LEAD FEATURE

AMiTe Treffpunkt - A proposal for communication between Kardashev Type IIb civilisations

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In this paper David Gahan suggests that advanced and very long-lived civilisations might meet and communicate at an agreed meeting point. He uses a published model, the Daedalus probe, as a benchmark to consider how this might be achieved.

The author would like to thank Adam Crowl for useful discussions.

Abstract

This paper proposes the ‘AMiTe’ point - the Andromeda/Milky-Way Treffpunkt - as a meeting point of civilisations driven by a shared motive. It takes the basic Local Group geometries as its starting point and discusses whether ‘Kardashev Type IIb civilisations’ would find any absolute impediments to sending probes there to make contact. It is based on published analyses of interstellar mission profiles, communication and energy budgets.

The proposal is to model a 59 million-year mission comprising 1,000,000 Daedalus-class [1] ‘Ships of the Line’, forming a chain of communication at a nominal 4.19 light-year inter-ship separation. This line, extended in space and time, would attempt to make contact with a similar line, travelling anti-parallel or parallel in the region of AMiTe, sent by long-lived, overlapping and similarly motivated Type IIb civilisations (to be defined in this paper). These could be from either M31 Andromeda or our own galaxy. The extragalactic meeting point is proposed in order to solve the ‘uniqueness’ problem of where to go looking.

Introduction and Motivation

This paper is in direct response to comments on the ‘Infinite Monkey Cage, UFO Special’ broadcast 17/2/20 [2]:

- “If civilisations don’t overlap, we will never meet the aliens.” Dr Maggie Aderin-Pocock
- “The question is how close the nearest civilisation (is at present); I think the answer may be outside the Milky Way and therefore forever inaccessible.” Professor Brian Cox

The paper posits a treffpunkt, watering-hole or poste-restante as a place for civilisations to meet. Recognising the useful work of Michael Hippke [3] on interstellar communications, this paper will adopt the German language word for meeting point, ‘Treffpunkt’ (so useful in German airports pre mobile phone), and refer to the unique point as the Andromeda/Milky-Way Treffpunkt or AMiTe (which could be pronounced ‘Amity’).

The paper takes as axiomatic that civilisations similar to ours would proceed from identical motivations to find each other, ie simple curiosity. If they develop the ‘Treffpunkt’ concept and conclude that a proposal to meet at AMiTe is both logical and technologically possible then it may already have been attempted many times by civilisations arising in, and over the long lifetimes of the Milky Way, Andromeda - and Triangulum - galaxies.

NB: given the extensive range of this paper, commonly accepted or uncontroversial numbers are sourced from Wikipedia unless otherwise stated.

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[1] See *Project Daedalus – A Beginners' Guide,* Patrick J Mahon in Principium 24, February 2019, page 30.

[2] www.bbc.co.uk/programmes/m000ffzg *The Infinite Monkey Cage* is a BBC Radio 4 comedy/pop science series hosted by University of Manchester physicist Brian Cox and comedian Robin Ince, running for more than ten years as of this issue. Maggie Aderin-Pocock is one of the current hosts of *The Sky at Night,* a monthly astronomy BBC TV programme television since 1957.

[3] Hippke's publications include - *Interstellar Communication Network. I. Overview and Assumptions*, The Astronomical Journal, Volume 159, Number 3, preprint arxiv.org/abs/1912.02616 - *Interstellar communication. II. Application to the solar gravitational len*s, Acta Astronautica, Volume 142, January 2018, Pages 64-74, preprint arxiv.org/abs/1706.05570 - more via scholar.google.com/ "Interstellar communication".

A Unique Meeting Point / Water-Hole / Poste-Restante / Treffpunkt

Our galaxy contains between 100 and 400 billion stars and at least that many planets. The difficulties of other civilisations finding evidence of our existence ‘at home’ is the converse of us finding them at theirs. It is the contention of this paper that only at an obvious Treffpunkt, watering-hole or poste-restante, will the needles emerge from the cosmic haystack.

The only clearly unique location within the Milky Way galaxy is the galactic centre (GC). The stars in the innermost 10,000 light-years form a bulge containing the GC, an intensely busy radiation environment including the Sagittarius A* supermassive black hole of 4.1 million solar masses. Any space probe would have to pass through the most complex navigational and gravitational path to get there, with the highest extinction path for any return signals. The GC thus appears to be a poor choice for a galactic Treffpunkt as being too complex and dynamical a challenge.

Within the immediate environs, the Large Magellanic Cloud (LMC, fourth largest member of the Local Group) provides an alternative, defining a point of galactic longitude which only slowly varies in time.

However, over the timescale of millions of years which may be necessary for civilisations to succeed in an encounter, the position (eg of the mid-point) will vary, thus blurring the target. Furthermore, the LMC currently lies on the opposite side of the GC from us and getting there presents a navigational and dynamical challenge. However, the mid-point between the LMC and the Small Magellanic Cloud (SMC) may be a logical choice for civilisations in that part of the cosmos; they are in a stable relationship and are gravitationally connected by a tenuous gas-bridge.

As an alternative, the neighbouring Andromeda Galaxy, containing an estimated one trillion stars, is much the most obvious other member of our Local Group. The mid-point between the two galaxies represents a unique location in the Group, for aeons in the past and aeons in the future. We will refer to this as the AMiTe Point or just ‘AMiTe’. The line connecting the Milky Way GC (Sgr A*), AMiTe and the M31 GC will be the ‘AMiTe Line’ which also defines the Interaction Cylinder, to be discussed later.

Figure 1 The Local Group and AMiTe Point (‘upside-down’ with galactic south at top)

Original graphic: Antonio Ciccolella / Wikimedia Commons

NB: Zero Galactic longitude is approximated by the Sculptor dwarf galaxy ‘near’ the LMC, so the Solar System is on the opposite side of the GC from this.

