look for small anomalies in the host of new astrophysical satellite observatories, see list in figure 3.

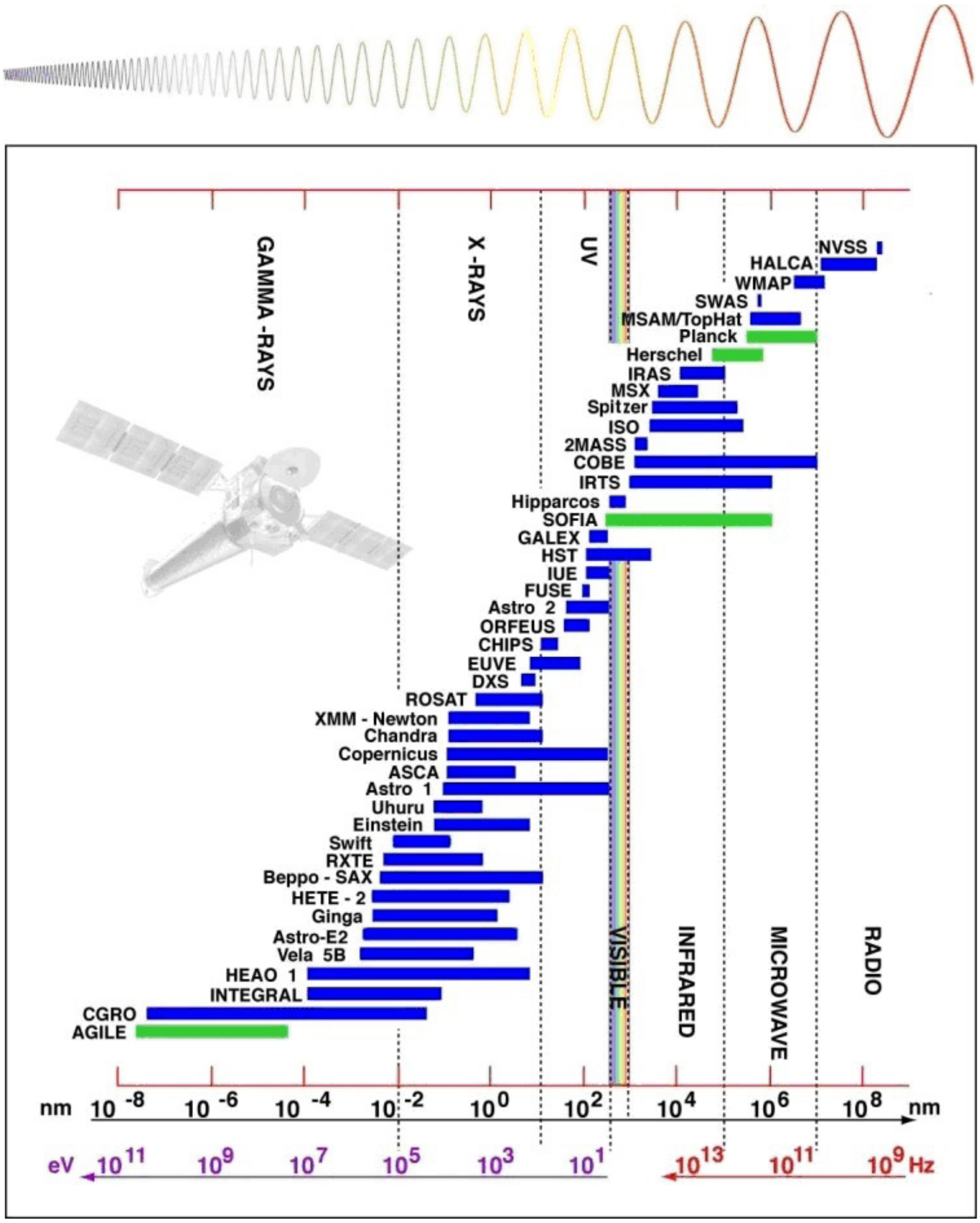



Figure 3 :
Astrophysical Observatories and the Electromagnetic Spectrum (source Wikipedia)

## III. Gravitational Machines

In 1963 Freeman Dyson [8] suggested that an advanced civilization might use massive binaries as 'slingshots'. A process used by spacecraft in the solar system, in astrodynamics called a Gravity Assist to save fuel and time. Dyson considered white dwarf binaries and neutron star binaries. To these one can add black hole binaries.
Like Dyson take the orbital distance of the objects to be circular with a semi major axis of 1,000 km.
Consider a ship approaching with a velocity V. Velocity gains then are of the order of 0.002 to 0.006 c. Not bad for free energy, except one has to live in the vicinity of or travel to such objects.
There is, however, bad news.  The lifetimes, t, of these binaries against gravitational wave energy loss and hence orbit decay to collapse is given by [9]:

$$t = \frac{5c^5 r^4}{512 G^3 m^3} \quad [3]$$

If both binaries have the same mass, m, where c is the speed of light, G the gravitational constant and r the distance between the binaries then for the separation r = 1,000 km the lifetimes are

White Dwarfs ~ 30 years
Neutron Stars ~ 18 years
Black Holes ~ 0.1 year

Larger orbital distances have larger lifetimes but much smaller velocity gains. Achieving high fractions of the speed of light does not look promising for Dyson gravitational machines.

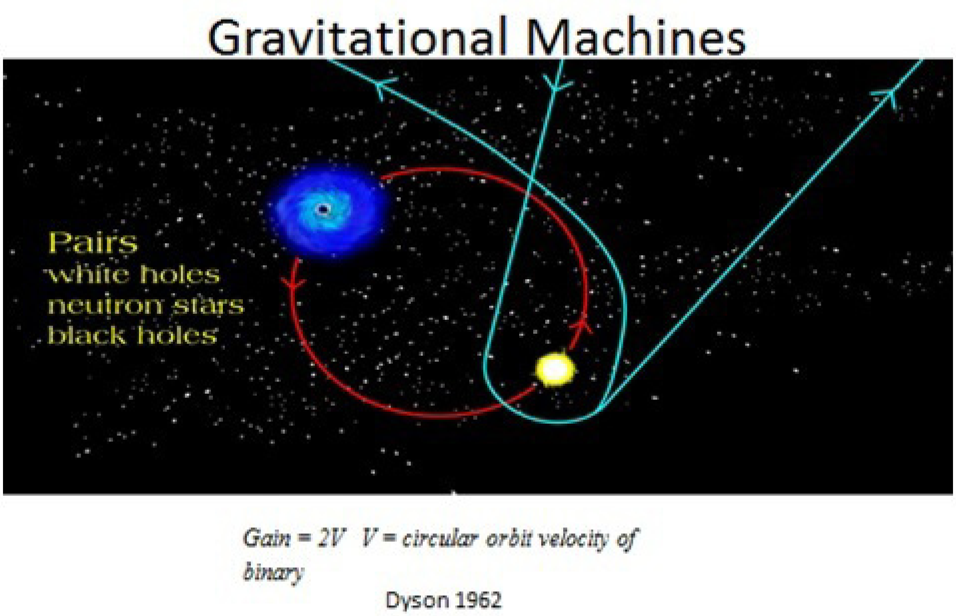



Figure 4: Gravitational Machines

## III.I Surfing Black Holes

Another place to look is isolated black holes. Rotating black holes (these will be referred to as Kerr black holes) and non-Rotating black holes have an interesting property when a particle has a trajectory close to black holes, it no longer moves according to Newtonian mechanics.

In Newtonian physics when a spacecraft approaches a planet with a speed at infinity that exceeds escape velocity, from that planet, unless that craft fires a rocket motor, encounters a planet's atmosphere, hits the surface, or uses some other dissipative mechanism it will return to infinity (for example, a parabolic or hyperbolic orbit). However in the case of a black hole when one gets close enough there are orbits that can go into temporary capture. If the Schwarzschild radius is, $r_s = 2GM/c^2$, then if a particle's encounter distance is less than $10r_s$ the motion is strongly non-Newtonian [10].

This article will only be concerned with trajectories (or more correctly time-like and null geodesics (photons)) that are initially unbound, that is that come in from infinity and have an impact parameter b. In Newtonian mechanics a particle has a total energy E then particles with E > 0 will be remain on unbound orbits (if they don't hit their central gravitating body) and with E < 0 will be bound to a gravitating body. In General Relativity trajectories in the field of a black hole with energy E > 0 can approach on an unbound trajectory; if they don't get closer than $10r_s$ they will remain unbound. However, for a non-rotating black hole between $3r_s > r > 6r_s$ there are unstable orbits that can loop the black hole once or several times. The exit direction will depend on the approach impact parameter, energy, angular momentum of the particle. (The whole subject of trajectories about a Schwarzschild black hole is somewhat involved, we shall not delve into here, see the excellent exposition in Chandrasekhar [11] chapter 3, and even more complicated for Kerr black holes [11]).

Suppose that a K2 civilization can send a relativistic starship (slower than light, yet with a high Lorentz factor) in only a certain direction, because of the interstellar medium or some pointing advantage in a beamed energy system. If this K2 civilization has black holes mapped in the galaxy then a relativistic ship can be turned in the direction of the target by using this capture-unbound orbit mechanism with only a small expenditure of energy. It would demand that there is a K2 level of guidance, navigation and control and computational power to hit the right impact parameter. A vehicle can graze the distance of $3r_s$ making many revolutions before exiting, but one must stay outside of $3r_s$ or otherwise plunge into the hole. [10, 11]. Setting u= 1/r for the Schwarzschild metric an ultra-relativistic particle, with impact parameter b, equations of motion can be written as [11]:

$$\left(\frac{du}{d\varphi}\right)^2 = 2Mu^3 - u^2 + \frac{1}{b^2} \qquad [4]$$

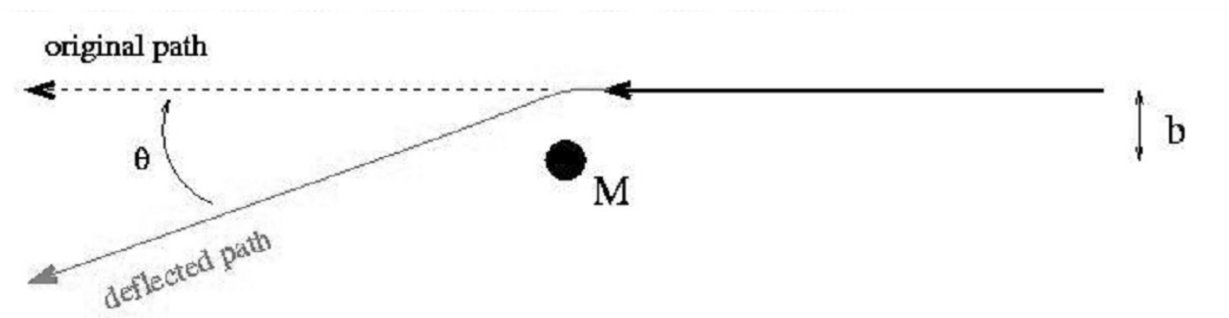



Figure 5. A relativistic particle deflected by a black hole.

Equation [2] has an approximate solution, if $b_c = 3\sqrt{3}M$, is the critical impact parameter and a particle approaches close to $b_c$ then the angle θ will become 'winding', that is it can orbit 0 to $2n\varpi$ times, Chandrasekhar [11].

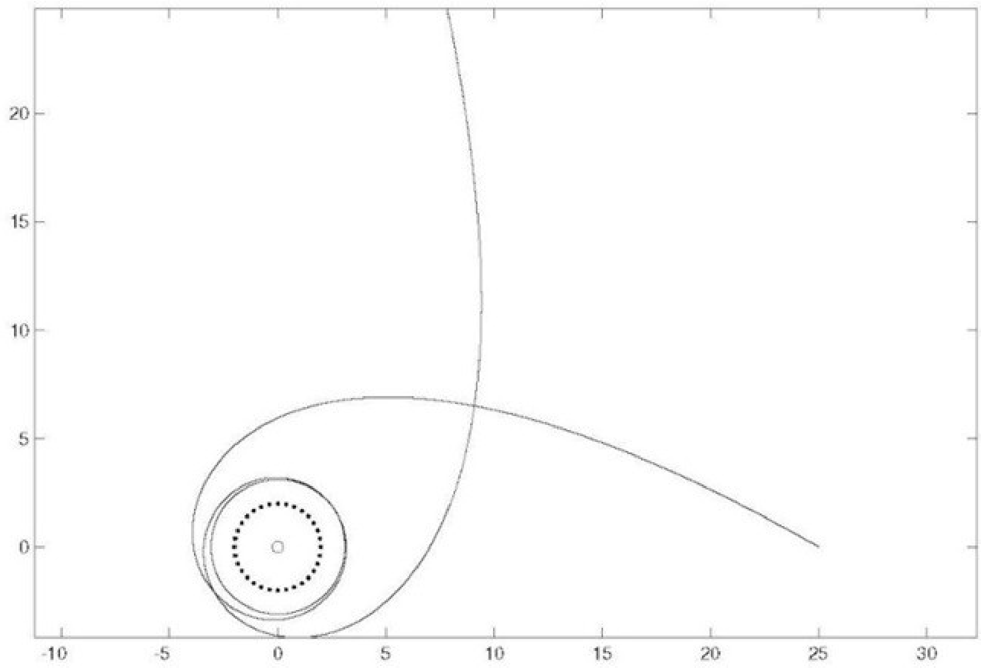



Figure 6: Winding orbit about a non-rotating black hole.

Of what advantage is this? First a K2 civilization might use such a capture orbit as a free source of direction change. A ship moving at, say, 0.5 c, would have to expend a lot of energy to change direction if a desired destination is not along a given trajectory. That is some fraction of the ship's total energy $E = \gamma m^2$ would be needed to turn it. For instance, for a 1,000 metric ton starship, E ~ $10^{13}$ terawatts, thus some fraction of that will be needed to turn it. A ~ 3 solar mass black hole can turn it for free. Why not move in that direction in the first place? That might be possible, but a ship may be constrained to a 'take off' path not in the target direction. Alas, if the black hole is in the vicinity of a target destination it would not be possible to use the fact that an orbiting particle close in a black hole will lose energy to gravitational radiation. Energy loss by gravitational radiation goes like

$$\Delta E = \frac{m^2}{M} f$$

where $f \sim 1$, the mass of the ship, m, will be much smaller than the mass of the black hole, the ship would have make ~ $10^{19}$ orbits!

To use this mechanism would require K2 technology capable of calculating the right impact parameter and have the shielding to survive the close by environment which may be an accretion disk (though there should be some 'bare' black holes in the universe). Kerr black holes will be the most common present extreme astrophysical environments (note: almost all stars that collapse to black holes will be rotating). For Kerr black holes such orbits exist but analytic calculations are extremely difficult [11] and will most likely have to be made numerically.

Any K2 civilization 'hot' starship orbiting a Schwarzschild or Kerr black hole will have its waste radiation focused. Thus whenever an observer is in the line of sight a close orbiting object will have a fluctuating emission, peaked in the observer's direction. A starship looping a black hole like this would have an odd observational characteristic.

## III. Bow Shocks

The use of magnetic fields for interstellar flight, first considered as a ‘scoop’ by Bussard [13]. Sagan suggested magnetic scoops this was extended to Mag-Sails by Andrews and Zubrin [14] who consider using them as ‘brakes’. A magnetic field plowing into the interstellar medium (particularly dense regions) will incur both energy and momentum loss, noted by Bussard, quantified by Fishback in 1969 [15]. This can be useful in stopping or at least slowing down a relativistic interstellar spacecraft. The byproduct of this process can produce a Bow Shock. Runaway neutron stars show such a structure,

Figure 7: Neutron star bow shock analog for a starship. (source Wikipedia)

Radiation from the bow shock can range from the optical to the x-ray bands mostly produced by synchrotron radiation. A starship will be much smaller than a neutron star thus flux smaller, but it's observation could imply a very peculiar object.

## IV. Black Hole Lensing

If K2 civilizations utilize black holes as a method of redirection or as ‘brakes’ using gravitational radiation by orbiting in the non-Newtonian zone then the waste heat of the ship will be focused by the black hole one should see an anomalous peak in whatever part of the spectrum emerges from the black body radiation. A word of caution, strong gravitational field focusing is very complicated, where by ‘strong’ we mean the use of a Schwarzschild or Kerr black hole to bend light as a gravitational lens.

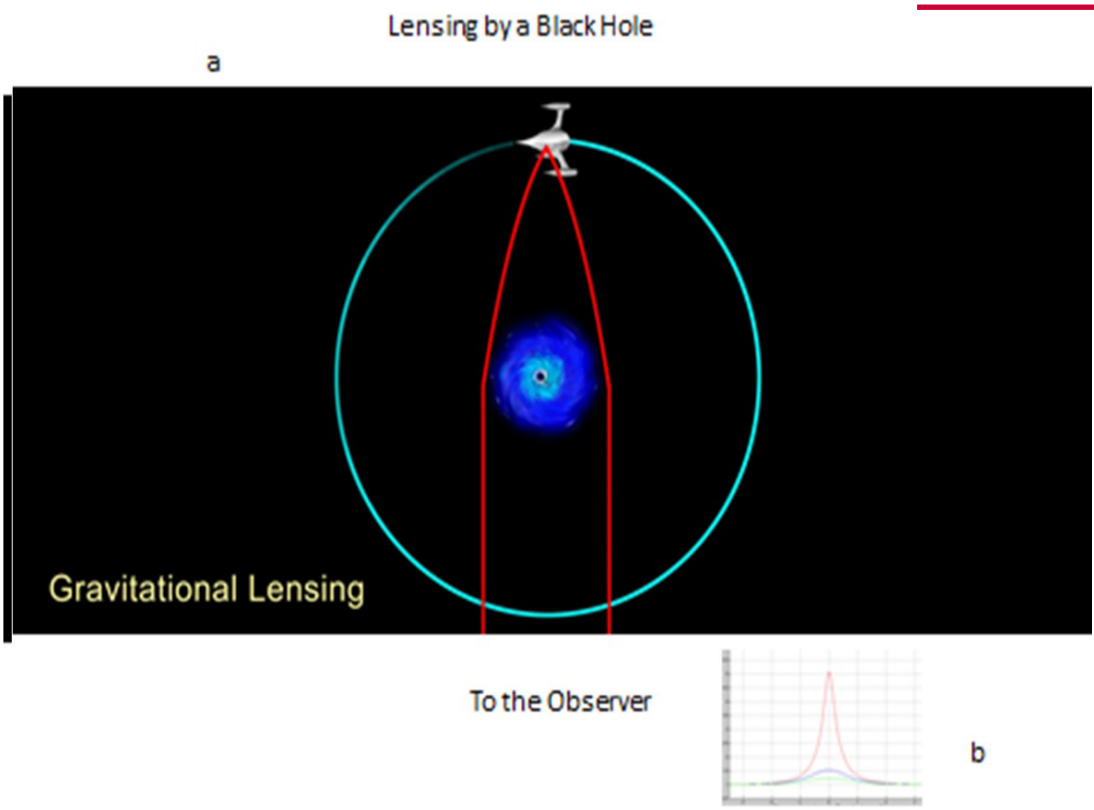



Figure 8:
Lensing of a starship's waste radiation by a black hole. (a) is the lensing, (b) image in the optical plane.

## IV.1 Black Hole Beamed Propulsion

Consider a K2 civilization taking advantage of a Schwarzschild or Kerr black hole as a means of focusing radiation from a beaming station onto a sail. The advantage of this is the enormous amount of amplification possible. One of the most promising modes of interstellar flight propulsion methods is the use of a sail, a transmitter and maybe a 'lens' to focus a beam of laser light or microwaves. Extrapolate to a K2 civilization using a black hole as the focusing device. An approximate calculation for a Schwarzschild black hole shows that beamed radiation can be amplified by a factor $10^5$ to $10^{15}$. Caution is now advised. Almost all of the many astrophysical papers on 'strong focusing' consider a lens that is either a Schwarzschild or Kerr black hole, but in that case the source is either many light years away or is in orbit about the black hole but is physically larger in extent than the black hole. These constraints, though a realistic astronomical configuration, may not match the K2 technological engineering set up considered here. There are physical consequences to consider too. A source behind a Schwarzschild black hole does not come to focus at a point but creates, in the first approximation, on the optical axis (the axis that connects the source and the observers), a 'caustic' where the amplification is extreme [16], [17]. A caustic (en.wikipedia.org/wiki/Caustic_(mathematics)), in the Schwarzschild case may be thought of as a 'tube' on the optical axis. This is because of the non-Newtonian nature of the strong gravitational field of a black hole. Photons that come from the right direction can go into orbit either permanently or for a finite number of revolutions as described above. With focusing the location of the source image will be displaced on the image plane. In Weak Lensing there will be an Einstein ring that is the deformation of the light from a source into a ring through gravitational lensing of the source's light by an object with an extremely large mass; black holes are the lenses of interest here. In the case of Kerr black holes the 'caustics' will be 'sheets' complicating the process to the extreme.