Removing the Time Constraint: Type-IIb Civilisations

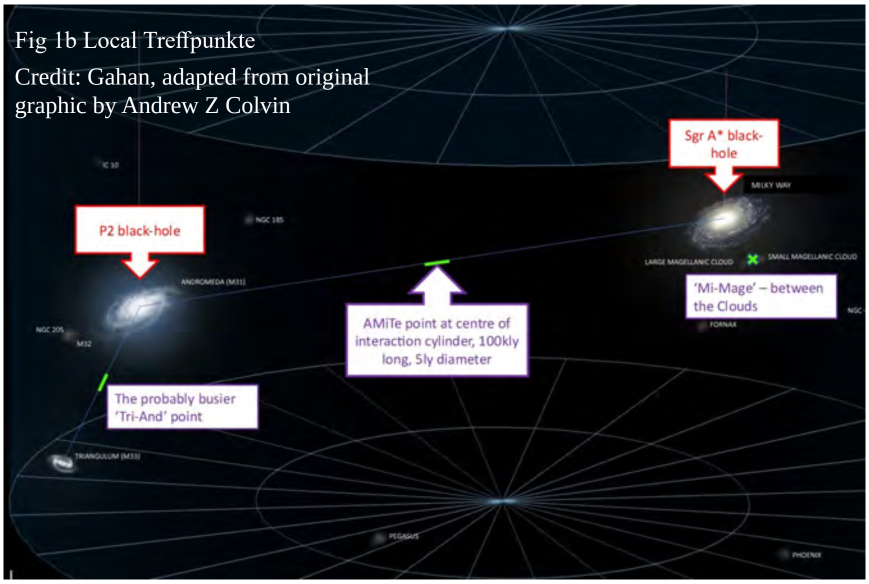

Fig 1b Local Treffpunkte

Credit: Gahan, adapted from original graphic by Andrew Z Colvin

The Drake equation requires a value for the longevity, L, of candidate civilisations. Drake's original estimates included a lower bound of 1,000 years [1]. Recent commentators have suggested values as short as 420 years [1], in part as an explanation of why 'they' haven't found us (the Fermi paradox). The author of this paper proposed an effective value for L based on an extrapolation of current endogenously (socially) driven human Total Fertility Rate (TFR) trends. Taking future trend TFR to be 1.6 (>40 states currently at or below this level, also the average of high-income countries, 2018 figures [2]), a peak population of 10 billion in 2100, and using three generations per 100 years, gives a constant logarithmic decline. In engineering terms, this is a factor of -1dB per generation or -3dB per ~100 years, ie a halving in the number being born. Figure 2 shows this extrapolated reduction to a level where arbitrary reasons might lead to the temporary extinction, technological disengagement or hibernation of the human race. A recent academic publication [3] has suggested that the absolute decline will start earlier than the author's model but did not extrapolate to the logical conclusion of maintained 1.6 fertility. No economic or socio-dynamic reasons why the decline (or change in TFR trend) will be arrested/reversed have been proposed.

A dwindling towards possible 'extinction', for instance ~5-6,000 CE, leaves plenty of time for our descendants to make every effort on currently envisaged SETI efforts and (if unsuccessful) consider very long-lived missions such as AMiTe. It seems entirely possible that they would consider a 'new start' for humanity in the future, either when the planet has been renewed or an alien race has been found with whom to commune, and make provisions for that. There would therefore also be time to perfect a robotic guardian/caretaker capability and biological sciences capable of effecting the new start. This could happen several times. With reference to the Kardashev scale, we may call a periodically 'hibernating' species plus its robotic caretakers a 'Type IIb' civilisation. For a Type IIb civilisation, with the entire resources of the Solar System at its disposal (Kardashev Type II), timespans of tens of millions of years required to send an AMiTe mission may be perfectly acceptable in order to achieve the Prime Directive decreed by the founding controlling human authority: 'Find other Civilisations!' This Type IIb concept removes any obvious time constraint on achieving that directive.

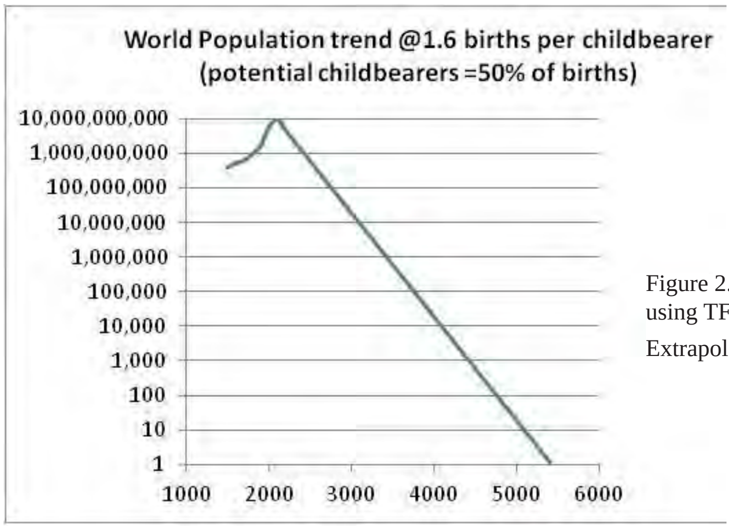

Figure 2. Historic growth of world population then decline over time, using TFR of 1.6 due to social factors.

Extrapolation/image by the author D Gahan

[1] The Drake Equation en.wikipedia.org/wiki/Drake_equation and *The Origin of the Drake Equation*, Drake & Sobel astrosociety.org/file_download/inline/58ee6041-5f61-4f88-8b15-d2d3d22ab83d

[2] Sovereign states by total fertility rate - en.wikipedia.org/wiki/List_of_sovereign_states_and_dependencies_by_total_fertility_rate.

[3] *Global population in 2100*, The Lancet, www.thelancet.com/infographics/population-forecast. Extract from Vollset SE, Goren E, Yuan. C-W. *Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: a forecasting analysis for the Global Burden of Disease Study.* The Lancet 2020. Published online July 14. www.sciencedirect.com/science/article/pii/S0140673620306772.

Indeed, if galactic civilisations flower only rarely and briefly [1], a timescale of 60 million years (MY) may not be unreasonable. It represents one-tenth of the time since the Cambrian Explosion origin of complex life and is similar to the length of the Cenozoic geological era, since the extinction of the dinosaurs. From dynamical considerations of the Sun's position and orbit in the Milky Way, this admittedly long timescale may also be considered reasonable.

Our Position in the Milky Way: A Good Time to Go

Milky Way Data (from Wikipedia [2])	
Diameter	Stellar disk: 170–200 kly (thousand light years); dark-matter halo: ~1.9 Mly (million light years)
Thickness of thin stellar disk	~2 kly, average ~1 kly
Number of stars	100-400 billion $(1–4)\times10^{11}$
Sun's distance to Galactic Centre	25.6–27.1 kly
Sun's distance North of galactic plane	16–98 ly
Sun's Galactic Rotation Period	240 MY (million years)
Sun's orbital velocity	~220 km/s
Velocity vector angle with respect to Andromeda	31.7 degrees (longitudinal only)
Escape velocity at Sun's position	550 km/s

From Wikipedia [2]: "Perhaps, the Milky Way may contain ten billion white dwarfs, a billion neutron stars, and a hundred million stellar black holes. Filling the space between the stars is a disk of gas and dust: the interstellar medium."

From the foregoing it will be seen that navigation within the disk of the galaxy is much more complicated than out-of-disk. Leaving the comparatively thin disk of the galaxy would reduce the amount of fuel needed for course corrections to avoid hazards. A distance of 1-2 kly (depending on angle) is 0.1 to 0.2% of the distance to AMiTe and so, during this portion of the voyage, could be navigated at lower committed speed with navigational information being passed backwards along the chain. Escape velocity is 2.6% of the (to be proposed) cruise speed and so can be neglected. Gravitational attraction of the outer disk, in particular the Perseus arm (Figure 3), may in fact assist the planned trajectory. It should be taken into account, together with navigational hazards from smaller, satellite galaxies and intervening masses in a future, more detailed analysis.

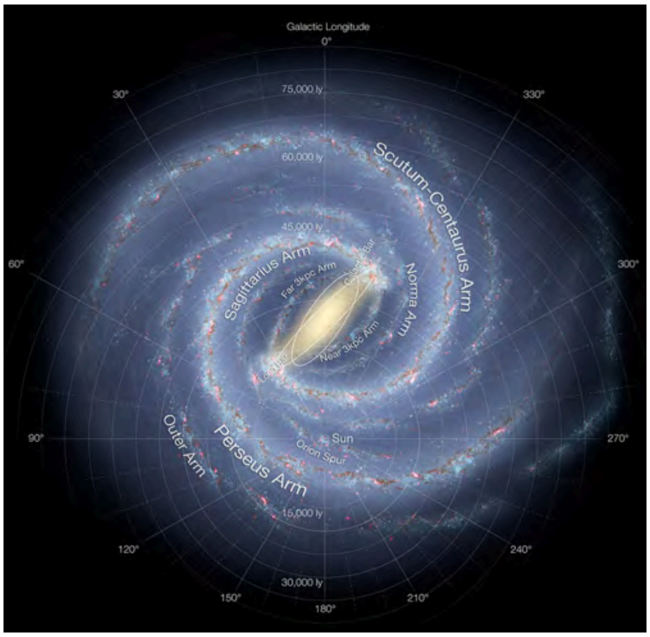

Figure 3 Spiral Arms of our home galaxy.

Credit: NASA/JPL-Caltech/ESO/R. Hurt www.eso.org/public/images/eso1339e/.

Our Solar System currently lies in an unusually propitious relationship (except for distance) with M31 Andromeda for our civilisation to consider a mission to AMiTe. In Figure 3, the galactic coordinate direction to M31 is along the 120° (actually 121.7°) galactic longitude line, through the final 's' of 'Perseus', about 10 diameters in this direction. The galactic latitude of M31 is -21°. For a description of galactic coordinates, see [3].

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[1] *A Statistical Estimation of the Occurrence of Extraterrestrial Intelligence in the Milky Way Galaxy*, Xiang Cai, Jonathan H. Jiang, Kristen A. Fahy, Yuk L. Yung arxiv.org/abs/2012.07902.

[2] Milky Way en.wikipedia.org/wiki/Milky_Way.

[3] Galactic Coordinate - en.wikipedia.org/wiki/Galactic_coordinate_system main article and item #2 on 'talk' page en.wikipedia.org/wiki/Talk:Galactic_coordinate_system.

A description of the dynamics of the Solar System's motion towards M31 Andromeda is given by 'SyntheticET', a contributor to the Wikipedia page on Galactic Coordinates (cited above): -

> **"If the galaxy were a carousel on a moving train, Andromeda's Galaxy would be dead ahead on the tracks and your horse would be moving 31.17° to the right relative to the train. At the present time Andromeda and the Galactic Centre are 121.17° apart along the Galactic Equator. About 19 MY ago Andromeda and the GC were 90° from each other and Earth was moving fastest toward M31. 65 MY ago when the dinosaurs disappeared M31 was in 'conjunction' with the Galactic Centre. The Milky Way Galaxy itself is moving in its entirety toward Andromeda. The Sun and nearby stars are moving and at a point in Galactic orbit somewhat past 90° from the GC. The two velocities - Galactic and Solar - add vectorially. At this time the Sun is 31.17° past the point where the velocity dead ahead is greatest."**

With the Sun's rotation period around the GC being ~240 MY, our closest approach to M31 will be in about 40 MY. The following 60 MY are therefore 'a Good Time to Go' in this direction, minimising distance but also avoiding the intervention of the GC which could disrupt the tenuous communication line. Type IIb civilisations on the opposite side of the GC from us may choose to wait another ½ rotation before attempting the AMiTe point.