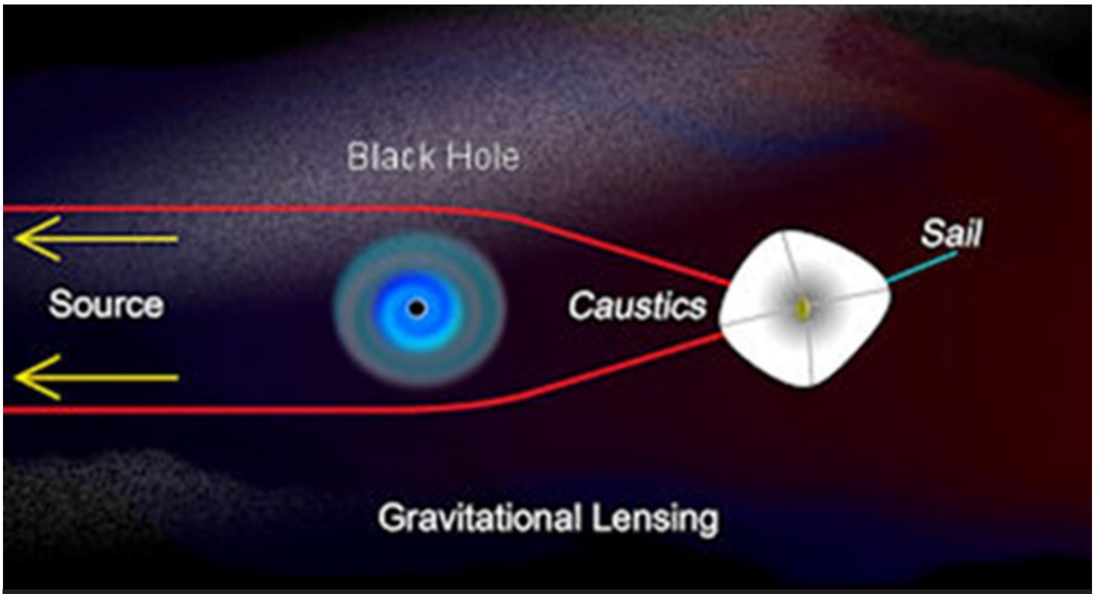



Figure 9. Black hole gravitational lensing as beamed propulsion.

The exact location of a source and the sail location are the subject of further study, Figure 9.

## V. Zero rest or near zero rest mass carriers

Observational SETI has concentrated on using electromagnetism as the carrier, namely radio waves and laser radiation. Michael Hippke [18] has pointed out that it may be possible to use neutrinos or gravitational waves as signals. Gravitational waves demand the command of the generation of very large amounts of energy. Neutrinos, like gravitational waves, have the advantage of extremely low extinction in the interstellar medium. To make use of neutrinos an advanced civilization could use a gravitational lens as an amplifier. The lens can be a neutron star or a black hole. As outlined above using wave optics one can calculate the advantage of gravitational lensing for amplification of a beam and along the *focal axis* it is exceptionally large. Even though the amplification is very large the diameter of the beam is quite small, less that a centimeter. This implies that a large constellation of neutrino transmitters would have to enclose the local neutron star or black hole to make an approximate isotropic radiator. The operational energy needed is about 0.01 Solar, this means that such a beacon would have to be built by a Kardashev Type II civilization.

**Table 2 Zero Rest Mass or Near Zero Rest Mass Carriers**

| Carrier | Rest Mass MeV/c2 | Lifetime | Extinction | Sources |
|---|---|---|---|---|
| Photon | 0 | Stable | 0.001 | Beacons<br>-Waste Heat<br>-Star Ships |
| Neutrino | ~0.001 | Oscillations<br>Stable | ~0 | Beacons<br>Beams |
| Graviton | 0 | Stable | 0 | Beacons |

## V.1 Black or Neutron Star Hole Beacon

For a compact gravitating body the gravitational gain by lensing is proportional to the ratio of the Schwarzschild radius and transmitter wave length, rs/λ and it is shown [6,8] that for amplification λ < rs. Suppose a K2 civilization deploys a laser transmitter in orbit about a black hole, this transmitter-black-hole-lens-amplifier comprises a beacon (or it could be a neutron star as the lens). Townes [12] has shown that at short wavelengths infrared is favorable for transmission at signals over interstellar distances. The exact mass distribution of black holes is unknown, but an estimate of stellar mass black holes from observations and stellar evolution, the mass, m, is in the range of 3 to 20 solar masses [9, 10, and 11], take 10 solar masses as representative. For a basic example take the signal to be transmitted at 1 micron, the near-infrared. Take the K2 civilization as having placed this transmitter about a black hole lens of mass of 10 solar masses then the gravitational lens gain is $1.2\text{x}10^{11}$, Jackson [19].

A one watt transmitter can reach a range of about 1 kpc (~ 3000 ly) and be detected within the magnitude 30 limit of

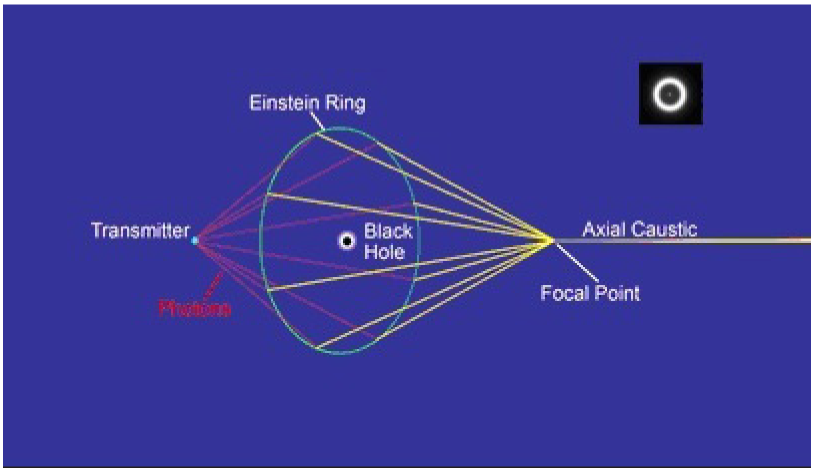



Figure 10: A schematic representation of gravitational lensing by a black hole

the JWST. A laser transmitter alone would take an instrument with the sensitivity magnitude greater than magnitude 50 to detect.

## V.3 Neutrino Beacon

To make use of neutrinos an advanced civilization could use a gravitational lens as an amplifier. The lens can be a neutron star or a black hole. Using wave optics one can calculate the advantage of gravitational lensing for amplification of a beam and along the *focal axis* and it is exceptionally large. Even though the amplification is very large the diameter of the beam, at the receiver, is quite small, less than a centimeter. This implies that a large constellation of neutrino transmitters would have to enclose the local neutron star or black hole to make an approximate isotropic radiator.

The engineering physics would be to build a constellation of neutrino beam transmitters. Place, in orbit, at 100 neutron star radii, $10^{18}$ advanced small Wakefield accelerators one meter long and 20 centimeters in diameter, figure 11. Then each point on figure 12 is occupied by an accelerator neutrino source, figure 11. Plasma-based accelerators are already producing high energy particle beams, what a K2 civilization may be capable of, for accelerators, is an extrapolation. With $10^{18}$ accelerators pointing four pi radians the probability of detection increases to approximately $10^{-3}$ at an Earth detector and the detection rate at 10,000 light years becomes approximately 5 per minute. The power required for the whole artifact is about 0.01 Solar, which is a K2 command of energy. The operational energy needed is about 0.01 Solar; this means that such a beacon would have to be built by a Kardashev Type II civilization, Jackson, [20].

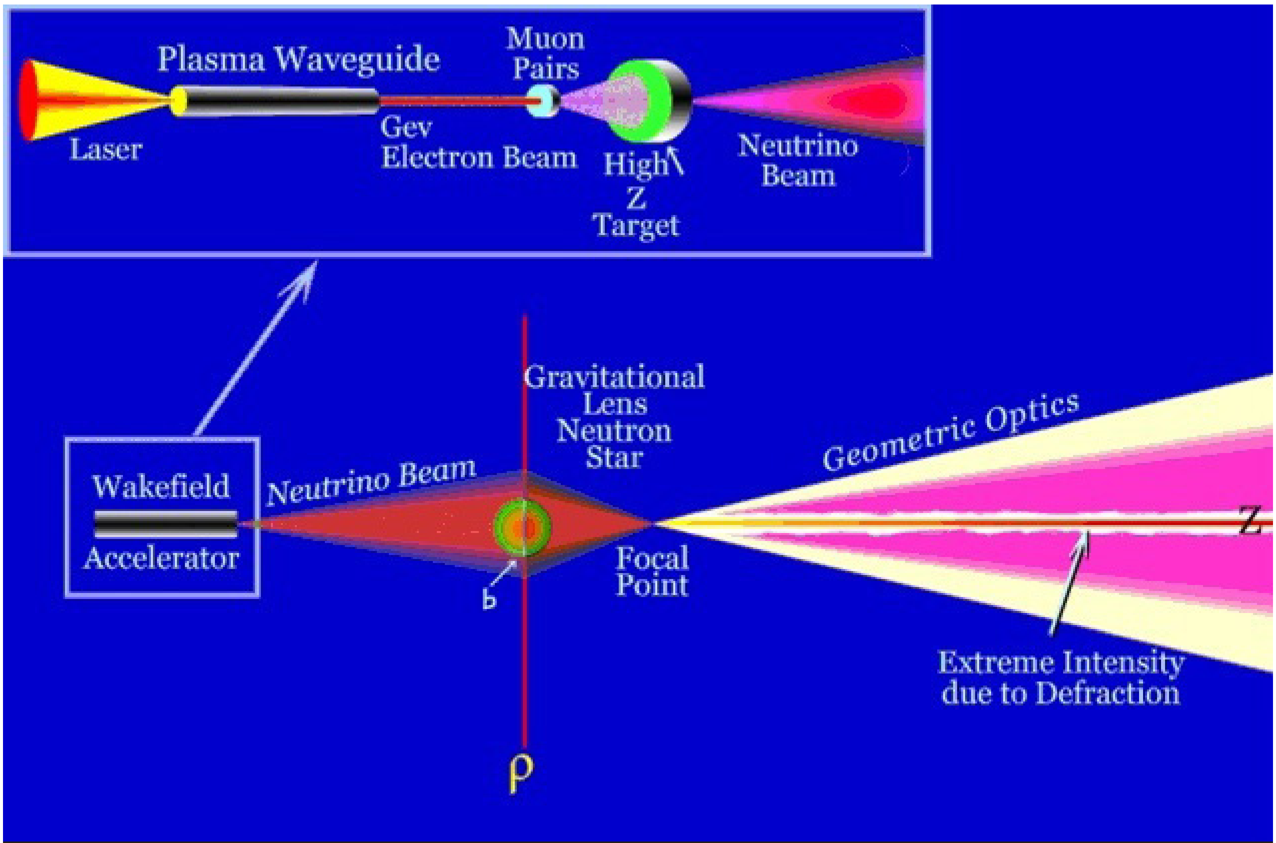



Figure 11. A gravitationally focused neutrino transmitter

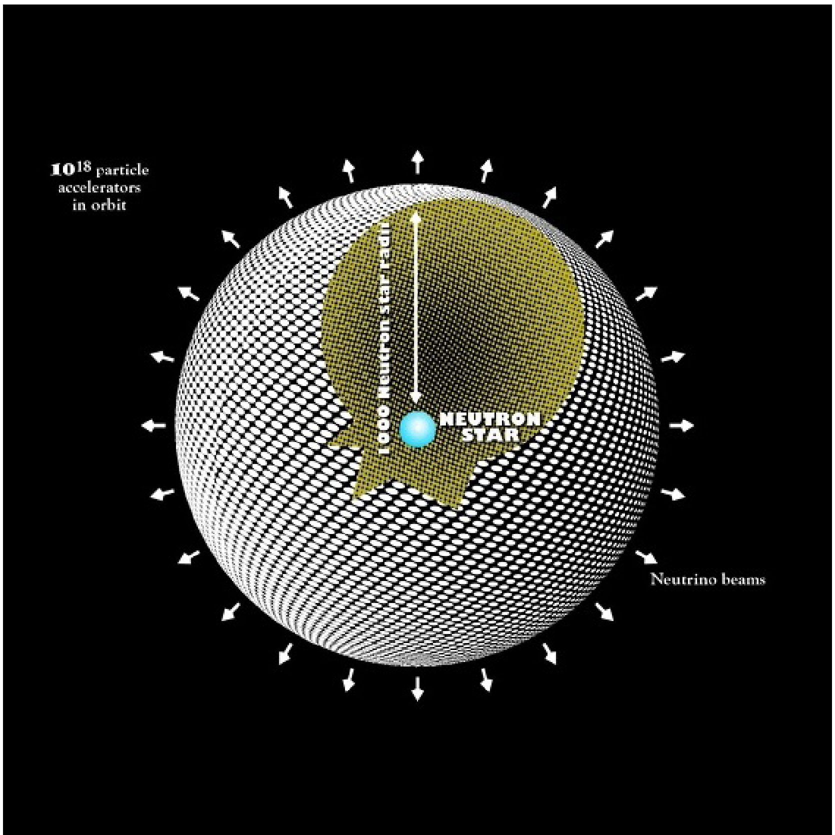



Figure 12. A schematic
Constellation of $10^{18}$ neutrino accelerator-transmitters in orbit (nothing to scale).

## V.4 Gravitational Wave Beacon

An advanced civilization might build a radiator to send gravitational wave signals by using small black holes. Micro black holes on the scale of centimeters but with masses of asteroids to planets might be manipulated by a super advanced instrumentality, possibly with very large electromagnetic fields. The machine envisioned emits gravitational waves in the GHz frequency range. If the source to receiver distance is a characteristic length in the galaxy, up to 10,000 light years, the masses involved are at least planetary in magnitude. Background gravitational radiation sets a limit on the dimensionless amplitude that can be measured at interstellar distance using an advanced LIGO like detector.

## VI. Gravitational Wave Transmitters

One could suppose that a civilization sends signals using gravitational waves. The LIGO receivers have seen gravitational radiation from natural objects. As a gravitational wave passes through matter it can change its geometry, namely its characteristic length. If one measures a length L and it responds to a gravitational wave by an amount ΔL, the 'strain' is measured by $h= \Delta L/L$. This dimensionless amplitude is very small indeed, due to the weakness of gravitational waves. LIGO can measure h to the value of $10^{-22}$, or in approximate physical terms 1/1,000 the diameter of a proton.

**Table 3: Advanced civilization gravitational wave transmitter located at 10,000 light years energy budgets.**

| Dimensionless Amplitude h | Mass converted to Energy (ergs) | Kardashev Scale Civilization | Gravitational Wave Receiver |
|---|---|---|---|
| $10^{-22}$ | ~0.1 Earth Mass 10:$^{27}$ grams | 3.6 | LIGO at 100 Hz |
| $10^{-25}$ | ~ mass of Ganymede ~$10^{26}$ grams | 3.0 | Advanced Gravitational Wave Detector ~1GHz |
| $10^{-33}$ | ~ The mass of asteroid Ida ~ $10^{17}$ grams | 2.4 | 'Planck' Length Detector |

LIGO can detect a Type 3 plus civilization 100 light years away, but presently only in the frequency range of ~100 Hz. A more plausible signal, we argue, may lie in the GHz range. (In the following it is taken that a Kardashev civilization of a certain order means more than a mastery of a level of energy, that itself, implies an ability to project an instrumentality, engineering physics of staggering sophistication.)
Physically, h is related to the transmitter by $h \sim \Delta E/r$ where ΔE is a burst of gravitational radiation energy and r is the distance from the transmitter. Take ΔE as the amount of energy produced by the annihilation of a mass m, namely $mc^2$, and take the distance of the transmitter to be at 10,000 light years (approximately the scale of the galaxy). The amount of energy produced can be related to the quantity specified by the Kardashev scale.
To configure a GW machine, suppose an advanced civilization has planetary size black holes in its inventory. Four (or more) of the small black holes become 'orbital machine', a large central mass plus an exciter mass is one component. One active element of the machine, the central and exciter black holes, form binary systems orbiting the home star. (All the 'small' black holes may be rotating, Kerr, types). See Figure 13.

To provide the energy for this system one posits a very advanced civilization that has also Kerr black hole as a component to provide a super-radiance power station, as proposed by Jackson and Benford [21], see this paper for details and section VII. Other gravitational wave beacons have been proposed Abramowicz et al [22], and Rana Adhikari [23].

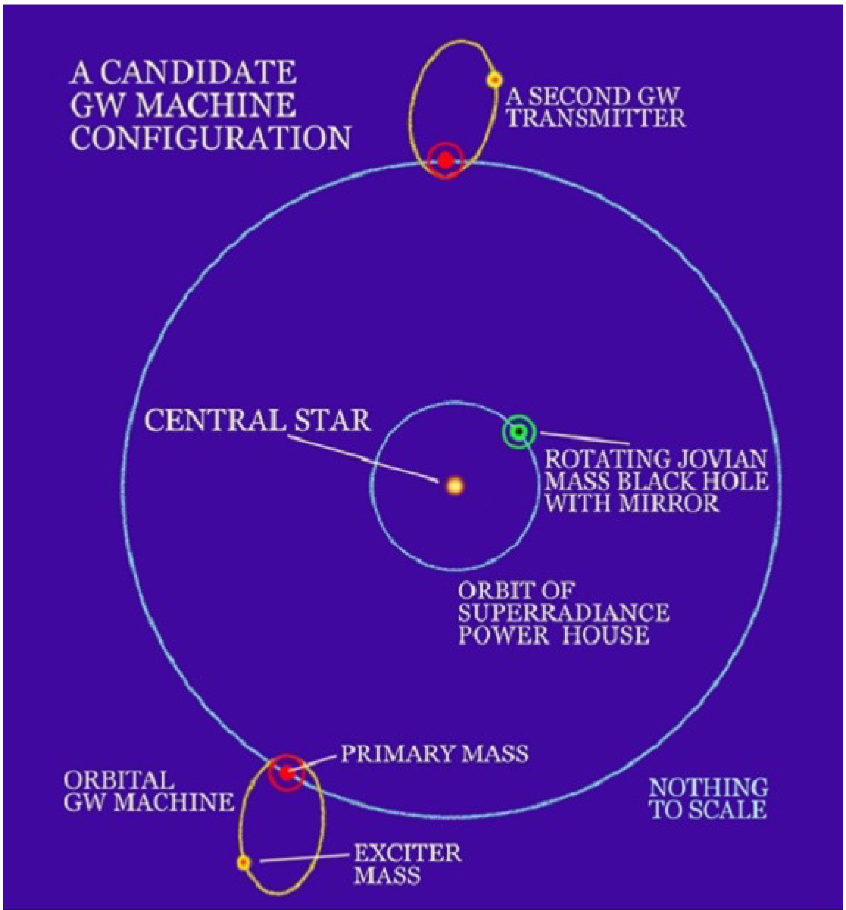



Figure 13. A schematic representation of a total 'gravitational wave machine' system. Note the 'Superradiance machine' is inward of the gravitational wave machines; the Home Star is located somewhere in this system.

## VII. Black Hole Bomb Beacon

An electromagnetic wave impinging on a Kerr black hole can be amplified as it scatters off the hole if certain conditions are satisfied giving rise to an amplified wave called superradiant scattering [24]. By placing a mirror around the black hole one can make the system into a bomb! In the modeling a wave with frequency $\omega < m\Omega$ impinging on Kerr black hole will be amplified (m is an azimuthal wave number and $\Omega$ the angular velocity of the Kerr hole at the horizon (The azimuthal number is a number for the wave that determines its orbital angular momentum.) The scattered electromagnetic wave will be amplified, the excess energy being drawn from the Kerr hole's rotational energy.