As given above, the galactic latitude of M31 Andromeda is -21.57 (note galactic +90° in Coma Berenices). The Sun's position at 16–98 light years (ly) north of the galactic plane, of 1-2 kly thickness, means slightly more of the thickness of the plane to traverse before emerging into less populated regions, but this seems one of the lesser concerns. The relatively high out-of-plane latitude of M31 seems favourable to minimise travel within the populated disk (versus travel to the GC).

Definition of the AMiTe Treffpunkt from both viewpoints

The distance to M31 is 2.54 ± 0.11 Mly (uncertainty of 0.11Mly depending on definitions) [1], therefore distance to AMiTe is around 1.27 Mly. It is taken as a given that civilisations in both galaxies would independently and unambiguously define their own GCs based on the 'sheet anchor' roles played by their respective black holes. These would be extrapolated to a space/time coordinate based on time-of-flight mission profiles, assumed for the purposes of this paper to be broadly similar (errors to be calculated).

We know where to find our own GC, Sagittarius A*, a black hole of 4.1 M solar masses; we presume that counterparts from M31 know this equally well. Any orbit of Sgr A* relative to the aggregate barycentre would introduce uncertainty over time. However, observations from home-system based telescopes at both ends of the chain during time-of-flight would allow for corrections. This would be spatial information but in the most logical timeframe or 'epoch'. The space coordinate of AMiTe for mission considerations would be the exact half-way spatial point between the best observed positions of the Galactic Centres, but the time coordinate would (probably) be 2.54 MY before AMiTe's notional present to allow for round-trip times for correction information. M31 is inclined at 13° relative to the line of sight to Earth, therefore M31 civilisations would have ample opportunities to observe the Milky Way and the long term location of Sgr A*, and send the latest estimates.

Images from the Hubble Space Telescope (2005) [2] of the Andromeda Galaxy's inner nucleus showed two concentrations. The dimmer concentration, designated P2, contains a black hole measured at 1.1–2.3 × 10^8 solar masses. The brighter concentration, P1, is offset from P2 by 4.9 ly; this separation distance could be among the considerations for a scaling rule for the target volume. Taking the location of both the black holes as the accepted GCs, it is proposed that the location of the AMiTe could be defined to a very few light years in a logically reasonable reference frame. In the absence of a more detailed mathematical treatment, we will consider an AMiTe uncertainty of +/-2.5 ly in X,Y,Z for the communications challenges, or a volume 5 ly in diameter.

An alternative scaling factor for the target volume would be the average interstellar distances in the vicinity of civilisations attempting this mission (assuming galactic disk, not core or globular cluster). In the case of the Solar System, this is approximately 5-6 ly, consistent with a stellar density of 0.004 stars per cubic lightyear [3].

[1] Andromeda Galaxy - Wikipedia, Distance Estimate en.wikipedia.org/wiki/Andromeda_Galaxy#Distance_estimate

[2] Andromeda Galaxy - Wikipedia, Nucleus, en.wikipedia.org/wiki/Andromeda_Galaxy#Nucleus

[3] Stellar density - Wikipedia en.wikipedia.org/wiki/Stellar_density

Once the midpoint has been determined, there is also an opportunity to define a cylindrical corridor along the AMiTe Line and centred on the midpoint. This Interaction Cylinder we might propose (for illustrative purposes) to be 5 ly diameter x 100 kly long. This would allow longer interaction times for fleets of probes. Figure 4 illustrates the scale length of the interaction cylinder around the AMiTe point (width not-to-scale) together with other Local Group 'Treffpunkte'. Before considering communications strategies, we will examine the nature of the probes.

Nature of the Probes

Project Daedalus [1] remains the benchmark 'heavy-ship' model in the literature and is referenced by most studies, including the in-progress 'Project Icarus' , see the 2011/2016 review of fusion based propulsion by K F Long [2]. Its respectability on the grounds of the laws of physics has not been formally challenged but Long notes that its performance is at the 'outer extreme' of parameters such as specific power (MW/kg).

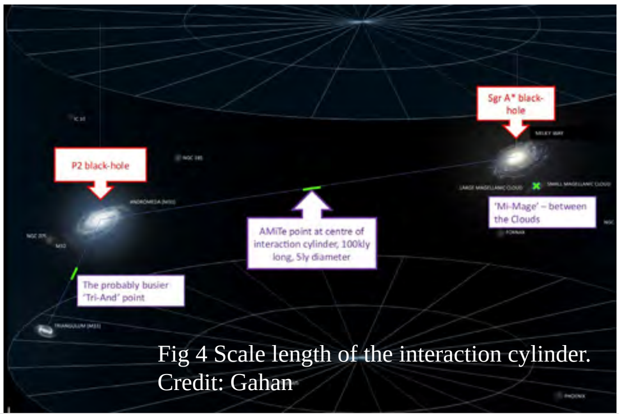


Fig 4 Scale length of the interaction cylinder. Credit: Gahan

Daedalus Target Capabilities:	First stage:	Second stage:
Empty mass:	1,690 tonnes (at staging)	980 tonnes (at cruise speed)
Propellant mass:	46,000 tonnes	4,000 tonnes
Engine burn time:	2.05 years	1.76 years
Thrust:	7,540,000 newtons	663,000 newtons
Engine exhaust velocity:	10,600,000 m/s	9,210,000 m/s
Final velocity:	0.071 c	0.12 c

However, we can join the other studies by quoting the projected capabilities and using those as an initial model for the energetics of the mission. Both Daedalus (and Project Longshot [3]) take the Pulsed Fusion Microexplosion Drive [4] as the only technology likely to yield sufficient specific thrust with feasible amounts of reaction mass. The system concept is to fire high energy beams at small fusionable pellets that will implode and be magnetically channelled out the nozzle. The projected specific impulse (I_{sp}) is 10^6 seconds. Long raises some specific concerns noted by the Icarus team on the uniformity of the inertial confinement fusion compression based on more recent ICF [5] studies. The Icarus team considered alternative drive schemes which could in the future be considered for a more realistic AMiTe study.

Daedalus (and Longshot) selected helium-3/deuterium (He-3/H-2) as the fuel since yielding no neutrons or a low flux of neutrons, which would otherwise irradiate the entire spacecraft over the 50-100 year transits. Availability of helium-3, very rare on earth (and only 0.0002% occurrence vs He-4), was flagged as a problem. The possibility of mining the atmosphere of Jupiter was proposed; this may be a suitable task for a robotic 'guardian' civilisation based on our or other moons. Saturn was not proposed, despite having an outer atmosphere of 3.25% (total) helium by volume, compared with 8-12% for Jupiter, but with a lower escape velocity. Such mining would consume a lot of energy, but much fusionable deuterium would also be obtained. For the purposes of this paper, we assume that sufficient fuel can be collected once every 59 years (time taken for the Sun, Jupiter and Saturn to return to the same configuration). We take this 59 year interval as a possible launch frequency. Future studies may decide that He-3 is not required, possibly relaxing some constraints including the proposed launch interval.

[1] A. Bond & A.R. Martin, *Project Daedalus – Final Report,* JBIS, pp.S5-S7, 1978, also *Project Daedalus – A Beginners' Guide,* Patrick J Mahon, in Principium | Issue 24 | February 2019, page 30 and all the Daedalus papers are collected in the BIS book. *Project Daedalus: Demonstrating the Engineering Feasibility of Interstellar Travel,* www.bis-space.com/eshop/products-page-3/merchandise/books/project-daedalus-demonstrating-the-engineering-feasibility-of-interstellar-travel/

[2] *Project Icarus: Specific Power for Interstellar Mission using Inertial Confinement Fusion Propulsion* JBIS Vol 69 pp190-194, 2016, static1.squarespace.com/static/565a1ea9e4b0f0c1a0216d38/t/5855d2106a49634cd5552c84/1482019348621/190-194+%281%29.pdf

[3] en.wikisource.org/wiki/Project_Longshot/Spacecraft_Systems#3.1

[4] Inertial Confinement Fusion - nuclear fusion initiated by heating and compressing a fuel target using lasers as in the US National Ignition Facility (NIF) lasers.llnl.gov/science/pursuit-of-ignition.

[5] Project Icarus:Development of Fusion Based Space Propulsion for Interstellar Missions JBIS Vol. 69 pp 289-294, 2016.

Project Longshot acknowledged that a fuel injection in a system that must run for 100 years continuously, without repair would be problematic; however the AMiTe mission profile is far more demanding and requires ship operation for millions of years. While the majority of the extra-galactic part of the mission will be in cruise mode, the mission profile would require a minor course correction (1-2% delta-v) after ~96% of mission time and therefore a healthy propulsion system with some remaining fuel. In 'Longshot', a fission reactor is available for constant power for the communications lasers. Since AMiTe requires power for the lasers over very long (but not necessarily continuous) periods, and then also to re-start the main drive for at least one course correction, either an alternate fusion reactor mode or a small additional fission reactor (if mass-efficient) would be required, perhaps taking advantage of the extraordinarily long half-life of U-235 (703.8 million years).

Entering Kardashev Type II (and then IIb) stages, human civilisation will have thousands of years before attempting an AMiTe mission to develop and perfect starship technologies as proposed for Icarus and Daedalus. These and the required communications chain technologies could be perfected during hundreds of visits to nearby stars. Taking for the moment an assumption that successful missions over some thousands of years will enable the numerical performance goals at the Stage1 / Stage2 transition of Daedalus to be realised, it follows that 'Daedalus-class' starships can at least be despatched towards AMiTe to attempt contact.

Energetics

To estimate the ongoing communications power requirements, the energetics of Project Longshot are instructive. Longshot was designed "with existing technology in mind" and maintains communications with earth from the Alpha Centauri system (see Communications). The power plant is a 'long-lived' fission reactor "initially generating 300 kilowatts". The Longshot mission reactor would be used initially to power the ICF [1] fusion lasers, the ongoing ship-control needs and then, during encounter, the full power would be used for a 250 kW communications laser back to Earth. During cruise phase (most of the journey) the Longshot laser would be used at a much lower power for sending data about the interstellar medium or (more relevant for AMiTe) 'keep alive' tracking signals for ships up and down the line.

While AMiTe mission profiles seem to rule out a fission reactor as sole energy source (because 'always on' over extended timescales), the power budget of 250/300 kW calculated by Longshot designers is a useful benchmark. For the whole mission energy budget, taking Daedalus as a model and comparing the available energy budget with the requirements for communications over an 'Alpha Centauri' distance of 4.37 ly:

Daedalus Class ship on AMiTe Mission:		
Cruise velocity	0.071c	Cruise velocity = Daedalus 1st stage terminal
Mass at 0.071c	6,670 tonnes	Daedalus 1st /2nd stage plus 2nd stage fuel
Required fuel to 0.071c	46,000 tonnes	If propulsion system is feasible
Available fuel mass at 0.071c	4,000 tonnes	Used by Daedalus 2nd stage to achieve 0.12c
Kinetic energy at 0.071c	1.51E+21 J	Simple ½ mv2
Energy in 4,000 tonnes	1.32E+20 J	Simple 4/46 calculation; need to model efficiency for power plant (non-drive) uses
Distance to half-way point plus 50 kly	1,320,000 ly	(0.5*2.54 Mly) + 50 kly; would be somewhat longer due to path curvature, but not much
Time at 0.071c	18.6 MY	Note, this permits 100 kly of anti-parallel path
Available energy/time (W) for 18.6 MY	224 kW	Approximately 2x power of a London bus,