If a K2 civilization builds a 'mirror' about a Kerr black hole undergoing this process the radiation will be amplified exponentially until the mirror fails as the radiation is released. The mirror cannot be a solid shell since that would be mechanically unstable. It would be an orbiting ensemble similar to a Dyson swarm. The orbits could be an oscillating shell, the technology keeping it in configuration at a K2 level.

Consider a mirror assembled from a large number of elements of a truncated icosahedron, figure 14, it might be some other solid as long as the inside surface forms a mirror. As long as the configuration is such that transmitter reflectors located towards the Kerr black hole can efficiently contain the scattered radiation. The process would be that the transmitters fire once and then by K2 technology become reflectors, then the initial radiation would be amplified until the strength of the K2 'mirror-ships' artifact can no longer contain the electromagnetic energy and release it through ports.

Consider a 1 solar mass black hole rotating at about 10,000 radians per second, one can calculate the critical distance for spherical 'super radiant' mirror [24a]. It is located at 22 km (the event horizon is approximately at 3 km). When in operation at the end of 13 seconds the energy content is $10^{17}$ times the initial pulse. To match the 'bomb' constraints the transmitted pulse wavelength should be at about 18 km. How one would reflect and absorb long wave length radio waves is a problem to be solved by a K2 civilization. A possibility is that a spectrum of primordial black holes (PBH) exist left over from the Big Bang. PBH's in the range of $10^{-5}$ to $10^{43}$ grams might exist. For an Earth mass Kerr black hole with event horizon 9.0 mm, placing the mirror at 1 m one gets a growing timescale of about 0.02 seconds the critical radiation would be a high frequency radio wave at about 33 GHz.
With amplification factors of the order $10^{17}$ one has K2 civilization solving the containment mirror problems, keeping the system from melting or being shattered. It would mean the system would have to be fine-tuned to these effects. With the right configuration the structure would hold the energy until some material strength is exceeded while keeping the radiation absorption from vaporizing and the fleet of transmitters fly off with some fraction of the amplified energy. One watt in $10^{17}$ watts out! As a beacon it would be an unusual object.

The Black Hole Bomb

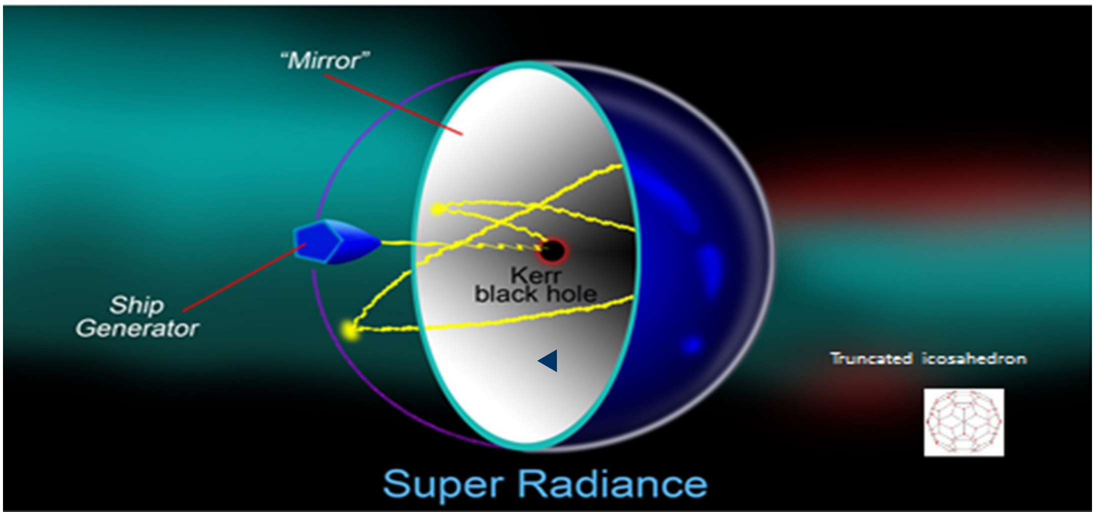



Figure 14. Black Hole Bomb

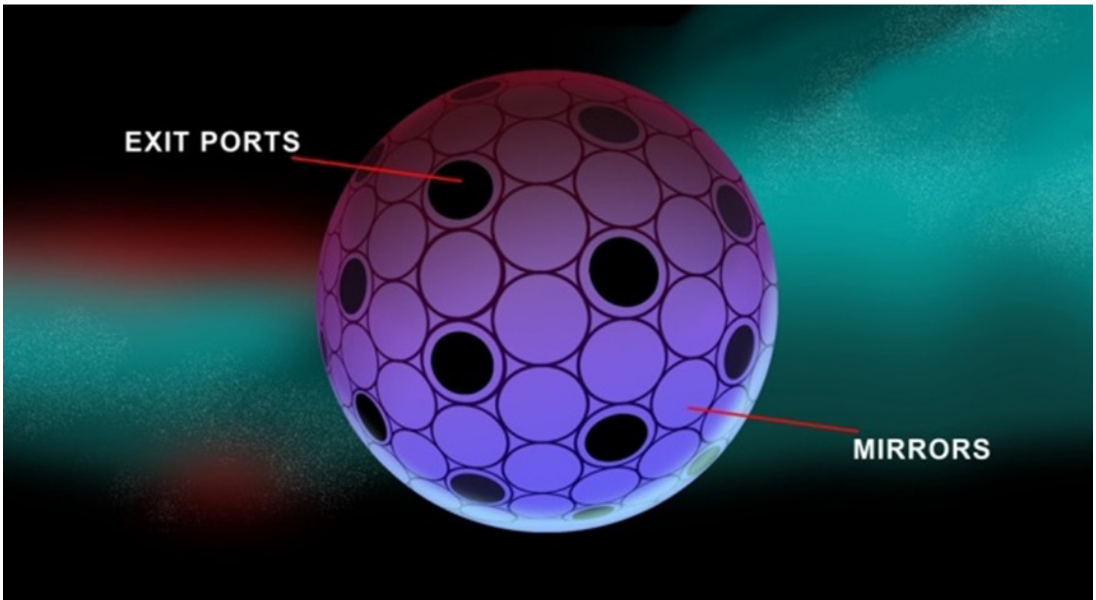



Figure 15. Black Bomb as a beacon.

The beacon configuration is in figure 15, exit ports allow beams of amplified radiation out as signals.

## VIII. Megastructures

In 1960, Freeman Dyson described how the exponential rise in energy requirements by a technological civilization might lead to the construction of a Dyson Sphere around a star [4a]. This is a hypothetical mega-structure encapsulating a star in order to completely capture its energy output. A habitable surface would offer the additional bonus of having extra space for a continually expanding civilization. Therefore, the discovery of such an object would be an indicator of intelligent life.

Given the great number of observatories that have surveyed the sky, it can be said, relatively safely, that with more stars measured more accurately than ever before, zero Dyson spheres have been found at the present time. There may yet be intelligent aliens out there, building vast trans-planetary empires to collect and utilize as much energy as possible, but the evidence for them is nil thus far [1].

A galaxy filled with Dyson Spheres might appear as a Kardashev III, this has been looked for and not found [25].

An extreme artifact that has been envisioned is the Shkadov thruster [26]*.

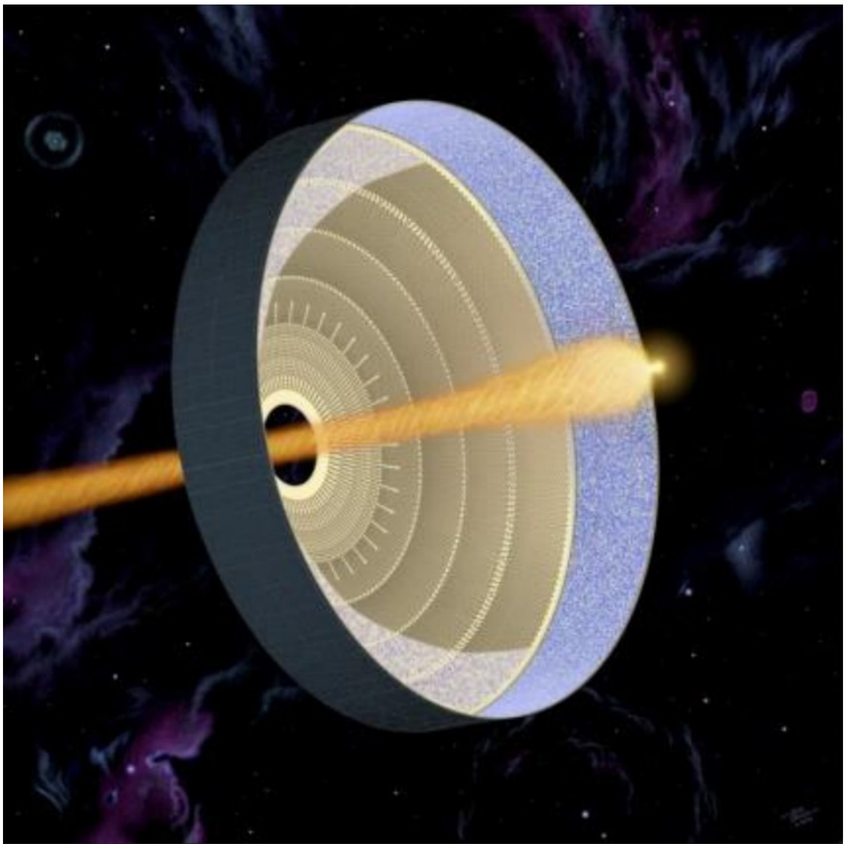


Figure 16. Shkadov thruster (Don Davis)

The concept takes a planetary system on a galactic voyage the whole world of planets becoming a starship [26]. This would make a very unusual observational object.

Traversable wormholes might not be megastructures but they might be observable. Much has been written about the concept of traversable wormholes as 'faster than light' transport about the universe [27]. Traversable Wormholes would be extreme technological objects, possible K3 level, if constructed they might be observable by means of gravitational lensing of light. 'Warp bubble' transport might also display observable effects [28], maybe gravitational shock waves or worse destruction of destination!

* See also *Engineering New Worlds: Creating the Future*, Dmitry Novoseltsev in Principium 17 May 2017 - i4is.org/principium-17

## IX. Conclusions

We have presented some exotic techno-signatures attributed to advanced civilizations. At the moment SETI focuses almost solely on electromagnetic signatures with favor given to directed signals, beacons or possibly ambient leakage. This is likely the best way forward; however we have pointed to possible signatures that are not directed. Interstellar transport may have a detectable component. Megastructures other than Dyson spheres may have an observable existence also. Of interest is other carriers of information that may be directed such as neutrinos and gravitational waves. Since there are more instruments being built or planned for doing non-electromagnetic astronomy it is of interest to be mindful of possible anonymous signs received in that observable data.

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# Aerographite: A Candidate Material for Interstellar Photon Sailing

## Summary of a paper by Greg Matloff and Joseph E Meany

John I Davies

Aerographite, as a strong and light material for the construction of photon-propelled interstellar vehicles, was first mentioned in Principium back in P35, November 2021. Dr Andreas Hein, i4is Technical Director, was awarded a grant by the Limitless Space Institute in 2022 for his team at the University of Luxembourg to study *Extremely Light-Weight Solar Sails for Fast Deep Space Missions (SEEDLING)*, investigating the viability of fabricating µm thick aerographite sheets and determining load capability and integrating into feasible sailcraft.

We also reported on Professor Greg Matloff's (New York City College of Technology) paper *Aerographite: a Candidate Material for Interstellar Photon Sailing* at IRG23, Montreal in P41 in 2023 (i4is.org/wp-content/uploads/2023/05/Principium41-23052291003-opt.pdf).

Here John Davies summarises Prof Matloff's later JBIS paper *Aerographite: a Candidate Material for Interstellar Photon Sailing*, V77 #5 May 2024 - with Joseph E Meany (Savannah River National Laboratory, South Carolina) for a wider readership. We will likely hear much more about aerographite and its cousin, aerographene, as we progress the technology for relatively short term interstellar exploration.

The paper also considers a further future scenario, Aerographite Sun-Launched Interstellar Arks which we may review in a later issue of Principium.

## Introduction

i4is and Space Initiatives have been studying downlink communications from interstellar laser sails based on a model probe constructed from aerographite for several years - see *News Feature: i4is delivers Communications Study to Breakthrough Starshot* in P38 May 2023 and Interstellar News item *i4is Presents at NASA NIAC* in P47 November 2024.

This later paper includes extensive references to earlier work including Matloff's own.

Professor Greg Matloff is both a pioneer and a continuingly active researcher in Interstellar Studies. His book *The Starflight Handbook: A Pioneer's Guide to Interstellar Travel*, co-authored with Dr Eugene Mallove, was published 35 years ago. For several years he has been researching ultra light materials for photon sails and his paper is a recent broad-based study of aerographite.

## Properties

Aerographite is one of the lightest known solids-

| | density, kg/m$^3$ (kg per cubic metre) |
|---|---|
| Helium | 0.179 |
| Aerographite | 0.18 |
| Air | 1.2 |

In other words, you could in principle construct an airship out of aerographite.

It achieves this lightness by consisting of an interconnected network of carbon nanotubes. In all the cases explored by the paper the payload mass is assumedto be one-tenth of the sail mass.

## Solar propulsion

Professor Matloff assumes conservative operational material properties, density of 0.2 kg/m$^3$, fractional absorption and reflection of sunlight 0.9 and 0.1 respectively, maximum operational temperature of 3,500 K and a tensile strength of 100 KiloPascals.
Matloff's Table 1 presents performance characteristics of sample aerographite solar-photon sail interstellar probes.
Matloff assumes "In all cases, the payload mass is ... one-tenth of the sail mass" and "the spacecraft areal mass density is $10^{-6}$ kg/m$^2$ ".

**TABLE 1: Performance of Aerographite Solar-Photon Sail Interstellar Probes***

| Perihelion Distance (Dau) | Interstellar Cruise Velocity (Vfin) | Perihelion Temp. (Tperi) | $ACC_{peri}$ |
|---|---|---|---|
| 0.04 AU | 6,125 km/s = 0.020 c | 1,655 K | 319 g |
| 0.06 AU | 4,900 km/s = 0.016 c | 1,324 K | 142 g |
| 0.1 AU | 3,834 km/s = 0.013 c | 1,036 K | 51 g |
| 0.5 AU | 1,645 km/s = 0.0055 c | 467 K | 2 g |
| 1.0 AU | 1,225 km/s = 0.004 c | 331 K | 0.5 g |

* Spacecraft areal mass thickness ($\sigma_{s/c}$) = $10^{-6}$ kg/m$^2$. Sail sunlight absorption (A) and reflectivity (R) are respectively 0.9 and 0.1. Sail Lightness Factor ($\eta$) = 845. Perihelion Acceleration = $ACC_{peri}$. Perihelion temperatures conservatively assume 100% absorption.

The perihelion distances are -
0.04 AU perihelion - closest planned solar approach for the Parker Solar Probe.
0.06 AU perihelion is close to the smallest "safe" perihelion distance (~0.07 AU) for a beryllium hollow-body solar-photon sail
Graphene interstellar solar-photon sails by Matloff have assumed at 0.1 AU perihelion

## Laser propulsion - ground-based

Project Starshot (breakthroughinitiatives.org/initiative/3) assumes a ground based laser array. Given funding, power source and regulatory approval a ground based laser array presents less challenges than a space-based laser array, hence its choice by Starshot.
However, with patience, a space-based laser array offers advantages of efficiency and scalability.

**Comment**

The solar constant, the amount of energy received by a given area one astronomical unit away from the Sun, is about 1.3 kW per square metre. Around the likely time of establishment of a space-based laser array we can assume efficiencies of around the current best performance, 50%. So we can expect at least 6.5 kW per square metre. So a 1,000 square metre solar array would produce 6.5 MW, 10,000 square metres - 6.5 GW and the base Starshot demand of 100 Gw to require 150,000 square metres. Thus a 387 square metre array of solar cells would be sufficient to the task. Crude approximation of course!
JID

## Laser propulsion - space-based

Setting up a space-based laser array is clearly not possible immediately but it has advantages over a ground-based array including a non-rotating platform and effectively limitless energy from the Sun. The paper assumes efficiency of conversion of solar energy to laser beam energy of 33% and a distance from the Sun of 1 AU (ie the same as the Earth).

Matloff and Meany go for a less ambitious scenario than Starshot (20 years to Alpha Centauri at 0.2c) especially citing the uncertainty of robustness of aerographite under the required photon intensity. They assume that the payload has the areal mass thickness of a graphene monolayer ($7.4 \times 10^{-7}$ kg/m$^2$). As above, the sail's areal mass thickness is $8 \times 10^{-7}$ kg/m$^2$. Therefore, the spacecraft areal mass thickness is $1.5 \times 10^{-6}$ kg/m$^2$ and the sail cross sectional area is $10^4$ m$^2$. The sail diameter normal to the beam, Ds, is about 100 m. The mass of the spacecraft ($M_{s/c}$) is therefore about 0.015 kg or 15 grams, about an order of magnitude greater than the metamaterial sails considered in Project Starshot.

They assume a terminal velocity of the laser probe of 0.033 c. They also assume that the sail is accelerated by the laser over a distance of 1 AU or $1.5 \times 10^{11}$. The lasers must vary in their focus so the beam is used efficiently over this considerable distance and a ~3-hour acceleration run.

Avoiding an atmosphere in the beam path greatly reduces beam losses and allows designers to choose a wavelength based on other criteria.

## Issues, Unknowns and Conclusions

The production methods and resultant properties of aerographite may modify the current uncertainties of this novel material. Aerographite does not have the reflective properties required for a sail under high intensity photons. The paper does not discuss reflective coatings. The authors conclude with "In any event, aerographite is a fascinating material. It is nice that graphene may not be the only metamaterial capable of launching interstellar solar-photon-sail missions. It is worth noting that other candidate materials may exist."

## Conclusion

This article has skimmed fairly lightly over a complex paper which has yet to be published on open access. Those interested in the paper need to join the BIS with the appropriate membership level, check the legal deposit libraries in UK and Ireland (Cardiff, Dublin, Edinburgh or London) or contact a friend who has BIS membership access. Sadly the Library of Congress in the USA appears to have ceased stocking JBIS several decades ago but university libraries in many countries may have it.

# The Interstellar Coracle at the NIAC Symposium in Pasadena


## Robert G Kennedy III, PE (K3TVO)

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In Principium 47, November 2024, *Pringles is a Verb: Fabrication and Exhibition of "the Big Object" at WorldCon 82 in Glasgow* (i4is.org/principium-48/), Robert Kennedy explained how a replica interstellar spacecraft conceived by i4is and Space Initiatives was shown at the 2024 SF Worldcon. The informal name "Pringles" is based on the trademarked saddle-shaped snack which it resembles - we also sometimes refer to the "Coracle", after the tiny Welsh fishing boat. Here Robert refers to the "big object" and the pictures show why. The project which the team executed was supported by the NASA Innovative Advanced Concepts programme and was shown at the annual NIAC Symposium in Pasadena as described here. The team created another such replica which was shown at the First European Interstellar Symposium (FEIS) 2-5 December 2024 at the University of Luxembourg as described in Principium 48 February 2025.
Robert is President, Institute for Interstellar Studies-US, our US organisation, based in Tennessee.


Figure 1 (from left to right): The Swarming Proxima Centauri team onstage presenting at the NIAC Symposium in Pasadena, 12 Sep 2024: T Marshall Eubanks, chief scientist of Space Initiatives Inc (SII), Robert Kennedy III PE, president, I4IS-US, Andreas Hein, Ph.D., ExecDir I4IS-UK, W Paul Blase, chief engineer of SII. Team members not present: Adam Hibberd and Dr Manasvi Lingam of i4is.