Thus modifying the Daedalus mission profile to achieve an extra-galactic cruise velocity of 0.071c by a mass of 6,670 tonnes including 4,000 tonnes of convertible fusion fuel the probe would have sufficient 'energy' on board to be equivalent to a time-averaged shipboard power of ~225 kW for 18.6 MY for all communications and detection purposes. This power/energy budget over mission life, being within 10% of 'Longshot' power requirements is a serendipitous conclusion from the adapted Daedalus numbers; even being within a factor of 10 would be encouraging. Energy conversion efficiencies will be much lower than the primary drive but much more advanced mission modelling may permit a more realistic profile.

[1] inertial confinement fusion. en.wikipedia.org/wiki/Inertial_confinement_fusion

See Rob Swinney's introduction to ICF at ISU Strasbourg in *2.12 M8-ISR-L12 Advanced Propulsion Systems 2* summarised in Principium 31 November 2020 page 79 and his earlier *Extreme Deep Space Exploration: A Personal Perspective* Principium 25 May 2019 page 24.

The energy requirement for a final course correction along the ‘AMiTe Line’ would represent a delta- v of 1-2% (actually maximum now at 1.8% for a straight course, due to the current position of M31 at galactic longitude of ~121 deg). While this must be budgeted, the energy could be saved by reducing cruise velocity to 0.0697c, so not significant overall.

While the above assumes that the power conversion rate of ~224 kW would be ‘always-on’ during the entire mission, the search phase part of the mission lasts for less than 10% of the journey travelled (100 kly in 1.32 Mly). There may be an opportunity to save energy during the ‘quiet’ part of the cruise where mostly keep-alive data will be sent/received. However, this depends on power-plant design.

Communications: The Chain

There are two clear communications challenges:

(1) AMiTe Treffpunkt to Solar System chain and inter-ship communications, including (when found) with ‘ET’.

(2) First Contact, ‘We’re Here’ signalling.

We will address these in the order above, since (1) constrains (2).

Using Project Longshot as a communications model [1] for an Alpha Centauri mission within the disk of the Milky Way, we take this link-length to be the standard link-length for the entire chain. To paraphrase the Longshot scheme:

> “The major challenges for the communications system are at the range of 4.3 light-years (4.1 x 10^{16} metres - the maximum transmission range). A data rate at about 1 kilobit per second must be maintained, since all probe instrumentation is returning data. The only type of communications system capable of the necessary directivity and data rate is a high-power laser using pulse code modulation (PCM).”

Low background noise from the target system is necessary for a low power level, so a laser wavelength of 0.532 microns was chosen by Longshot. Radiation of this wavelength is almost totally absorbed by the outer atmospheres of K and G type stars such as Alpha Centauri, leaving a hole in the absorption spectrum (no transmitted radiation). (NB Doppler shift at velocities of 0.045-0.071c will change this). Laser radiation of this wavelength can then be produced by a frequency-doubled diode-pumped YAG laser with an optical attachment to provide a large initial aperture.

The Longshot transmitter aperture is 2 metres in diameter with receiving mirrors (solar system) of 24 metres diameter. The spreading angle is 1.22*lambda divided by the aperture diameter, or 3.25 x 10^{-7} radians (0.067 arc-seconds. At 4.3 light-years, the spreading results in a footprint radius of 13.4 million kilometres, 8.9% of an astronomical unit). Both the pointing accuracy of the laser mount and the attitude determination capability of the probe must be within 0.067 arc-seconds so very low error laser mounts and star trackers are required. (NB for AMiTe, we will consider send/receive optics of 10 m diameter).

A total input power of 250 kilowatts is needed for each laser that is transmitting. With an assumption of a 20% lasing efficiency, the transmitted power is 50 kilowatts. If the power is distributed isotropically over an area of 5.64 x 10^{20} square metres (the area subtended by the laser beam when it reaches the target distance), the power density is 8.87 x 10^{-17} watts per square metre, or 222 photons per square metre per second. For a 24 metre diameter mirror (area of 452.4 square metres), the received power level is 4.01 x 10^{-14} watts, or 100,000 photons per second. Using the assumption that a digital pulse 'on' level is 100 photons, the receiver sees 1000 pulses per second. So, data rate at maximum range for ‘Longshot’ was 1 kbit/s. Compare with the NASA probe ‘New Horizons’ which achieved a data rate of 1 kbit/s at P = 13 W (radio frequency) from Pluto, and transmitted a total of 50 Gbits over the course of 15 months.

Longshot posits six 250 kilowatt lasers, operating at ‘slightly different’ wavelengths (although not clear if this is consistent with the reactor power). The estimated weight of the communications lasers is 2 metric tons. If we retain the 4.3 ly range for communications, the above worked example shows that communications could be maintained along a chain using ~250 kW of peak power for the required mission length. The principal assumptions we will change are the diameter of the sending (2 m: diffraction limited) and receiving (24m: satellite based) optics. The number of received photons in the scheme scales as the

[1] Project Longshot Communications System Design en.wikisource.org/wiki/Project_Longshot/Spacecraft_Systems#3.4