NASA's Innovative Advanced Concepts (NIAC) Symposium took place 10-12 September 2024 at the Pasadena Hilton in Pasadena, California. It was 112°F (44°C) in Burbank when your correspondent and his wife landed on Saturday the 7th, which matched the all -time record, but cooled off during the Symposium. Monday the 9th was for setting up and also a guided tour of the Jet Propulsion Laboratory not too far away. Per the Phase I contract with NASA, the Swarming Proxima b team had to be there and present our results thus far. See Fig 1 above. The short story about the Symposium is, the NIAC staff were magnificent! They were so welcoming and extraordinarily helpful. They purposefully stationed the Swarming Proxima team and the Big Object #2 (the one with gold Mylar™ on the back) right at the main entrance to the big room so our display would be the first thing everyone saw. Even the showrunner and writers from "Star Trek" wanted to get their picture made in front of the Big Object.
All thirteen Phase I award winners this year presented, as well as an even dozen Phase II awardees, and one Phase III. Of these 26 presentations altogether, ours was the only straight-up interstellar work shown

at this year's Symposium. However, three of these (one Phase I, two Phase IIs) involved work that could bear on, or be useful to, a long-term interstellar exploration effort, especially early precursor missions. Of particular interest was "ScienceCraft for Outer Planet Exploration" (SCOPE II) by Dr Mahmooda Sultana of NASA's Goddard Space Flight Center (GSFC), and "The Great Observatory for Long Wavelengths" (GO-LoW) by Dr Mary Knapp of MIT's Haystack Observatory, a radiotelescope [1]. SCOPE is about sailcraft to the outer planets; GO-LoW is about huge swarms with a hundred thousand nanosats organized in a very flat pyramid. Followers of Swarming Proxima over the last four years will recognize commonalities in both, which is validating, as these works were utterly unknown to this team.

This year, the organizers did something quite different – at the Kickoff/Orientation in March, they verbally mandated that all teams had to prepare a video not to exceed 10 minutes. This wasn't even in the contract and ended up consuming a lot of effort. But it turned out to be a blessing in disguise. Because of it, we produced and uploaded the 10-minute video as instructed, but we also commissioned a 1-minute CGI animation which by now all of you have heard about. NASA very specifically asked us to make that – they have plans for it – so we invested a month of intense work and £3,000 (UK pounds) in that. We were lucky to find a CGI studio in England, Dr Mark Garlick, www.markgarlick.com/ a PhD astronomer whose day job is making beautiful art. How lucky is that? The 1-minute video was a huge hit with NIAC. As for the longer 10-minute videos, their purpose turned out to be (1) respect for others, and (2) time management, which is related to [1]. How many conferences have you been to wherein a speaker fills up every last second with their content leaving no time for Q&A, or worse, a speaker could not get to the point and as a result some poor guy at the tail end gets his time cut or dropped from the program altogether. Your correspondent has personally seen this. Well, it did not happen here. The formal remarks were entirely prerecorded; the latter 10 minutes of every team's allotment on the podium was for answering questions from the audience, and written ones online. Everything was recorded and uploaded to the cloud, in this case Vimeo (vimeo.com/showcase/10973241?video=1008860866 from 2:20:30), so the audience could concentrate on listening, thinking, and posing queries, and not worry about note-taking, forgetting or losing material. It takes a lot of technology to pull this off, but the result was worth it. An example to emulate.

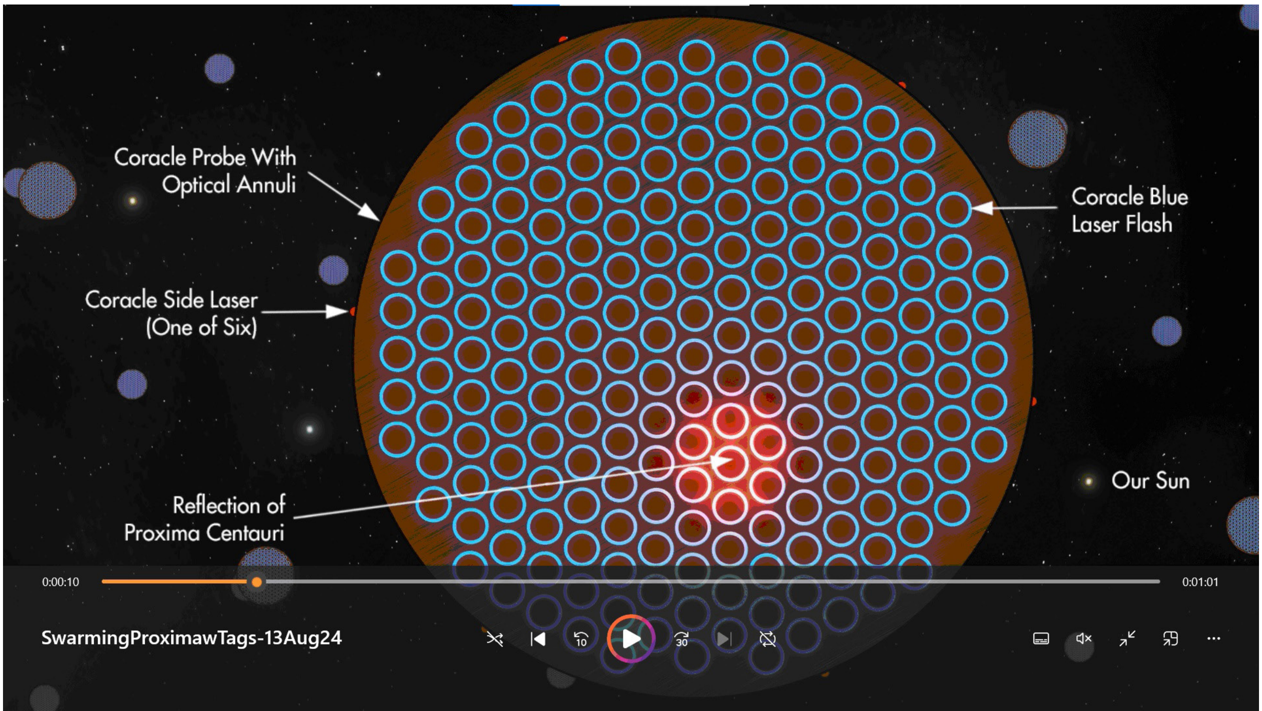



Figure 2: The light of the red dwarf Proxima Centauri, our nearest stellar neighbor, reflected in the surface of an approaching probe. The blue flashes, 432 nm, are staggered laser pulses emitted in synchrony by all thousand probes in the fleet (or however many survive the trip), demonstrating the principle of "operational coherence" like a "reverse interferometer". Due to the red-shift by the source moving away from Earth at 20% of c, the color that actually arrives on Earth is green, 539 nm. This is the one thing that really grabbed NASA's attention this time. And that's how you get a useful signal across four light-years from something that's only four grams – send loads of them, one at a time, let them catch up to each other by applying the military "time on target" technique, then coordinate their pulses with the really good clocks that every single one carries onboard.

[1] No disrespect by your correspondent, but it seems contrived abbreviations have become de rigueur in space science. He therefore beseeches the readers to start ginning up clever acronyms for Swarming Proxima.

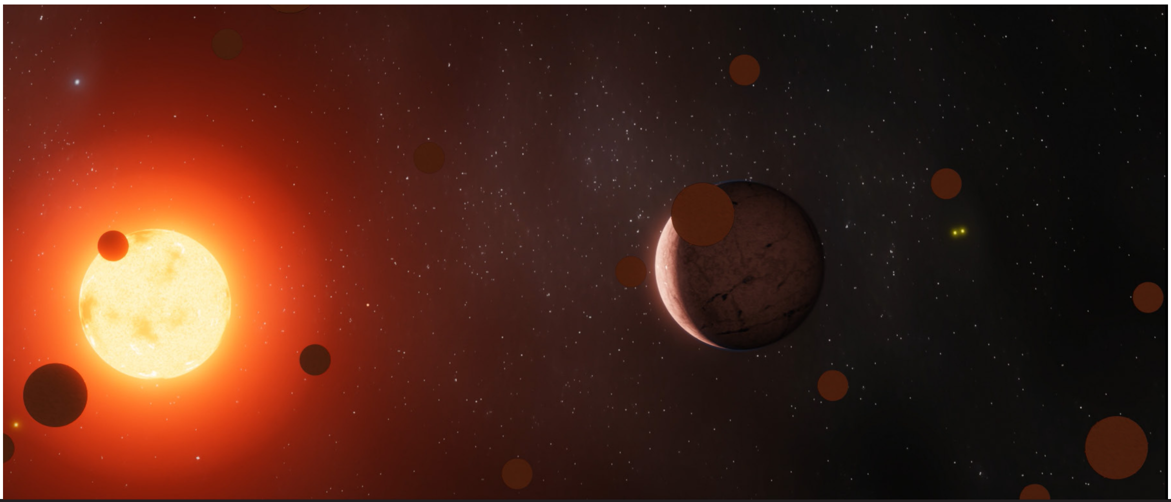


Figure 3: Approaching Proxima's planet "b" from its night side, at 20% of the speed of light. Our Earth is exactly behind the viewer, four light-years behind. On the far left is Proxima Centauri, the closest star to Earth hence its name, which is a red dwarf 1/10th the mass of our Sun, and only 1/1000th as bright. Borderline miraculous that our nearest neighbor is the one to possess a world with the best chance of habitability (that we know about). To the right of planet "b", the reader can see a bright yellow pair – these are the "A" and "B" stars of Alpha Centauri, which is actually a binary. Together with Proxima, they form the triple star system visible in our Southern Hemisphere [1]. When planet b's atmosphere (if it has one, that is not known yet) eclipses those twins suns, the probes can do "transmission spectroscopy" which is not possible to do from Earth in any other way. Imagine the exquisite timing it will take to pull this off. But (1) we have *lots* of probes so lots of bites at the apple, and (2) building really good really small clocks is something the human race is really good at.

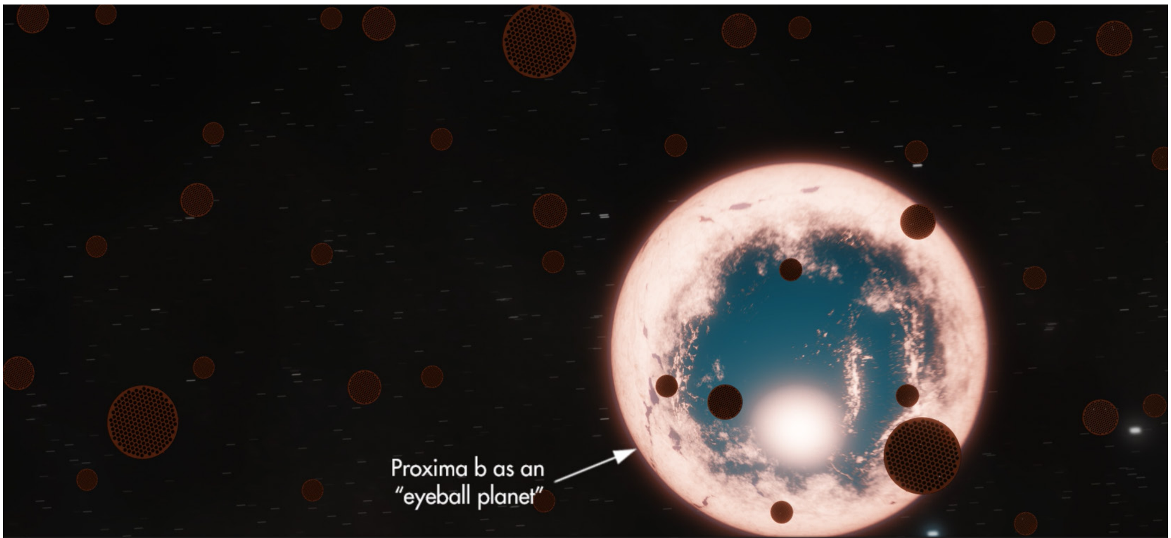



Figure 4: Looking backwards at Proxima b after the flyby at 20% of c. Note the "eyeball world" appearance. That's because the Proximan system is so small, less than one-tenth the extent of ours, that planet b is probably tidally locked, like our Moon always presents the same face to Earth. This would give planet b a hot pole with its sun always overhead and a cold pole in perpetual night. If life-as-we-know-it exists, it would be in the twilight zone girdling the planet along the terminator between the light and the dark. Planet b's equilibrium temperature is rather cool, making it an ice world (if there's water) but if there's an atmosphere then the greenhouse gas effect might make it habitable with liquid water. So that is its sun Proxima Centauri reflected in its day-side ocean. But that's all speculation of course, which is why we should send something to find out.

Every couple of hours would be a short break, during which the Planetary Society would conduct interviews for their Planetary Radio podcast. Ours is here: www.youtube.com/watch?v=4w90runKsKg . Start @ t=13m and go to t = 29m.

[1] Loyal readers may remember the "Alpha Centauri Sunrise" drinks your correspondent ginned up a decade ago: www.centauri-dreams.org/2013/02/15/alpha-centauri-sunrise/

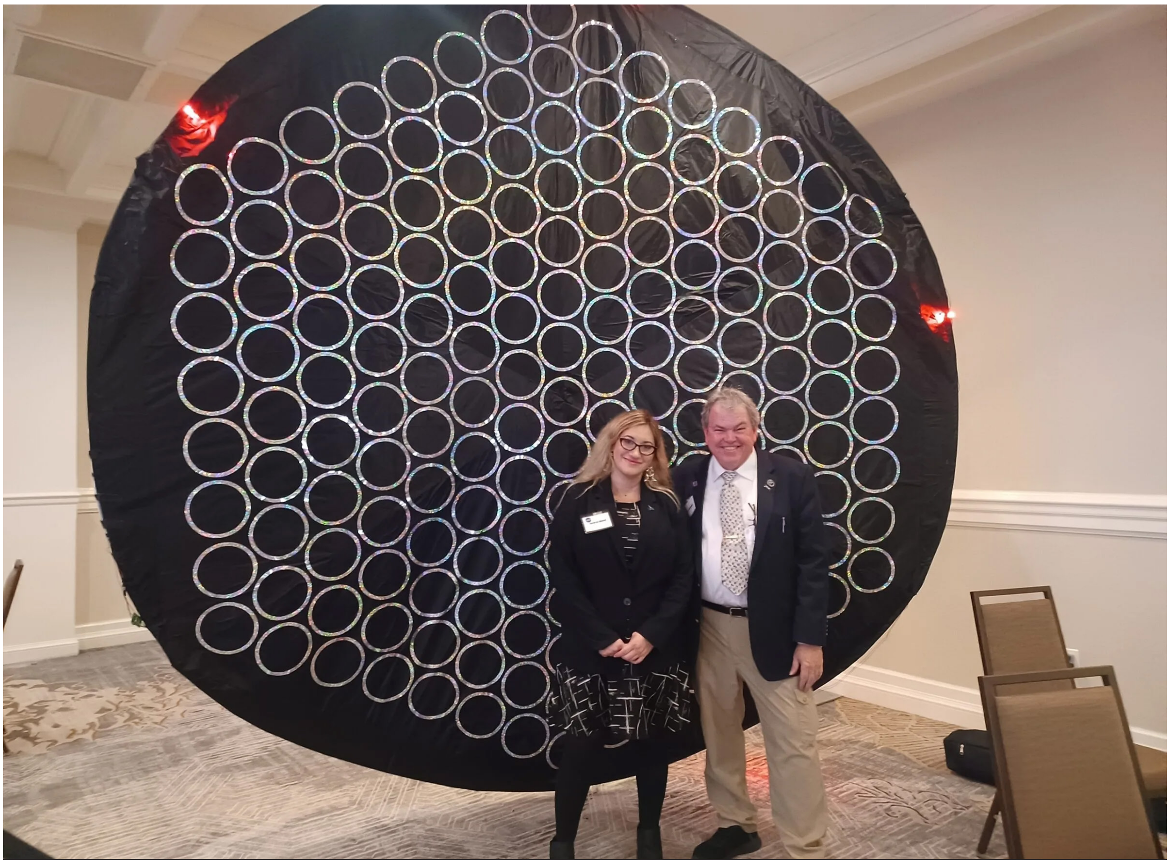


Figure 5: Sarah Al-Ahmed of Planetary Radio and Robert Kennedy of i4is-US, at the NIAC Symposium in Pasadena, 10 Sep 2024.
Source: www.planetary.org/space-images/swarming-proxima-centauri-example-sail-at-the-2024-niac-symposium

This correspondent must observe that Ms Al-Ahmed is extraordinarily well-informed; her interview was both full of subtle questions and exhilarating. It's always a pleasure to encounter someone who has read and actually understood one's work.

Late afternoons Tuesday and Wednesday were dedicated to poster sessions in an offline gallery. The presenters were very well-prepared, and the conversations were intense.

It helps to know that NIAC's almost official motto is "turning science fiction into science" – this phrase was dropped on the dais at least half a dozen times during the Symposium. So, Wednesday started with a twist. NASA and the National Academy of Sciences, Engineering and Medicine (NASEM) brought in a panel of Hollywood types. Not celebrities, but upper-level working folk: writers, directors, producers, and "showrunners" (a relatively recent term for someone who does "all of the above" and is "where the buck stops".) Hence why the Big Object #2 [1] got swarmed by Hollywood.

[1] Big Object conceived, designed, fabricated and built by Robert Kennedy PE, Institute for Interstellar Studies-US, Inc, Oak Ridge, Tennessee USA. Kudos to the talented wedding dressmaker, Ms Denise Johnson, also of Oak Ridge
LED wire harness design and fabricated by W Paul Blase, Space Initiatives Inc, wpb@space-initiatives.com
Flat holographic Mylar™ rings provided by Dan Sparkes, SparkGraphik, dan@sparkgraphik.com
Big Object disk sewn by Denise Johnson, Sew New Alterations, Oak Ridge, Tennessee, sewnewalterations1@yahoo.com

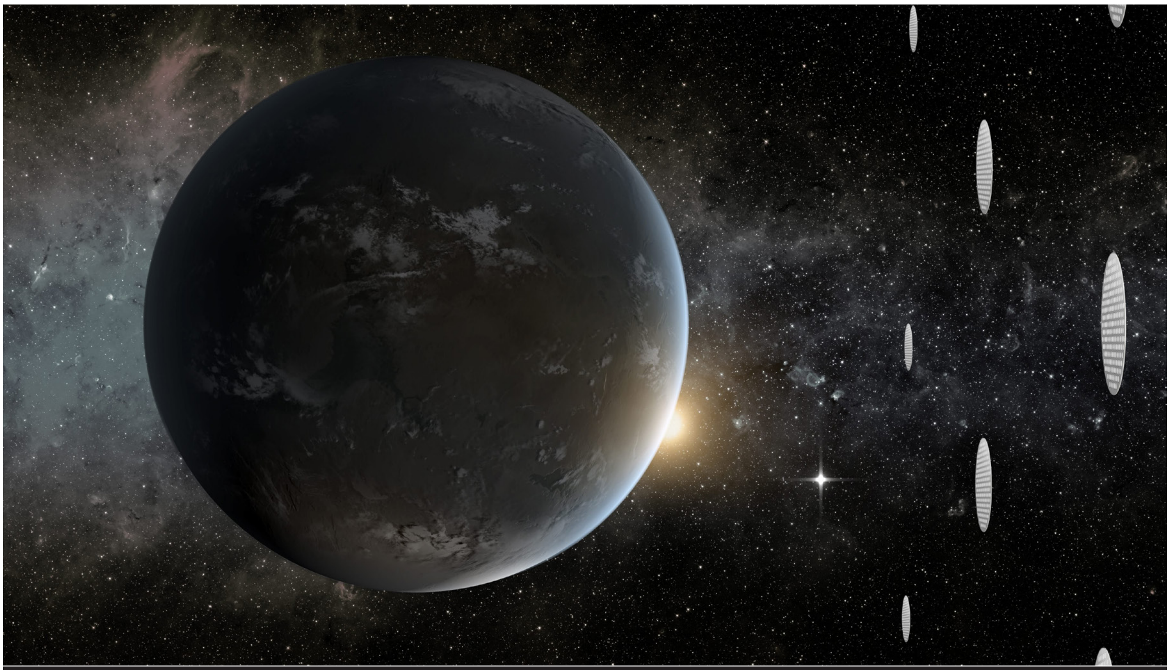


Figure 6: Probes edge-on to minimize damage during cruise prepare to snap images during fast flyby of Proxima b. Image credit: W Paul Blase

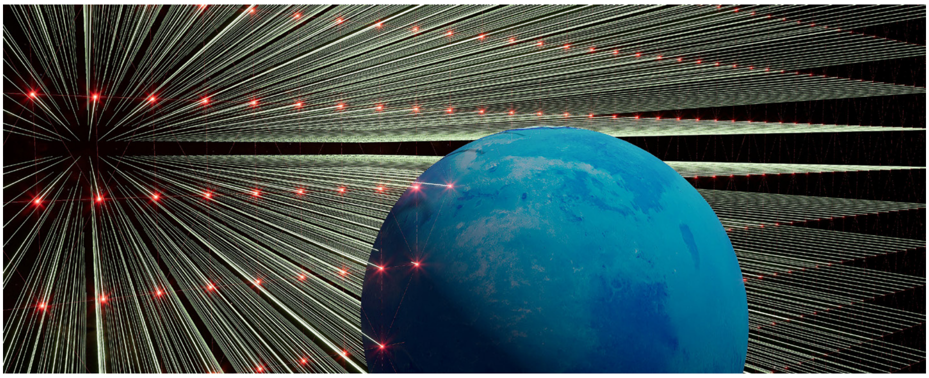


Figure 7 (above and right): The fleet encompasses Proxima b. Probe-to-probe spacing is approximately correct. Red flashes in right hand pane are near-relativistic probes interacting with Proxima b's atmosphere, yielding 1-2 kilotons each. Some may find these images unsettling.
Credits: Michel LaMontagne P Eng, I4IS

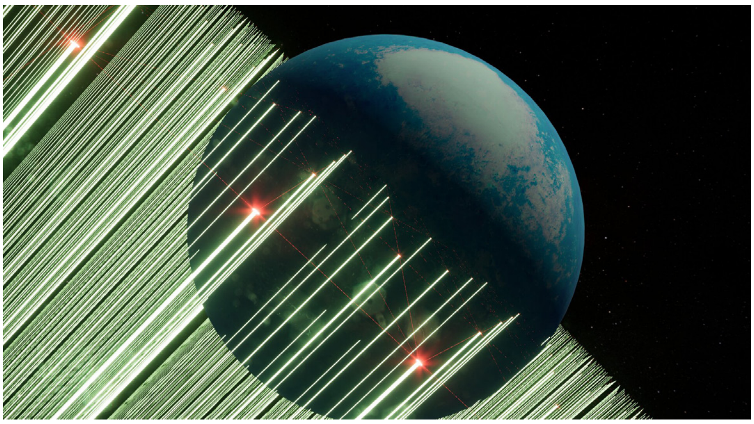


Figure 8: Yet another innovation (which makes seven) from the Swarming Proxima b team [1]. While time-delayed-integration (TDI) has been applied to mitigate image smear, such as on the Juno spacecraft's "Junocam", with near-relativistic probes a never-before-seen technique will become necessary: velocity-shifted integration (VDI).
(left) Normal unshifted view of Earth, $\beta$=0.0;
(center) blue-shifted Earth as it would appear to a human eye during approach at 0.2c, $\beta$=+0.2;
(right) red-shifted Earth as it would appear to us during departure at 0.2c, $\beta$=-0.2. Note the shift in which hemisphere is observed as point of view changes during flyby.
Image and animation credit: Adam Hibberd, i4is.

If the reader is ever buttonholed to give an elevator speech about Swarming Proxima b, here's a simple list of five questions and answers to be ready:

***Where do we want to go?***

We want to go to Proxima b, a planet orbiting our closest stellar neighbor, Proxima Centauri, which is part of the Alpha Centauri triple-star system.

***Why do we want to go there?***

Planet b is in Proxima's habitable zone and is by far the closest such world to us in the entire universe.

***How do we want to go there?***

The only currently feasible way to get there within a human lifetime is to push a miniscule mass (a few grams) with beamed power to a significant fraction of the speed of light.

***What major hurdle do we want to solve?***

Getting a useful signal back from such tiny things across the gulf of four light-years is a very tall order - but not impossible!

***How do we want to solve it?***

With such tiny probes, we can send a huge swarm, which eliminates single-point mission failure, and autonomously coalesce them into an operationally coherent mesh network during the long decades of flight.
After the flyby, the swarm would coordinate its many individual laser blinks into a single extremely bright albeit short (nanoseconds) wall of light that surpasses background noise enough to be visible on Earth.

[1] The first six innovations are:
1. Swarming with thousands to eliminate single-point failure & provide basis operational coherence.
2. Modulating launch laser to initially forming swarm with "time-on-target".
3. Exploiting drag from interstellar medium (ISM) to maintain swarm once formed, or "velocity-on-target.
4. Intra-swarm communication for position-navigation-timing (PNT) to nanosecond level via optical means.
5. State-of-the-art (with frequency stability goal of $10^{-19}$ at Earth & $10^{-13}$ at Proxima) optical clock metrology combined with time- and frequency-bandpass filtering to improve data collection and signal-to-noise ratio (SNR).
6. Repurposing the drive laser at flyby as an interstellar flashlight.

**What do we hope to accomplish?**

Collect good enough data and imagery of Proxima b to determine if:

- it has conditions to support life-as-we-know-it, or
- harbors life itself, or
- even some kind of civilization, or
- perhaps hosts life-as-we-don't-know-it.

The Swarming Proxima team presented on the morning of the last day. The presentation and associated Q&A may be found here at vimeo.com/showcase/10973241?video=1008860866 ; move the slider to t=2 hr 21 min 30 sec. It begins with the 1-minute CGI animation, with labels, which is only a minute long. Try not to laugh about 2½ minutes into the talk (slider =2 hr 24 min 17sec). At t=2 hr 35 min 00 sec, there's a question from the audience and a very funny response by Paul Blase. Swarming Proxima finishes @ t=2 hr 43 min 28 sec.

**Conclusions**

- We are just at the dawn of an exciting new in age space exploration. There is lots to do before our first interstellar mission.
- A swarm of Coracles would provide a strong initial survey of Proxima b and should be able to detect an exobiology and even exotechnology signatures on Proxima b, should these present.
- This will provide science that cannot performed from Earth.
- The ephemeris error for the Proxima missions will require work:
  - o Direct observation of Proxima b in optical or radio bands, to determine its orbital inclination, together with regular radial velocity measurements.
  - o The Proxima parallax needs to improved by 2 orders of magnitude.
- The first flyby with Coracles should improve Proxima b's ephemeris by at least 5 orders of magnitude!

# The Initiative & Institute for Interstellar Studies

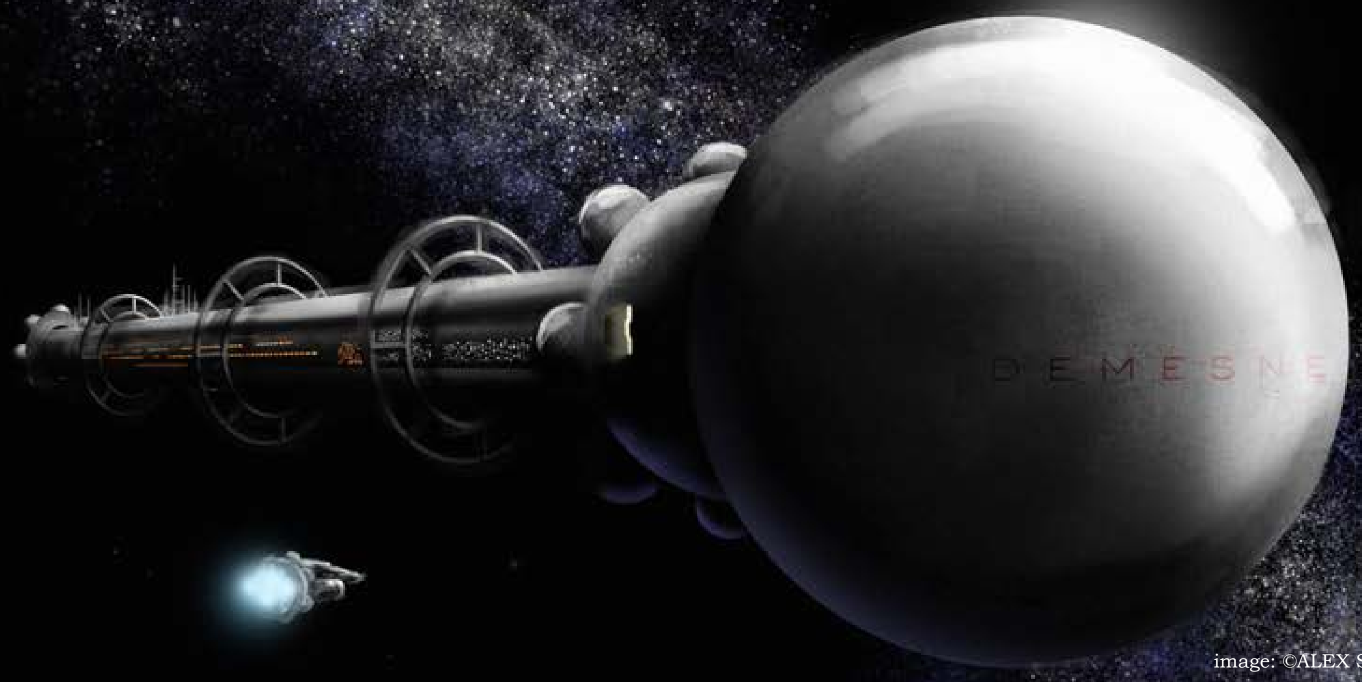



image: ©ALEX STORER

## JOIN US

### Working towards the real Final Frontier

Help us to realise our mission to reach the stars - we need your help - physics to software engineering, graphic design to project management - and rocket engineering of course! ...and much more....
Some of us have PhDs, some masters and first degrees and others simply have talents! What we all share is enthusiasm for the interstellar future of humanity.
We have about 20 active team members, led by -

- Dr Andreas Hein: Executive Director/Technical Director - andreas.hein@i4is.org
- Robert G Kennedy III: President i4is USA - robert.kennedy@i4is.org
- Rob Swinney: Education Director - rob.swinney@i4is.org
- John I Davies: Editor Principium - john.davies@i4is.org
- Tam O'Neill: Manager Membership/Website team - tam.oneill@i4is.org

**Join the team if you can help - become a member if you simply want to support our work.**

**Contact:** info@i4is.org

**Principium:** tinyurl.com/principium

**Web:** i4is.org

@I4Interstellar

## John I Davies reports on recent developments in interstellar studies

### Is There Life on an Alien Planet?

Universe Today *Is There Life on an Alien Planet? Fresh Findings Revive the Debate*, Alan Boyle April 17, 2025 (www.universetoday.com/articles/fresh-findings-fuel-debate-about-life-on-alien-world) and others report.
Boyle cites two papers – *Deciphering Sub-Neptune Atmospheres: New Insights from Geochemical Models of TOI-270 d*, Christopher R Glein, Xinting Yu and Cindy N Luu (all Southwest Research Institute) at arxiv.org/abs/2504.09752 and *New Constraints on DMS and DMDS in the Atmosphere of K2-18 b from JWST MIRI*, Nikku Madhusudhan (University of Cambridge) et al in The Astrophysical Journal Letters, Volume 983, Number 2 (iopscience.iop.org/article/10.3847/2041-8213/adc1c8). Both based on recent data from the James Webb Space Telescope with signs of dimethyl sulfide (DMS) and dimethyl disulfide (DMDS). Boyle advises caution with suggestions of uniquely biological origin for the chemicals.
Glein and his colleagues suggest that TOI-270 d is a superb model for the temperate sub-Neptune population, prime candidates for biological activity, and therefore merits substantial further examination. Also further modelling, characterisation of its stellar environment and comparisons to other planets. A planned NASA mission to Uranus, a similar world, would yield much more detailed data for comparison [1]
Madhusudhan et al comment "Overall, our findings continue to raise the prospect of possible biological activity on K2-18 b and motivate new experimental and theoretical work for detailed characterization of its atmospheric properties".
They point out "the acute need for laboratory and theoretical work to derive high-fidelity absorption cross sections for these and other biosignature molecules, to enable their robust detection and abundance estimates in habitable exoplanets" and detail a number of possible sources of false postives.
Overall, this and its analysis does not yet represent inconvertible evidence of biological activity but I believe it gives grounds for increasing optimism about the search for our biological cousins elsewhere in the universe.

### Project Hyperion Design Competition: Status Update

The Project Hyperion design competition has successfully concluded its Phase 1, marking an important milestone in the initiative. Submissions from participants are now under evaluation by a distinguished jury comprising architects, social scientists, and engineers, ensuring a well-rounded assessment of the designs. The most compelling and innovative proposals will advance to Phase 2, where further refinement and development will take place. This next phase is set to conclude in May, after which the final winners will be selected. The competition continues to generate excitement as participants push the boundaries of design and technology in pursuit of groundbreaking solutions for an interstellar generation ship habitat.
Meanwhile, the competition continues to garner interest from the media and general public. For example, German outlets such as Die Zeit, BILD and MSN have reported on the competition in 2025. This has been preceded by a massive number of articles back in November 2024, which introduced the competition to the world.

### IRG Alert DataBase Search

Using the alert database access kindly provided by our friends at the Interstellar Research Group (irg.space/) we created an enhanced search facility which searches all database fields as you type (IRG Alert DB Search i4is.org/irg-db).
For example try "starshot" in the search box.

[1] *The first dedicated ice giants mission* www.researchgate.net/profile/Kathleen-Mandt/publication/368574642_The_first_dedicated_ice_giants_mission/links/64142a37a1b72772e4047c48/The-first-dedicated-ice-giants-mission.pdf

## Pulsar Fusion announces fusion power

Spaceflight, the monthly magazine of the British Interplanetary Society reported "British nuclear propulsion firm Pulsar Fusion unveiled its interplanetary transfer vehicle propelled by fusion power. " SpaceFlight Vol 67 May 2025.
Pulsar released pulsarfusion.com/products-development/sunbird-fusion-propulsion/.
If this succeeds it will be in the vanguard of feasible large probes to the stars.
More reporting at space-comm.co.uk/pulsar-fusions-sunbird-unveiled-nuclear-powered-rocket-to-slash-interplanetary-travel-times/


Visualisation of the Pulsar Fusion *Sunbird* vehicle.
Credit: Pulsar Fusion

## Joseph Meany elected President, Interstellar Research Group

Joseph Meany has taken over from Doug Loss as IRG president. Here is a precis of his announcement -

I have been elected as President of the Board of Directors for the Interstellar Research Group. To me, being elected to this position is a great privilege, and one that I am ecstatic to announce. I joined the organization in 2014 when I was a graduate student at The University of Alabama at the time. From the first meeting, I kept finding ways to listen, learn, and provide feedback, later being on the board of directors. I have gone on to earn my PhD in Chemistry and now I advise the advanced research agencies across the US government.

In the short term, I want to focus on improving the interactive experience of you, our supporters, with the organization. We have recently brought on new volunteers to re-shape the membership and communication experience. We want to make sure that we can achieve the quality that you expect from a professional organization and we are taking on new volunteers to ensure that. Furthermore, we are interested in exploring the opportunities presented to us for further symposia in Europe and elsewhere.

We want to continue being a hub for topical research for interstellar progress, and we want to continue hosting our mainline Interstellar Symposia series in the United States. In 2023 and 2024, the Interstellar Research Group saw back-to-back international symposia! The first was held in conjunction with McGill University and led by a long-time friend of IRG, Professor Andrew Higgins. The second was our first cooperative event in Europe. In collaboration with Institute for Interstellar Studies (i4is), IRG sponsored the First European Interstellar Symposium (FEIS) with the generous support of University of Luxembourg and Dr Christophe Duplay.

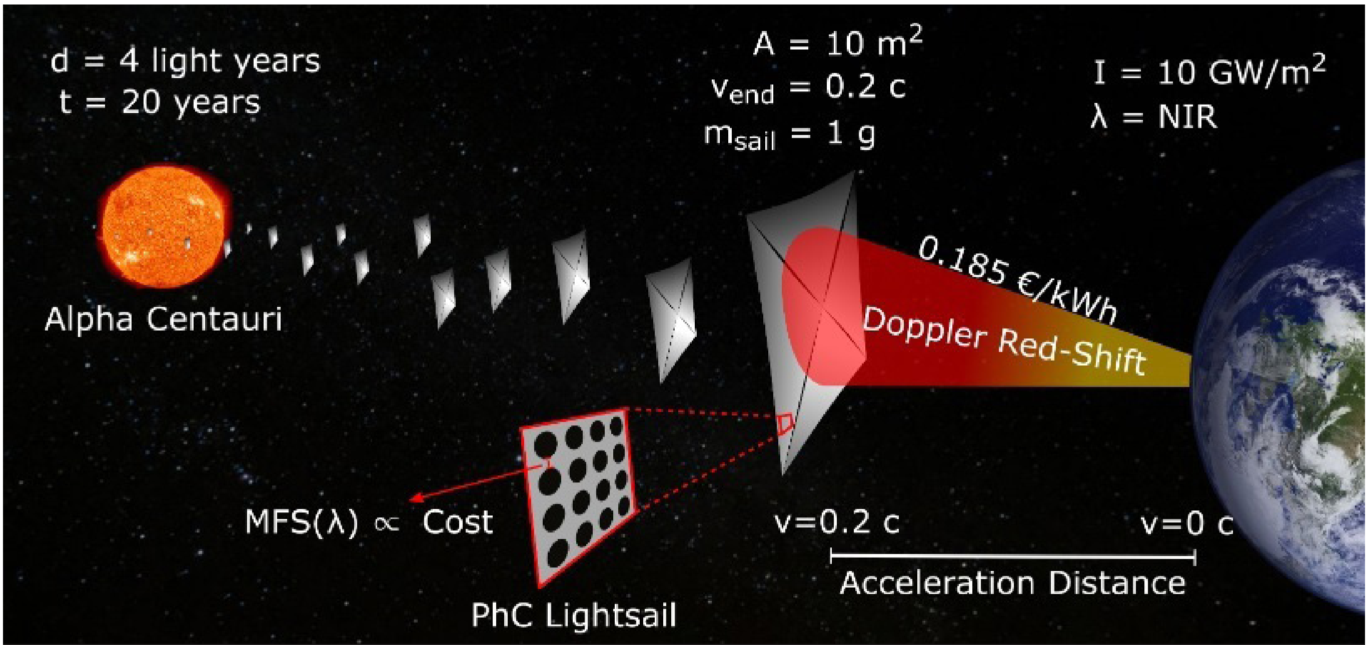
I would like to thank the previous TVIW/IRG Presidents, John Preston, Sandy Montgomery, and Doug Loss for their leadership. There's enough room for everyone in space. Let's build that Ladder to the Stars, together.

See you in Austin, October 12 – 15, 2025!

The announcement will, no doubt, soon appear on the IRG website, irg.space.

## Scalable nanotechnology-based lightsails

Researchers at TU Delft and Brown University have developed scalable nanotechnology-based lightsails (www.eurekalert.org/news-releases/1077908). Their study uses neural topology optimization, revealing a novel pentagonal lattice-based photonic crystal (PhC) reflector. The optimized designs significantly lower the acceleration times and, thereby, launch cost. The team fabricated a 60 × 60 mm$^2$, 200 nm thick reflector with over a billion nanoscale features, achieving a 9000-fold cost reduction per m$^2$. They believe this represents the highest aspect ratio nanophotonic element to date. Their designs significantly lower the acceleration times and, thereby, launch cost of the gram-scale microchip probes to Alpha Centauri envisaged by Breakthrough Starshot. Their research is published in Norder et al, Nature Communications, 2025, and in an arXiv preprint (arxiv.org/abs/2407.07896).




High power earth-based laser propelling a fleet of lightweight sails to 20% of the speed of light, to reach Alpha Centauri in 20 years ( Breakthrough Starshot breakthroughinitiatives.org/initiative/3). The lightsail needs to be reflective over a broad bandwidth due to the Doppler red-shift of the laser resulting from the change in velocity of the sail. The minimum feature size of a photonic crystal based lightsail is related to the fabrication cost. A commonly used performance metric for a lightsail is the acceleration distance. The launch cost is mainly determined by the energy consumption of the laser (Eurostat, "Electricity prices for non-household consumers," ec.europa.eu/eurostat/databrowser/view/nrg_pc_205/default/table?lang=en).
Credit: Norder et al, Fig 1

## Photonic lightsails – a review

In *Photonic lightsails: Fast and Stable Propulsion for Interstellar Travel* (arxiv.org/abs/2502.17828) Jadon Y Lin (University of Sydney) et al suggest that lightsails offer tantalizing opportunities to probe nearby stellar systems within a human lifetime. Advances in photonics and metamaterials have created novel solutions to challenges in propulsion and stability. Their review introduces the physical principles underpinning lightsail spacecraft and discusses how photonics coupled with inverse design substantially enhance lightsail performance compared to plain reflectors.