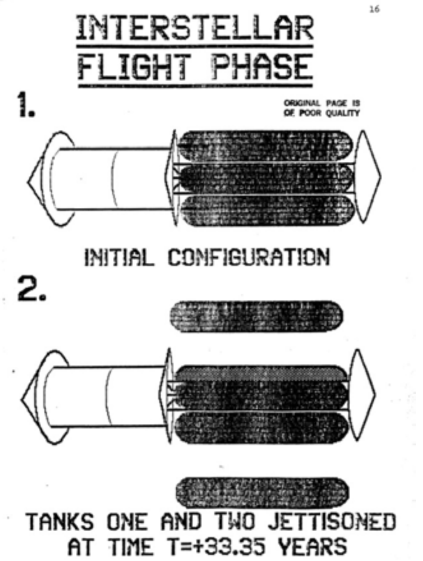
product of the optics diameters squared, ie $(D_{send} \times D_{rec})^2$. For our mission, we'll assume (as does Hippke [1]) 10 m diameter send optics which improves divergence by a factor of 52 and 10 m receive optics reducing light collection efficiency by 2.42. The net change is an improvement by a factor of ~4. Technologically, the compensating improvement due to larger send optics may be harder to achieve than the countervailing reduction in receive area but we will take this modified Longshot model and scaled numbers as an indication that a ~4.3 ly ship separation (in the extra-galactic cruise phase) gives reasonable communication bandwidth. According to Hippke [1], the time to transmit 1PB = 10^{15} bytes, 'the information content of a human brain' at 1 kb/s would be 250 thousand years, not long by the AMiTe mission scale.

At 4.3 ly *2 round-trip times, pointing feedback would require continuous but low bandwidth monitoring, especially in trajectories affected by nearby stars during traverse of the galactic disk. Lower data rate signals at higher divergence could be sent to avoid losing contact and inter-ship distances kept smaller due to lower speeds. Outside the galactic plane there would be greater predictability and perhaps ability to compensate if a ship 'falls silent' by missing out a link in the chain, so 4.3 ly separation is retained for modelling. Links to next-but-one ships at lower data rates should be possible.

Thus, the chain of communication is proposed to be Daedalus-class 'ships of the line', using 532 nm and 10 m optics. We modify the inter-ship separation (during the extra-galactic cruise) to 4.19 ly, the modified distance comes from allowing for one launch every 59 years and assuming a 'Daedalus' cruise velocity of 0.071c). The line can tolerate a few fall-outs but must be largely maintained for secure data-transfer back to Earth for 40-60 MY, ie up to one million ships.

Hippke in his thoughtful series has also examined extreme distance communications at optical wavelengths [1]. Assuming that laser physics for all civilisations converge on the most efficient technology, Hippke discusses wavelengths including Nd:YAG (1,064 nm), its second harmonic (532 nm), and also at the sum frequency and/or second harmonic generation of Nd:YAG and Nd:YLF laser lines eg 393.8 nm (near Fraunhofer CaK); for known Doppler shifts, these can be observed through a narrow filter for long-chain communications. From extinction considerations, and for strong signals, he concludes that shorter optical wavelengths such as 532 nm are optimal for distances up to ~ kiloparsecs (kpc) ~3,000 ly.

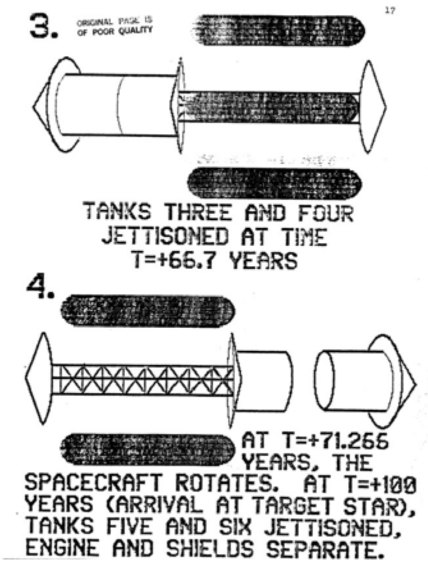
These extreme distances are dependent on high power pulses and high bit/photon efficiency, and so are quoted here to put bounds on signalling distance. Hippke gives an analysis of extreme distance (kiloparsec [2]) point-to-point signalling using Megajoule pulsed lasers and concludes that a 1 MJ laser outshines a host star (eg the Sun) by a factor of 10^4 during a pulse if the wavelength is known, independent of distance. However, for an AMiTe mission, the line connecting the GCs terminates on the bright and extended areas of the galactic cores and so this calculation needs to be verified against the GC brightness over extended spectral bands owing to Doppler uncertainty (due to ship velocity).



Longshot vehicle configuration from *Project Longshot: An unmanned probe to Alpha Centauri*, ntrs.nasa.gov/citations/19890007533

Credit: NASA / Beals et al, US Naval Academy Annapolis, 1988

NOTE: There is some doubt about the relative size of the fuel tanks, based on the calculations in the study.



[1] Hippke eg *Interstellar Communication. X. The Colors Of Optical Seti* - arxiv.org/abs/1804.01249 and *Interstellar communication network. I. Overview and Assumptions* arxiv.org/abs/1912.02616

[2] One thousand parsecs. A parsec is about 3.26 light-years. It is the distance at which an astronomical unit subtends an angle of one arcsecond. It thus relates directly to astronometry using the Earth's orbit as a baseline.