The review covers mission parameters, radiation pressure physics, materials, propulsion designs, thermal management, stability designs and experiments. They conclude that substantial further progress is needed in areas including availability of candidate materials and nanofabrication methods for the sail. However, they believe that advances in other requisite fields will naturally occur. These include progress in metalenses driven by mobile sensors and high-power laser miniaturization in industrial and defence industries. If lightsails become recognized as offering progress towards interstellar missions then then advancements in them will symbiotically create breakthroughs in numerous fields.

## Radio Telescope on the Moon

A paper by Joshua J Hibbard (University of Colorado Boulde ) et al *Results from NASA's First Radio Telescope on the Moon: Terrestrial Technosignatures and the Low-Frequency Galactic Background Observed by ROLSES-1 Onboard the Odysseus Lander* (arxiv.org/abs/2503.09842) presents technology analysis of this pioneering instrument.

The photo-Electron Sheath instrument (ROLSES-1) onboard the Intuitive Machines' Odysseus lunar lander represents NASA's first radio telescope on the Moon. It consisted of four 2.5 monopole antennas designed to study the low-frequency radio sky and the local lunar plasma wave environment between 5 kHz and 30 MHz. It landed on the South pole of the Moon near crater Malapert A. Sadly the craft toppled 30 degrees which limited both power and experiments.

Lunar radio astronomy will become especially valuable from the back of the Moon, perhaps the most radio-quiet place in the Solar System, though is threatened by some ideas for lunar communication networks.

## i4is at the Royal Institution of Great Britain

We again delivered our *Skateboards to Starships* day at the Royal Institution (www.rigb.org/) in London, 17 April 2025. The team this time was Rob Swinney, John Davies and, from KCL Space, Arya Gonullu.

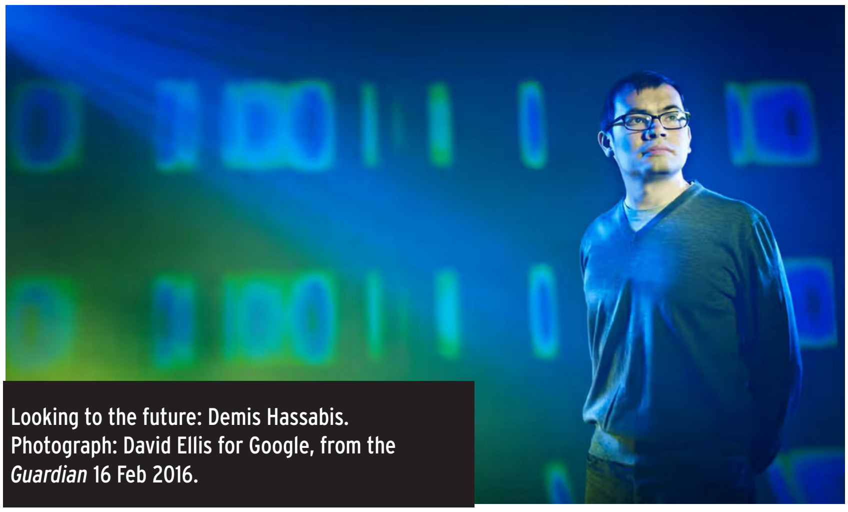

John, Rob and Arya at the Royal Institution

We'll be back at the RI in August and we'll have a full report of both events in Issue 51 (November).

## Beyond The Human

In the paper - Beyond The Human: Technological Advancements and Posthumanism in Cixin Liu's *The Three-Body Problem* (al-aasar.com/index.php/Journal/article/view/242/185) Waqas Yousaf and Abuzar Naqvi (Minhaj University, Lahore, Pakistan) examine the philosophical and ethical consequences of posthumanism as represented in Cixin Liu's novel.

Posthumanism (en.wikipedia.org/wiki/Posthumanism) has a history going back to Nietzsche and beyond but has acquired a new relevance given the claimed progress towards Artificial General Intellgence (AGI) most recently by the creators of Large Language Models and by AGI advocates such as Demis Hassabis of Google DeepMind. Will an interstellar future be posthuman in some sense? See also *Define Artificial General Intelligence! Levels of AGI: Operationalizing Progress on the Path to AGI* in Principium 44, February 2024.



Looking to the future: Demis Hassabis.
Photograph: David Ellis for Google, from the *Guardian* 16 Feb 2016.

# Breakthrough Discuss 2025

## April 23 – 24 2025, Oxford Town Hall

**David Gahan**

The Breakthrough Initiatives are a suite of space science programmes funded by the foundation established by Julia and Yuri Milner. The Initiatives investigate the fundamental questions of life in the Universe: Are we alone? Are there habitable worlds in our galactic neighbourhood? Can we make the great leap to the stars? And can we think and act together – as one world in the cosmos?" - breakthroughinitiatives.org/

The component programmes are

Listen

Watch

Starshot

Message

Discuss

The first Breakthrough Discuss conference was in 2015. Starting in 2024 when Breakthrough Listen relocated to Oxford, UK, the Discuss conferences have concentrated on that programme. i4is people at this year's conference were Andreas Hein (Executive Director) and Adam Hibberd (Lead Astrodynamicist). Gurbir Singh and David Gahan also attended. Gurbir is an old friend of i4is and David is a regular and highly original contributor to Principium. Here he reports his impressions from his first attendance at a Breakthrough Discuss conference. Gurbir Singh will discuss some specific issues from the conference in our next issue, Principium 50.

Breakthrough Discuss is an annual academic conference which is now focused on life in the Universe and related topics, funded by the Breakthrough Foundation (Yuri Milner et al) with the support of the Templeton Foundation and co-hosted by the University of Oxford Department of Physics and the University of Manchester Department of Physics and Astronomy.
This was the 9th such conference and the theme was very much LIFE focused, under the banner 'Life As We Don't Yet Know It.' There were three sessions over 1.5 days on:

1. FORMS OF NON-TERRESTRIAL LIFE
2. THE NATURE OF CONSCIOUSNESS AND INTELLIGENCE
3. DETECTING LIFE AS WE DO NOT KNOW IT

We'll come back to the second topic at the end as it was about Life but had only peripheral 'space' connections. Stay tuned!

## Timetable and Speakers

The timetable and speakers for the event can be found at -

**Schedule**

web.cvent.com/event/fa7350bd-1b0f-45f0-a508-28b529ca5f5b/websitePage:5b3fce3a-ec7f-4129-bbdf-f81b1456b062

**Speakers**

web.cvent.com/event/fa7350bd-1b0f-45f0-a508-28b529ca5f5b/websitePage:19d8762c-6446-4029-ad26-6c310ec694d8

**Some themes and 'quotable quotes'**

"If life is not DNA based, I'll be surprised" – Craig Venter, participating remotely

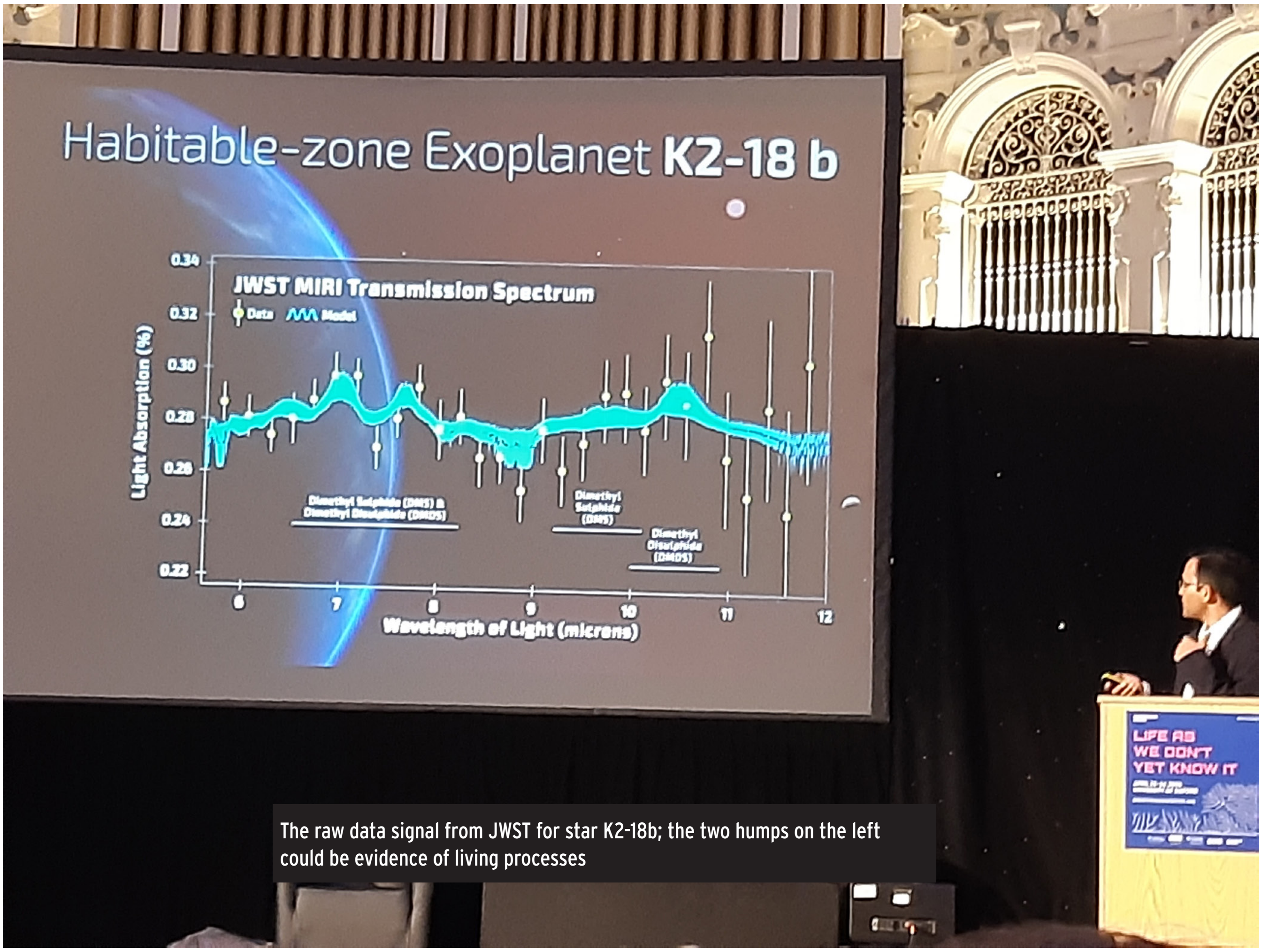

Panel discussion on detecting life as we do not know it – Craig Venter joining by video from California

"Even if we are not Alone, will we still be Lonely?" – panel discussion on detecting life

"A lot of life's interest is in the bits that don't fit." Dame Jocelyn Bell Burnell, referring to her discovery of pulsars in the 30 m of chart paper she had to examine every day and giving the keynote intro to the second day.


"A lot of life's interest is in the bits that don't fit" – Dame Jocelyn Bell Burnell.

This comment from Dame Jocelyn could have been made for the highlight of (and end of) the conference, even delaying lunch: a live punch-up debate on the 'strongest hint' so far of an exoplanet biosignature and cries of 'Whoa!' from the more cautious. Biosignatures or noise? New analysis of K2-18b data casts doubt:NPR (www.npr.org/2025/04/25/g-s1-62610/biosignatures-k2-18b-james-webb-exoplanet-doubt).



The raw data signal from JWST for star K2-18b; the two humps on the left could be evidence of living processes

Astrophysicist Nikku Madhusudhan, hot-foot from Cambridge, made an invited post-deadline presentation of his team's work analysing James Webb mid infra-red data to an audience well primed on the difficulties of such work by the previous speakers; something of a 'lion's den'. In fact he did a pretty robust job, also pointing out that they hadn't expected to find much in the MIRI (mid infra-red) JWST data to add to the easier 'visible' spectrum data – it did seem to chime with DJBB's invitation to go the extra mile on the data. Indeed there were lumps on the spectral data corresponding to known absorption lines from dimethyl sulphide (DMS) and dimethyl disulphide (DMDS) which would be biosignatures here on Earth. That's when things get complicated. Other speakers had warned us of three tests to apply to such indications:
1) is the data any good?
2) does it really indicate the gas you think it does?
3) does a 'biomarker' really imply life?
The signals really are tiny perturbations on the background star (which itself may not be uniform in colour due to sunspot activity). Only during transits (once every 33 days in this case) will light, travelling through the wafer-thin atmosphere (big, fat gas giants are easier here) - which represents a few parts per million of the received starlight - carry the information you're looking for. The 'rest of the atmosphere', its temperature and pressure and composition, all pull and push the signature you're looking for and all that has to be modelled. As an example, the planet K2 18b has an assumed mass of 8.6 Earth masses orbiting in the habitable zone of a red dwarf star. It's in the 'big gap' between Earth and Neptune where we have no analogue in the solar system and can't observe, so we have to guess. For this mass and position, Nikku presented three potential scenarios:
- 'Mini-Neptune', like ours with a thickening H2-water rich atmosphere
- 'Hycean' water world with pretty much a planetary ocean
- Magma ocean underneath supercritical H2O rich atmosphere
All of these have to be considered and you even have to guess the albedo; Nikku 'assumed' 0.5 – this sort of thing can lead to circular reasoning so care is needed. When he'd crunched the numbers, these

supported identification of the peaks as DMS/DMDS (with a 3-sigma confidence) at around the 10 ppm level. This is 10,000 times higher than in Earth's atmosphere so would indicate a lot of biological activity. Prof Chris Lintott (presenter of 'Sky at Night') asked the first audience question on whether abiotic processes had been considered (one of the 'three tests'), mentioning work of a 'Colorado' team. Nikku countered that abiotic would need the presence of large amounts of H2S which hadn't yet been identified. The main critique (just standard scientific caution) came from Dr Jake Taylor of Oxford who was invited onto the platform (see photo) to present arguments against and to debate. "Data-reduction is super-hard" he said, but praised Nikku for trying two different methods of processing the data (before he even got to assumed atmospheric models (NB, your correspondent has some experience with all the confounding effects, including photochemistry, in measuring the pollution in cities - one reason why low cost electrochemical sensors aren't used routinely). Jake also pointed out that JWST's MIRI is a "most challenging instrument for transits" and even the identification of methane on K2-18b had proved challenging.


'A very civilised punch up' – Nikku Madhusudhan (left) defending his hypothesis against Jake Taylor (right) who led the arguments for caution.

But in the end it was good science. With the 33-day frequency of the transits, a lot more data – and argument – can be expected. This happened for the 'discovery' of biomarker phosphine on Venus. Early indications were at the 15-sigma level but that's down to 2-sigma after 'systematic' instrument induced features were removed. But luckily we're going back to Venus in 2026 and will have a proper sniff.
In the end arguments will continue to be unresolvable for biosignatures 'observed' in transits.
Dr Sarah Ballard, U Florida, had given the earlier description of the difficulties of the method – you'd only have 4 photons carrying atmospheric information for every 10 million for an earth-sized planet transiting the sun. It's best used for 'big planet, small star' (this drove the specification of JWST) to give any decent signal to noise but that pushes towards M-class stars which are notorious for solar flares vastly more powerful than our quiet Sun: bad news for life, especially up close to the star. But powerful UV flares might induce some pretty nifty photochemistry so expect interesting molecules.
Her colleague Dr Sarah Rugheimer (U Edinburgh) concurred and stressed that the most convincing biosignatures for her would be the presence of mutually annihilating oxidising/reducing gases ie O2/O3 plus methane. Why O2? Oxygenic photosynthesis has been the biggest driver for biomass synthesis on Earth, and its precursors CO2, H2O and photons are abundant. But O2 without methane could be a false signal; M-star flares can dissociate H2O with hydrogen being lost to space.

A step change will only come when the next generation of space telescopes become available which permit direct observation of the whole planet in reflected light, needing 'removal' of the direct starlight by interference (but even then, detection of oceans will be difficult). LIFE – Large Interferometer For Exoplanets - Wikipedia (en.wikipedia.org/wiki/Large_Interferometer_For_Exoplanets) is now under active study but no date is yet projected.
For a low cost exoplanet hunter, see report on the Toliman Space Telescope in Principium 50.

## On Stranger Tides

Day 1 had an interesting session on 'Forms of Non Terrestrial Life'. The two first papers were the most thought-provoking: does life need water? All the conventional wisdom around 'Goldilocks Zone' is based on liquid water as the essential for life. What are the properties you actually need and are any other solvents possible? William Baines gave a good survey.

1. Abundance in space and over time (water is the second most common molecule in the universe after H2 so has a head-start).
2. Dense, 'mobile' host/support for chemistry – all life chemistry is expected to be catalysed and the catalysts need to move around.
3. Selective solvation; but not too much or we'd all dissolve!
4. If it takes an active part in some of the reactions, eg hydrolysis/polymerisation, so much the better.

It turns out that the long list of chemicals gets whittled down very quickly. Disappointing for those who are looking forward to Dragonfly mission to Titan (see report in Principium 50), methane doesn't look like a good candidate (especially Nos 3 and 4). While there may be lots of interesting chemicals there, self-organisation may be difficult. Baines basically reduced the list to three: liquid CO2, liquid sulphur, liquid (undissociated) H2SO4 – our old friend oleum! (ie Sulphuric Acid).
All these solvents imply different temperature and pressure regimes to be sufficiently liquid (probably the viscosity of toothpaste wouldn't be helpful; life doesn't need to be 'fast' but it does need to get going).
Liquid CO2 (a good solvent used in quite a lot of industrial processes) might be perfectly possible on a 'Cold Venus'. William even identified the planets of 'Trappist 1' as a possibility, but because of the evolution of such stars – they get hotter in time – an inner planet which was fine earlier might be roasting now; but a further planet which was frozen might be 'just right now'. It was a fascinating image but not quite as nice as Earth.
Liquid sulphur, surprisingly promising chemically, also has a temperature problem. The range of reasonable viscosities is, at 40 C, wide but that stretches from 120-160 C. Life in a volcano?
The intriguing idea that droplets of liquid H2SO4 (with no H2O!) in the clouds of Venus might be feasible hosts for simple life was explored by Janusz Petkowski (U Wroclaw) who is also the deputy Principal Investigator for the 'Morning Star' mission to Venus (private/public funded). This will be the first mission to Venus since the Russian lander and will sample the clouds. At an altitude of 50-60 km they're surprisingly temperate in the 100-0 C and 1-0.1 bar range (bottom to top). The right chemistry exists for the creation of polymers based on formaldehyde (formica!) and it's long been suspected that the clouds contain a 'great absorber' organic material that sucks all the blue out of the spectrum with incredible extinction coefficient (leaving the clouds slightly yellow). A later speaker Jan Spacek likened the droplets in the clouds to a head on a pint of Guinness; the droplets reflect due to tiny size but the liquid they're made from is incredibly dark...
So, droplets of H2SO4 can contain a dark brown organic (carotene is one possibility), but can they support the molecules of life without doing to them what conc sulphuric does to a sugar cube (rip out the atoms corresponding to water and leaving a carbon foam)? The answer seems to be 'yes' for all amino acids except the dangly tryptophan. But not so good when it comes to DNA. DNA backbone is based on a sugar (ribose), so think 'sugar cube'. An arrangement of the GATC bases on a peptide (amino acid) scaffold seems to survive (peptide-DNA) but it's unknown whether life can use that. All the above has been proven in the lab but the trick is – don't let any water near it! We'll learn more if the mission is launched in 2026.
Your correspondent asked if there were any known equivalents to hydrological cycles on Venus (ie the equivalent of rain to bring nutrients and create chemical/physical potential differences) but none are known.
Betül Kaçar (U.Wisconsin) looked back into Earth's ancient biology via 'rewinding the tape' of current life molecules. While the exact structure of ancient enzymes (eg the vital nitrogen reductases) can take many forms and use different metal centres eg copper or manganese instead of iron, it seems overwhelmingly likely to her that nitrogen-carbon architectures will be 'standard'. There were other interesting papers on what we can learn from very simple animals (worms) and those with alternative neuronal architectures (octopus) and even computer-inhabiting cellular automata, but these mainly showed that life (once started or kicked-off) is pretty good at finding solutions via Darwinian evolution.

## The Ghost in the Machine

Given our preoccupation with AI right now, and the fact that Oxford/Cambridge are home to Martin Rees' (the current Astronomer Royal) Centre for the Study of Existential Risk (www.cser.ac.uk/), it seemed appropriate that a session was given over to The Nature of Consciousness and Intelligence. Some very technical papers (mathematical formalism) were supplemented by lighter fare (octopuses!), but the two diametrically opposed views were put forward by Lenore Blum (Carnegie Melon U) "AI Consciousness is Inevitable: A Computer Science Perspective" and, speaking without notes or slides, Roger Penrose (U Oxford) "Why intelligence is not a computational process" who is maintaining his hunch that intuition is much more like the collapse of the wave function and may depend on some 'quantum substrate' in the nervous system. The format didn't permit a punch-up but Lenore's formalism looked an awful lot like the collapse of superposed states as different mental processes (there about $10^7$ of them, apparently) compete for the attention of 'awareness'.  It looked a bit like Grover's algorithm for those who've looked into quantum computing. All completely classical, of course, but maybe Roger wasn't so far off the mark.


A conscious Turing Machine presents the Conscious Turing Machine... Lenore Blum

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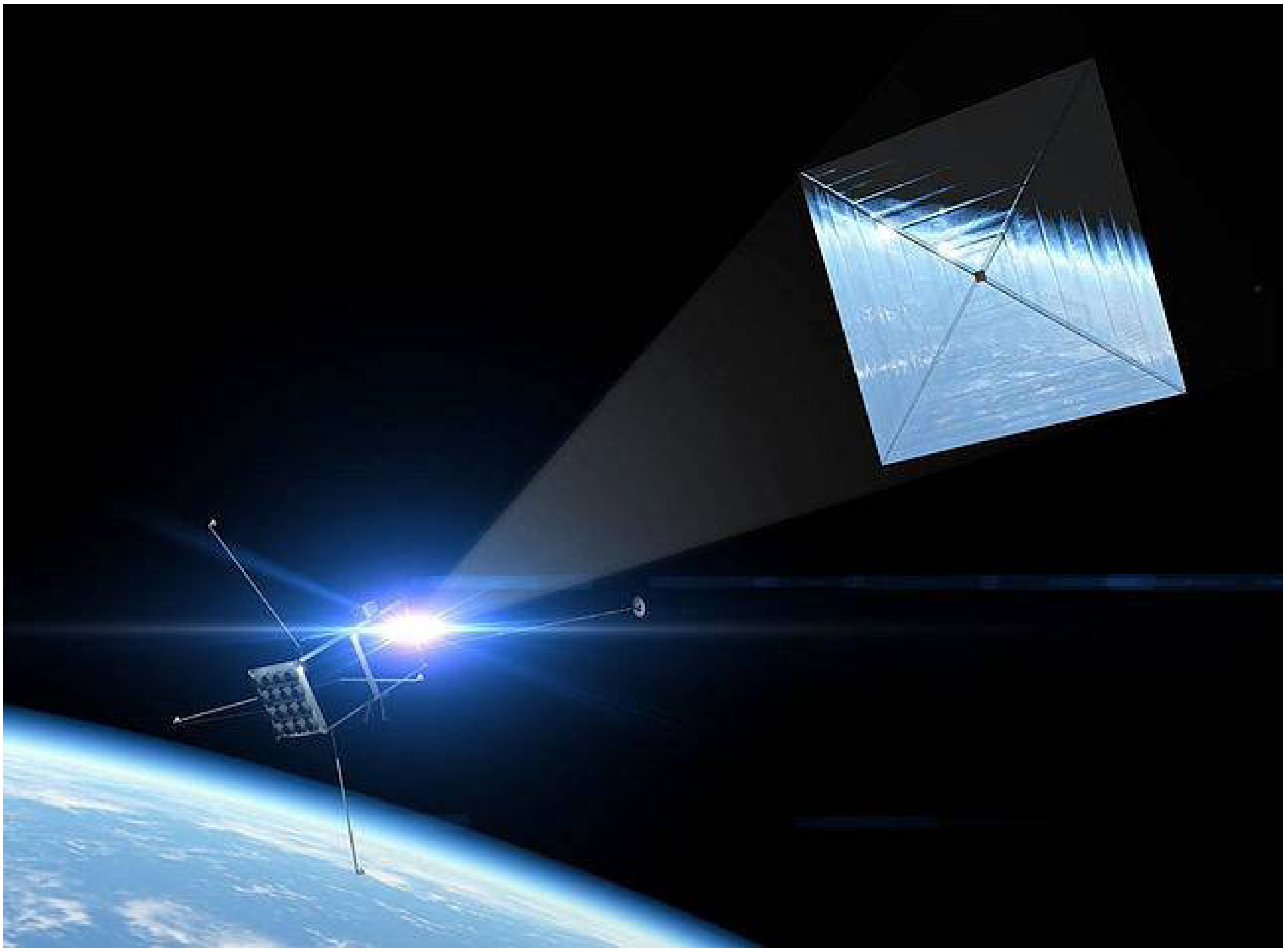

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# International Astronautical Congress IAC24

## The Interstellar Presentations Part 3

**Here are our third reports from the 2024 International Astronautical Congress held in Milan.**

Edited by John I Davies

## Introduction

i4is reports on presentations that relate to interstellar travel and communications - and to the Solar System infrastructure which must precede the extension of our species beyond it.
This is the third and final news feature following the Congress. The first was in P47, November 2024 (i4is.org/principium-47/) and the second in P48, February 2025 (i4is.org/principium-48/). All of the programme items listed here are text credited to the International Astronautical Federation (IAF) and are visible via the IAC24 Programme: iafastro.directory/iac/browse/IAC-24/.

## First Report Contents

These are the presentations and papers we reported on in issue P47 - in order of IAC24 reference -

| IAC24 reference | Title | Presenter | Reporter |
|---|---|---|---|
| A4,2,1,x81576 | KEYNOTE: Billingham Cutting-Edge Lecture - Global outreach and cultural impact of A Sign in Space, an interdisciplinary simulation of a First Contact scenario | Ms Daniela De Paulis | Simone Caroti |
| A4.2.2,x80945 | Re-examining AI as a "Great Filter" for Advanced Civilizations: The Transition to Post-Biological Life and its Implications for Technosignatures | Prof Mike Garrett | Simone Caroti |
| A4,2,3,x89071 | Causal Impotence and Cosmic Messaging: A Logical Response | Dr Chelsea Haramia | John I Davies |
| D4,1,3,x83992 | Artificial Magnetic Field as Active Shield against Cosmic Radiation | Dr Alessandro Bartoloni | John I Davies |
| D4,4,9,x81405 | Space Arks for the Nearest Stars: a Feasibility Evaluation | Prof Giancarlo Genta | Patrick J Mahon |

The reports in P47, *International Astronautical Congress IAC24: The Interstellar Presentations Part 1*, can be found at - i4is.org/principium-47/.

## Second Report Contents

These are the presentations and papers we reported on in issue P48 - in order of IAC24 reference -

| IAC24 reference | Title | Presenter | Reporter |
|---|---|---|---|
| A4,1,12,x91290 | RFI Rejection in Multi-Beam Receivers using a CNN | Ms Karen Perez | Peter Milne |
| A4,1,13, x82932 | Fine-tuning the Narrowband SETI Signal Processing Pipeline | Mr Kenneth M Houston | Peter Milne |
| A4,2,6 x84417 | The Future of the SETI Post-Detection Protocols: Progress Towards Revisions | Leslie I Tennen | Max Daniels |
| A4,2,9, x81864 | Moon Farside Regulated by a United Nations Treaty | Claudio Maccone | Max Daniels |
| A4,2,12,x85455 | Possible extraterrestrial Focal SETI and its implications for terrestrial SETI | Dr Nicolò Antonietti | Simone Caroti |
| A4,2,14,x88183 | Plurality in Post Detection Scenarios | Ms Kate Genevieve | Simone Caroti |
| C4,9,6,x85994 | Feasibility study of a mission to Sedna - Nuclear propulsion and advanced solar sailing concepts | Elena Ancona | Michel Lamontagne |
| C4,10-C3.5,2,x90149 | United Kingdom's Contributions to Enhancing Nuclear Power Systems for Space Exploration | Dr Mauro Augellia | Parnika Singh |
| C4,10-C3.5,8,x86317 | Addressing Challenges to Engineering Feasibility of the Centrifugal Nuclear Thermal Rocket | Dr Dale Thomas | Parnika Singh |
| D4,1,9,x80842 | Self-Replication Technology for Ubiquitous Space Exploration | Alex Ellery | Michel Lamontagne |
| D4,4,1 x89587 | Advanced Electric Propulsion Systems with Optimal Specific Impulses for Fast Interstellar Precursor Missions. | Nadim Maraqten | Adam Hibberd |
| D4,4,3,x84524 | Nuclear Electric Propulsion for Fast Interstellar Precursor Missions: Problems and Promises | Dr Ralph L McNutt Jr | Angelo Genovese |
| D4,4,7,x91195 | Interstellar Systems at the Edge of Chaos | Dr Angelo Vermeulen | Patrick Mahon |
| D4,4,8,x90437 | Technology Development Pace Coefficient for Reliable Interstellar Travel Timeline | Antoine G Faddoul | Parnika Singh |

The reports in P48, *International Astronautical Congress IAC24: The Interstellar Presentations Part 2*, can be found at - i4is.org/principium-48/.

## The Programme

Here are the reports with IAF identifying codes for the symposium sessions. Shown alphabetically by IAF identifying code.

Format of programme reports -

| | | | | |
|---|---|---|---|---|
| IAF identifying code | Title | Presenter | Institution | Country |

## The Interstellar Programme reports

| | | | | |
|---|---|---|---|---|
| A4,2,5,x85743 | State Responsibility for First Contact Under International Law | Andrea J Harrington | McGill University | Canada |

| | |
|---|---|
| IAF Abstract See also P46 report: | https://iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,A4,2,5,x85743.brief.pdf |
| IAF Cited Paper: | https://iafastro.directory/iac/proceedings/IAC-24/IAC-24/A4/2/manuscripts/IAC-24,A4,2,5,x85743.pdf |
| IAF Cited Presentation/Video: | https://iafastro.directory/iac/proceedings/IAC-24/IAC-24/A4/2/presentations/IAC-24,A4,2,5,x85743.show.pptx |
| Open Paper: if available | none found |
| Reported By: | John I Davies |

The authors ask, in summary -

- Are SETI activities considered a space activity in the context of Article VI of the Outer Space Treaty, and thus subject to national authorization and supervision in that context?
- Does the Outer Space Treaty create any other responsibilities for states engaging in SETI activities and do states have a heightened duty of care when seeking contact with extra-terrestrial intelligence?
- Is there a requirement under international law for SETI activities to conform to the precautionary principle?
- Does existing SETI-related 'soft law,' such as The Declaration of Principles for Activities Following the Detection of Extraterrestrial Intelligence, create any legal responsibility or liability for states?

They examine both statute and case law. They conclude that the provisions of the Outer Space Treaty appear to apply to SETI - either ground-based or space-based and either active or passive.

The Treaty addresses - cooperation, mutual assistance and due regard between states, harmful contamination and adverse changes to the Earth environment (ie: forward and backward contamination provisions) and consultation requirements for potential harmful interference.

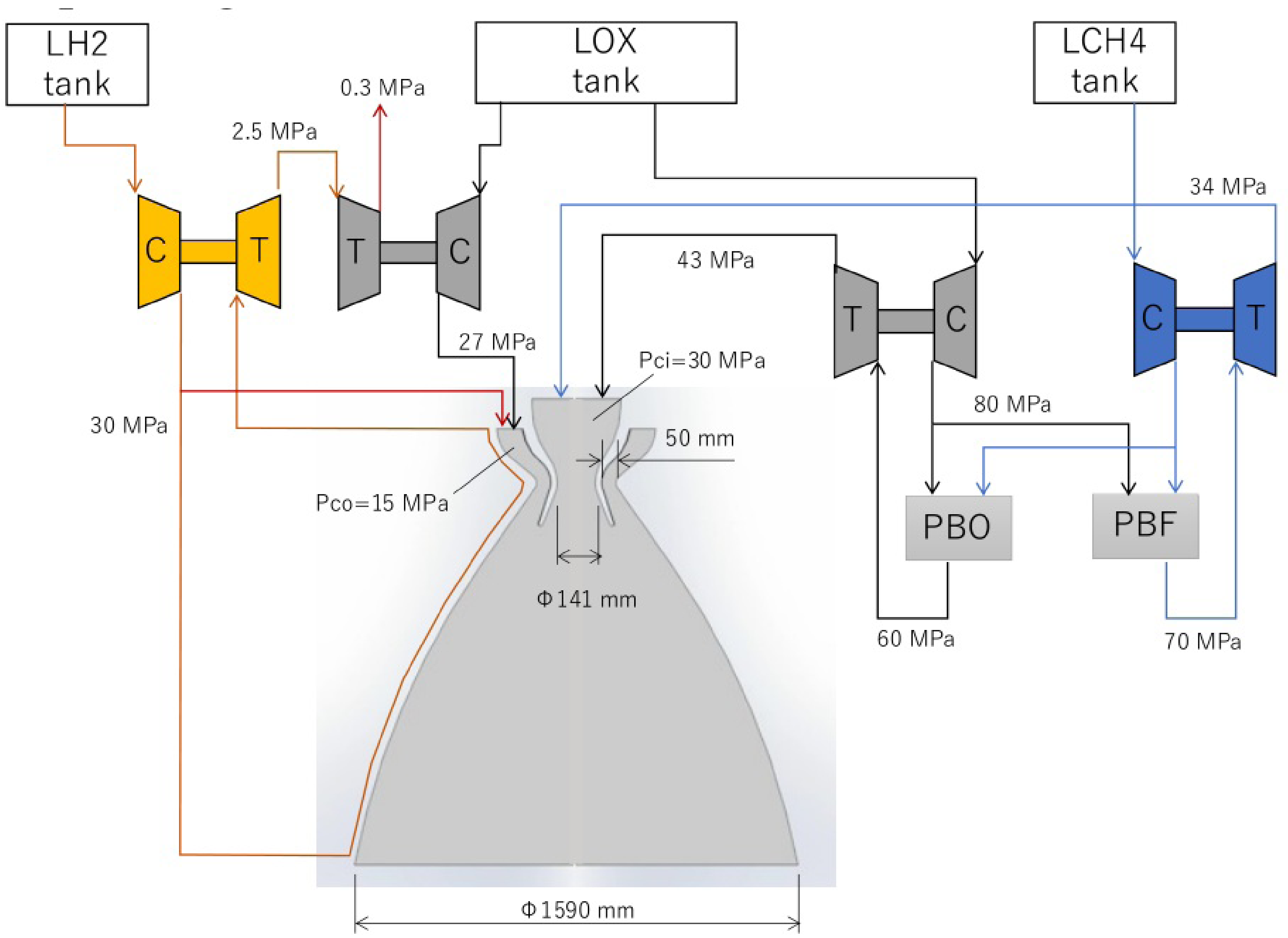
They believe humanity has already taken substantial risks with regard to contact with extraterrestrials and that states should act with caution in undertaking active SETI activities and managing such activities that take place from their jurisdiction.

| | |
|---|---|
| Co-authors | Charles Stotle, University of Mississippi |

| | | | | |
|---|---|---|---|---|
| C4,9,1,x86616 | Development of Tri-propellant rocket engine for reusable SSTO | Dr Tadayoshi Shoyama | Innovative Space Carrier Inc | Japan |

| | |
|---|---|
| IAF Abstract See also P46 report: | iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,C4,9,1,x86616.brief.pdf |
| IAF Cited Paper: | iafastro.directory/iac/proceedings/IAC-24/IAC-24/C4/9/manuscripts/IAC-24,C4,9,1,x86616.pdf |
| IAF Cited Presentation/Video: | iafastro.directory/iac/proceedings/IAC-24/IAC-24/C4/9/presentations/IAC-24,C4,9,1,x86616.show.pptx |
| Open Paper: if available | none found |
| Reported By: | John I Davies |

Single-stage-to-orbit (SSTO) is a long-sought objective. We would all like to overcome "The Tyranny of the [Tsiolkovsky rocket] equation". Cheaper access to low Earth orbit (LEO) is an important early step to the stars. Dr Shoyama and colleagues believe they have found a way.
A major challenge is high propulsion performance in both the atmospheric flight phase (high thrust) after launch and the vacuum flight phase (high specific impulse) after exiting the atmosphere. The paper suggests changing the propellant mix between the two phases.
They propose a dual-chamber (DC) tri-propellant engine using LH2/LOX and LCH4/LOX, liquid hydrogen




Schematic diagram of DC engine.
Credit: Shoyama et al Fig 2.

and liquid methane with liquid oxygen as the oxidiser.
Methane provides the high thrust for the initial phase, switching to hydrogen for the transition to orbit.

| | |
|---|---|
| Co-authors | Kazuaki Hirakawa |

| | | | | |
|---|---|---|---|---|
| C4,9,12,x86886 | Optimization of Solar Sail Trajectories under Uncertainties via Deep Reinforcement Learning | Mr Christian Bianchi | University of Pisa | Italy |

| | |
|---|---|
| IAF Abstract See also P46 report: | iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,C4,9,1,x86616.brief.pdf |
| IAF Cited Paper: | iafastro.directory/iac/proceedings/IAC-24/IAC-24/C4/9/manuscripts/IAC-24,C4,9,1,x86616.pdf |
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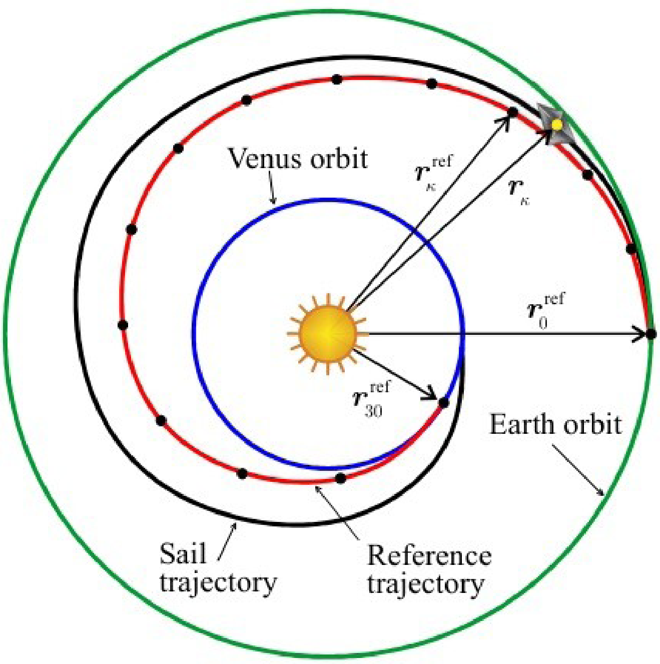
| Open Paper: if available | none found |
| Reported By: | John I Davies |

Bianchi et al analyse the optimal three-dimensional interplanetary transfers of a solar sail in the presence of various sources of uncertainty, typically inaccurate knowledge of the sail's optical parameters, affecting the magnitude and direction of acceleration, and the presence of wrinkles on the sail due to the folding and unfolding of the extremely thin membrane. They suggest that solar sails are particularly suitable for missions in which non-Keplerian orbits must be maintained by small and continuous propulsive acceleration, such as, for example, creating displaced geostationary orbits or artificial equilibrium points in the Sun-Earth system. They use reinforcement learning, in which an agent learns by trial and error. They describe a number of extant solar sailing missions and some machine learning techniques already used to develop trajectories for such missions. Specifically the paper analyses the three-dimensional transfer of a solar sail from the orbit of Earth to that of Venus to derive a robust control law in the presence of different sources of uncertainty.

Uncertainty in the optical coefficients is analysed using a 2.5 μm substrate coated with an aluminium layer of 10 nm on the front side. They observe that wrinkles have two main effects, a misalignment of the effective thrust vector compared to the nominal, smooth, case and a reduction in the reflective area of the sail due to shadowing of some portions of the surface. They consider only misalignment of the effective thrust vector. Using Monte Carlo simulations and a Markov decision process they find a transfer time about 10% longer than the optimal value found in a deterministic (un-perturbed) scenario.

| | |
|---|---|
| Co-authors | Lorenzo Niccolai, Giovanni Mengali |




Black points define the sail position vectors sampled at evenly-spaced time instants along the reference trajectory (red line). Credit: Bianchi et al Fig. 4

| | | | | |
|---|---|---|---|---|
| C4,10-C3.5,3,x88438 | A comprehensive methodology for designing a nuclear electric propulsion (NEP) concept | Prof Pablo Rubiolo | CNRS | France |

| | |
|---|---|
| IAF Abstract See also P46 report: | iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,C4,10-C3.5,3,x88438.brief.pdf |
| IAF Cited Paper: | iafastro.directory/iac/proceedings/IAC-24/IAC-24/C4/10-C3.5/manuscripts/IAC-24,C4,10-C3.5,3,x88438.pdf |
| IAF Cited Presentation/Video: | iafastro.directory/iac/proceedings/IAC-24/IAC-24/C4/10-C3.5/presentations/IAC-24,C4,10-C3.5,3,x88438.show.pptx |
| Open Paper: if available | none found |
| Reported By: | John I Davies |

A multidisciplinary team is assessing Nuclear Electric Propulsion technologies (NEP) for the European Space Agency (ESA) [1] to identify the more promising NEP concepts that could be developed in Europe. The assessment has a starting point of six Use-Cases (UCs) addressing demands for medium and long-term missions to Earth, Moon, Mars orbits and exploration beyond Mars. The selected Use-Cases serve as the starting point for determining approximate mission requirements. These requirements are then refined based on an initial market assessment. The use cases are -

**Use-Case identified in the ESA's SOW for the RocketRoll project [2].**

| Number | Name | Description |
|---|---|---|
| Use-Case 1 | GEO return | Repeated transfer between LEO (900 km) and GEO (35,786 km) orbits. |
| Use-Case 2 | One shade of Lagrange | Transit from LEO to Sun-Earth Lagrangian and for which Time-Of-Flight (TOF) is unconstrained. |
| Use-Case 3 | To the Moon and back | Transit between LEO and High Lunar Orbits, such as NRHO, will play a major role in the exploration of the Moon. |
| Use-Case 4 | D-Tour | Transit from Earth's parking orbit (900 km) to Mars. No transfer time constrain. |
| Use-Case 5 | D-Day | Potential crewed mission to the Red Planet. Transfer time between Earth Orbit and Mars is constrained to maximum 3 Months per transit. |
| Use-Case 6 | Road Trip | Transfer from Earth parking orbit (900 km) to Ceres Low Orbit. |

Credit: Rubiolo et al Table 1.

The team report that their studies indicate that NEP could be competitive in three of the selected Use-Cases: GEO return (Use-Case 1), To the Moon and back (Use-Case 3) and D-Tour (Use-Case 4). Finally, the preliminary safety analyses shows that the design of the NEP has to provide equal or better safety performance than RTGs and no major blocking point for safety have identified.

| | |
|---|---|
| Co-authors | Nicolas Capellan, Stefano Lorenzi, Ricardo Boccelli, Andrea D'Ottavio, Angelica Peressotti, Federico Romei, André Cuenca, Alessandra Barc, Alesia Herasimenkaj, Adam Abdin, Andreas Makoto Hein |

[1] Within the frame of the Future Launcher Preparatory Program (FLPP)
[2] V Girardin, Statement of work ESA Express Procurement – Expro, "Preliminary European reckon on nuclear electric propulsion for space applications (RocketRoll)", ESA-STS-FLP-SOW-2022-0025, (2022)

# The Journals

## John I Davies

Here we list recent interstellar-related papers in the **Journal of the British Interplanetary Society (JBIS)**, which has been published since the 1930s and in **Acta Astronautica (ActaA)**, the commercial journal published by Elsevier, with the endorsement of the International Academy of Astronautics.

### Acta Astronautica

Acta Astronautica papers are published online before print. The issues below with relevant papers have appeared since our last issue, Principium P48.

| **Algorithms for encoding interstellar messages** | **Volume 229<br>April 2025** | **Michael Matessa** |
|---|---|---|
| Previous work has developed algorithms for decoding the meaning of an interstellar message from a distant civilization (Matessa, 2022). What about the inverse problem: if you have a concept like the mass of an object that you want to discuss, how can you create a message with that concept that can be easily decoded? This paper describes algorithms for creating a sequence of symbols that introduce concepts leading from basic mathematics to a target concept. The algorithms work with a data structure containing an expression form that relates concepts, a precondition of concepts that have been introduced previously in the message, and a postcondition of concepts that should be understood after the expression form is presented. These algorithms have been implemented in software, and results are shown for creating a message given a target concept. Messages that are created by the algorithms in this paper can be decoded by the algorithms in Matessa (2022). By developing algorithms, it is hoped that message encoding and decoding can grow from an art done by individuals to a science done with algorithms. | | |

| **To seed or not to seed: Estimating the ethical value of directed panspermia** | **Volume 232<br>July 2025** | **Asher Soryl, Anders Sandberg** |
|---|---|---|
| Directed panspermia involves the deliberate spread of life between planets by intelligent actors. While it was originally proposed to explain the origin of life on Earth, recent advancements in space and bio-technology suggest that humans could soon attempt this – and perhaps even succeed. Biocentric ethical theories support attempting directed panspermia to increase life's cosmic abundance and to protect it from possible extinction risks on Earth. However, if this project succeeds and sentient life evolves within the resulting biospheres, it also carries the moral risk of creating astronomical levels of suffering. Taking into account epistemic and normative uncertainty, the potential irreversibility of our actions, and the lack of global coordination on the development and implementation of space technology, we argue for a temporary moratorium on directed panspermia – at least, until we can predict its long-term outcomes to ensure that whatever decision we make is ethically robust. | | |

### JBIS

Several issues of JBI have appeared since the report in our last issue, P48 but none are yet available online to subscribers.

**“A journey of a thousand miles begins with a single step.”**
**Lao Tzu, ancient Chinese philosopher**

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**Patrick Mahon**

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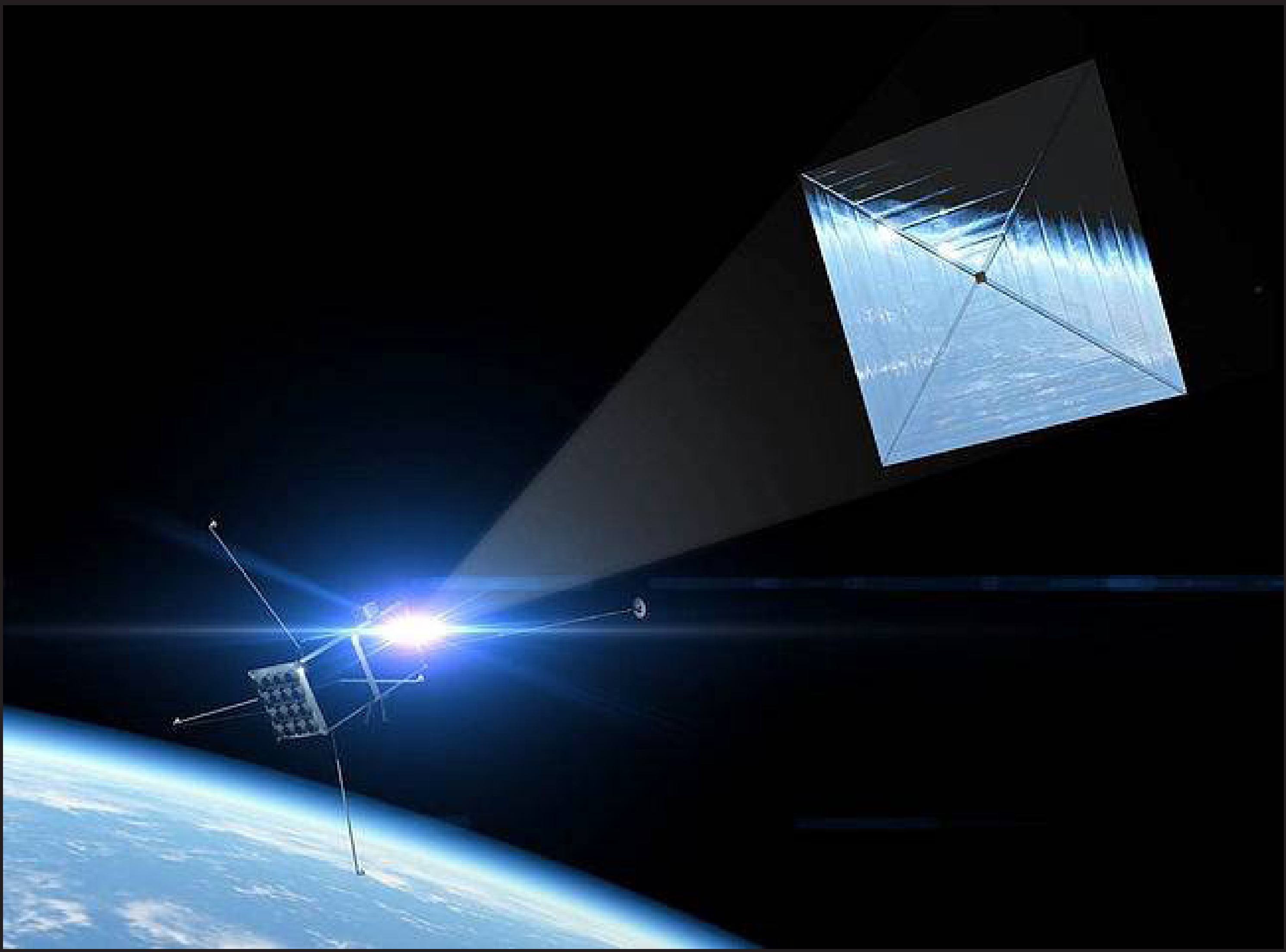

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# THE i4iS MEMBERS' PAGE

## John I Davies

The i4is membership scheme exists for anyone who wants to help us achieve an interstellar future. By being a member of i4is, you help to fund our technical research and educational outreach projects. Members can access the members-only area of the website including our video talks, members' newsletter and Principium preprints.

### Recent member newsletters

There have been two member newsletters and a special announcement of Breakthrough Discuss in April since P48, our last issue. All member newsletters are emailed to members and also available from the members-only area on the website - i4is.org/members.
The most recent, April 2025, included the discovery of DMS and DMDS in the Atmosphere of K2-18 b - much discussed at Breakthrough Discuss 2025 as reported in this issue.

### Could you be our new News Editor?

With the departure of our Interstellar News Editor, Parnika Singh, who is off to college this year we need a successor. If you take a continuing interest in matters interstellar then this could be for you! Contact our current editor, John Davies john.davies@i4is.org, our Deputy Editor, Patrick Mahon patrick.mahon@i4is.org or our incoming Editor, Gill Norman gillian.norman@i4is.org.

There is also lots to do in the rest of i4is, whether your skills are technical, educational, administrative or financial. The more volunteers we have, the more we can achieve! Please get in touch at info@i4is.org.

i4is Deputy Executive Director Rob Swinney at our ***Skateboards to Starships*** workshop in April.
The Royal Institution have invited us back for another session in August. Visit www.rigb.org/whats-on and look for Holiday Workshops to reserve a spot for your up-and-coming space scientists and engineers!

### Writing for Principium

If you have a particular topic which interests you then please propose an article to the Editors. Email john.davies@i4is.org or patrick.mahon@i4is.org with a brief summary of your idea and a little about yourself.

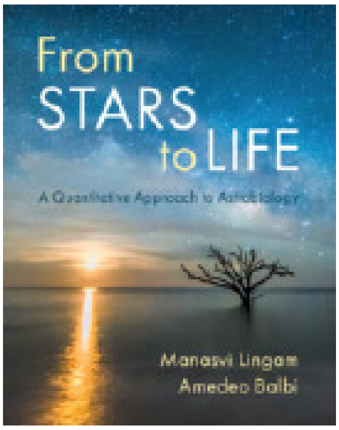
*"Tyranny is a human trait that we sometimes project onto Nature."*
*"The giant leap for mankind is not the first step on the Moon but attaining Earth orbit."*

*The Tyranny of the Rocket Equation,* Don Pettit - NASA, 05.01.12

*web.archive.org/web/20220113075707/https://www.nasa.gov/mission_pages/station/expeditions/expedition30/tryanny.html*

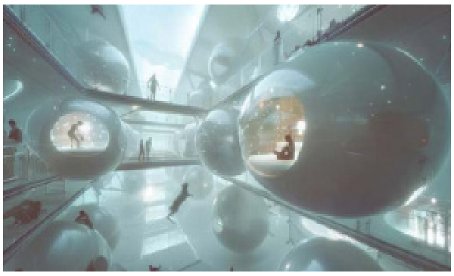
# NEXT ISSUE

## Next time, in P50 - August 2025

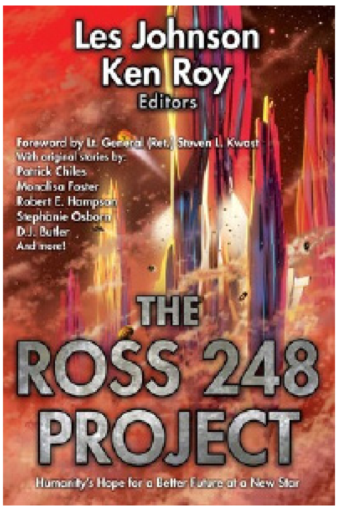



**From Stars to Life**
**A Quantitative Approach to Astrobiology**
A review by Andreas Hein of the new book by Manasvi Lingam, Florida Institute of Technology and Amedeo Balbi, Università degli Studi di Roma 'Tor Vergata'.


**IAC25 - Preview**
Announced interstellar papers and presentations at the 2025 International Astronautical Congress.



**Project Hyperion progress report**
An i4is world ship competition to design multi generation ships using current and near-future technologies with self-sustaining ecosystems, featuring agriculture, habitation, and other necessary life-support systems.




**The Ross 248 Project**
A team coordinated by Les Johnson and Ken Roy, two engineers who have pioneered interstellar studies, have produced a shared world anthology about the arrival of a mission to a known star - and the problems they confront from arrival onwards.
Reviewed by Patrick Mahon.

And of course there will be the usual Interstellar News and journal reports.

**Our 50th Issue!**

# COVER IMAGES

## Cover images for this issue 49

Our cover images for this issue reference an Interstellar News item and our lead article.

### FRONT COVER

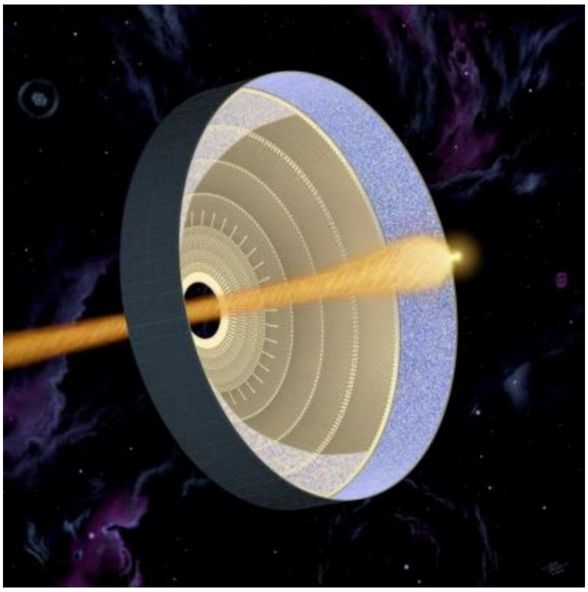
## Dual Direct Fusion Drive (DDFD)

Science X network has announced an *AI-Optimized Lightsails Bring Interstellar Travel Closer to Reality* phys.org/news/2022-12-team-physicists-ligo-giant-alien.html
"The Sunbird: a marvel of space propulsion innovation, powered by Pulsar Fusion's state-of-the-art Dual Direct Fusion Drive (DDFD). With its remarkable high specific impulse (10,000–15,000 s) and 2 MW of power, the Sunbird redefines what's possible in space travel."
Pulsar fusion pulsarfusion.com/products-development/sunbird-fusion-propulsion/ illustrated their announcement with this rather fine, though science-fictional visualisation.

Image Credit: Pixabay/CC0 Public Domain

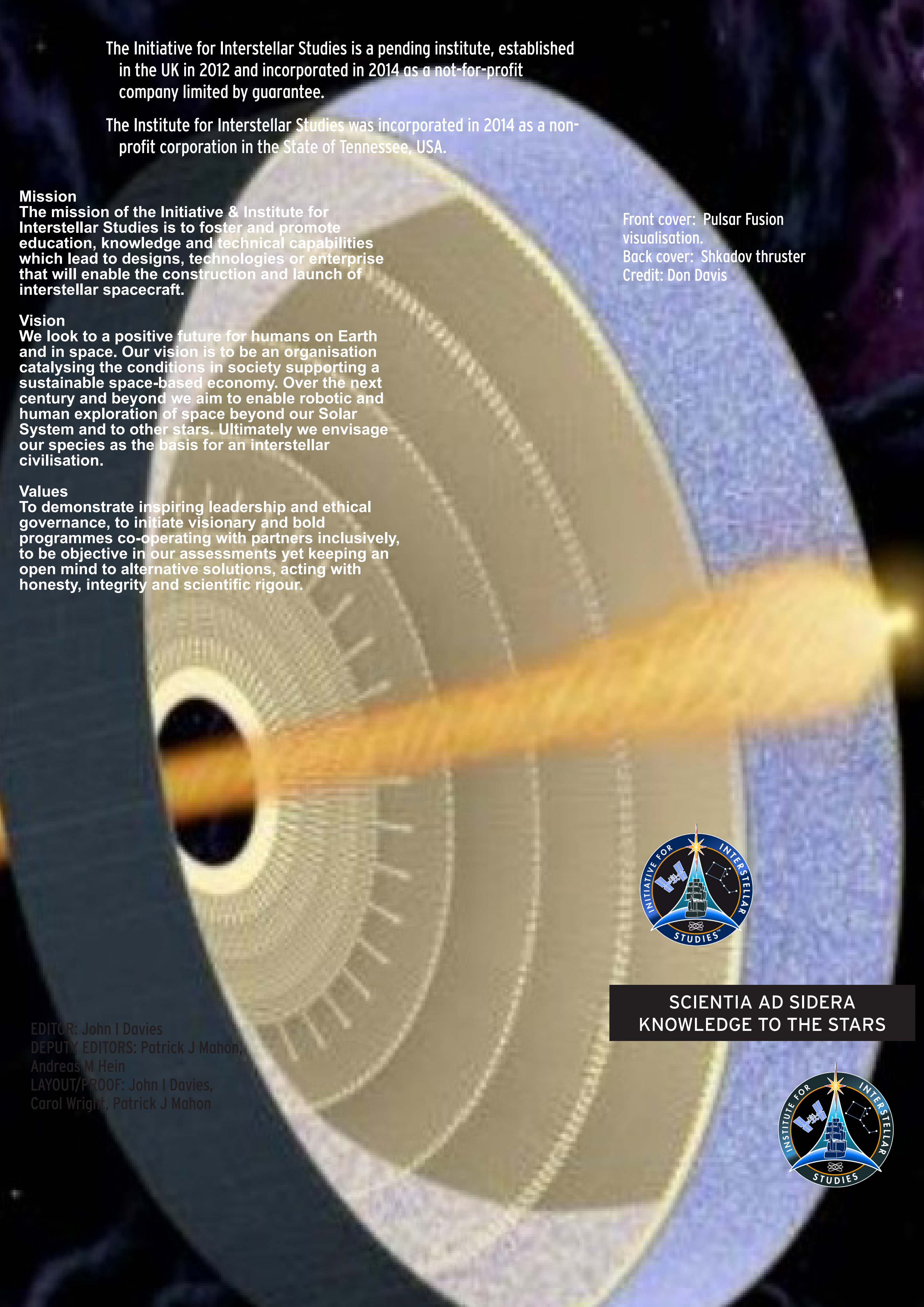
### BACK COVER

## Moving a Solar System



A Shkadov thruster is illustrated in Figure 16 of the lead article in this issue, Novel Technosignatures. Such a "solar system exploring the galaxy" would be a very visible technosignature.

Image Credit: Don Davis.



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.

**Mission**
**The mission of the Initiative & Institute 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 look to a positive future for humans on Earth and in space. Our vision is to be an organisation catalysing the conditions in society supporting a sustainable space-based economy. Over the next century and beyond we aim to enable robotic and human exploration of space beyond our Solar System and to other stars. Ultimately we envisage our species as the basis for an interstellar civilisation.**

**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.**

Front cover: Pulsar Fusion visualisation.
Back cover: Shkadov thruster
Credit: Don Davis

SCIENTIA AD SIDERA
KNOWLEDGE TO THE STARS

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