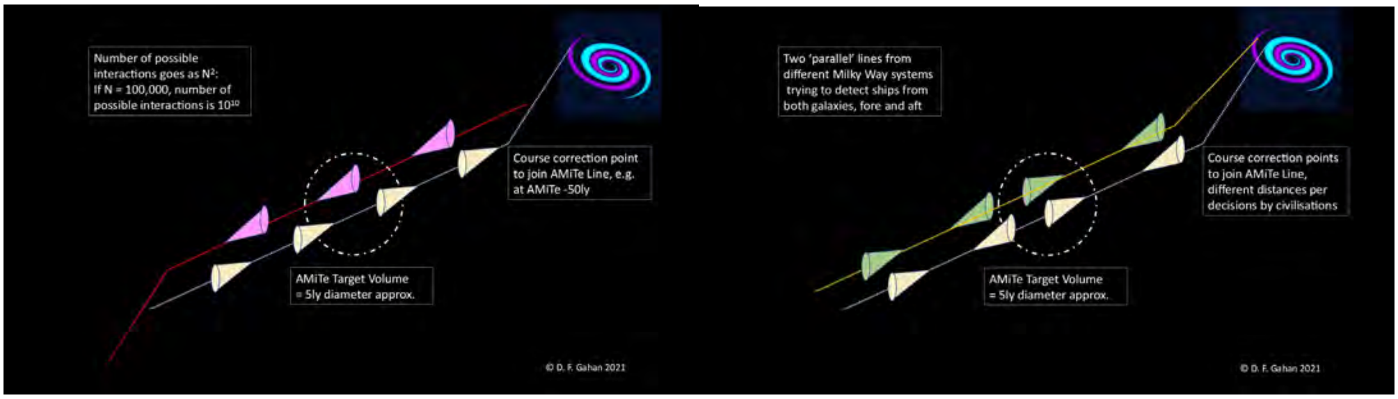


Fig 5: Interacting lines of ships attempting contact while travelling antiparallel and parallel in the vicinity of AMiTe: Lines from Andromeda and Milky Way conducting forward searches (a); Lines searching both forward and backward can detect probes from their galaxy of origin (b).

Credit: Gahan / Local Group montage

Credit: galaxy icon – Vectorstock,

The importance of N for 'First Contact'

From the above, it will be seen that we are trying to establish contacts between two putative lines of ships, anti-parallel or parallel (Figure 5). If participating civilisations came to the same or similar conclusions, the main parameters might be:

- AMiTe point location: mid-point between GCs, epoch 2.54 MY before AMiTe present, uncertainty +/2.5 ly xyz
- Core target area: sphere of 4.9/5 ly diameter (scaled by AMiTe uncertainty, Andromeda central concentration separations, average stellar distances in the galactic disks)
- Desirable number of ships in target volume at any one time: one (from each line)
- Interaction cylinder length (parallel/anti-parallel trajectory from any point in approaching quadrants: unknown. 100 kly has been arbitrarily chosen for energetics calculations, ie life of probes, but multiples of 10 and 'light-years' are not obviously meaningful bases for other species
- Length of mission: ¼ of galactic rotation period: 60 MY for both
- Length of mission overlaps: unknown, depends on Drake equation parameters
- Actual velocity and separation in interaction zone: unknown, depends on arbitrary factors
- Wavelength selected: probably common, but at unknown Doppler shift

If all the arguments above concerning Type IIb civilisations, Prime Directives, uniqueness of AMiTe, technological feasibility are held to be reasonable, the problem reduces to a core Drake equation question: will two Type IIb civilisations send out missions as above which travel along antiparallel/parallel paths for a significant portion of time, and what is the probability they will communicate?

Taking the case where the only relevant Type IIb in M31 'approaching quadrant' is dephased from ours by 30 MY, eg we start sending probes now but they don't develop the capability and the intention until 30 MY in the future, and where the transit time to AMiTe is ~20 MY: many of our Daedalus ships will have no opportunity to interact. ET will only start sending ships when the first of ours is already 0.75 of the way to M31 and will be dead, per the design energy budget. Their line of ships will only reach the interaction cylinder ~50 MY in the future when we have already despatched 5/6 of the ships that will ever be sent, and 10 MY before the chain is broken at our end. This clearly gives 10 MY of interaction time.

To calculate interaction probability, we will take the length of the interaction cylinder as 100 kly, at the far end of which, all available energy has been expended on communications attempts. How many ship-ship encounter possibilities will there be over 10 MY? This is easy to calculate: three of our ships passing three of theirs gives 3*3, so goes as N-squared. With 10 MY interaction time representing over 100k ships, there are more than 10^{10} opportunities for interaction within the target area before the chain is broken. Even at very high individual probabilities of 'ships passing in the night' without communicating, the odds seem favourable. Higher numbers of participating civilisations greatly increase the possibilities of many-to-many communication.

‘We’re Here’ Signalling

At first glance, the problems for two small starships trying to find each other in a 5 ly volume appear daunting. The modelled communications over 4.3l y to Alpha Centauri depends on pointing accuracy within 0.067 arc-seconds and known wavelength, permitting narrow-band filtering.

While we have chosen 0.071c for historical reasons (Daedalus study and available calculations), the actual relative velocities of ship trajectories is unknown and Doppler shifts could be either blue for approaching ships or even slightly red, in the case of overhauling other Milky-Way outbound chains. Taking the extreme case of two probes approaching with a relative(istic) velocity of 0.2c (both ships at near Daedalus maximum velocity), signals would be significantly blue-shifted. The standard Doppler calculation shows, for wavelengths considered by Hippke:

λ-emitted (nm)	λ-received (nm) at 0.2c
1064	869
532	434
395	322

The large uncertainty in blueshift would preclude the use of fixed narrow-band filters in the initial detection phase; this would add to the difficulty of initial detection phase against the background of the bright GCs. If a sufficiently strong signal for spectral analysis, and with an unusual repetition (‘Little-Green-Men' LGM pulses [1]), Doppler shifts might be useful for positive identification. Of course, any help from blue-shift in this respect would only apply to approaching ships and be of little help in contacting outbound ships.

However, there would be no help from filtering for initial detection, and none from direction due to the geometric uncertainty of the AMiTe GC/GC line. In fact, for central line +/-2.5 ly, a ship on the periphery of the circle of uncertainty would subtend an angle of +/-30° to the centreline for a ship entering the central volume on the connecting line so could be coming from ‘anywhere’. Clearly, any reduction in assumed uncertainty would help to narrow the search volume.

Thermonuclear explosion signalling

A further possibility which can be numerically considered and perhaps quickly dismissed, is to examine the effectiveness of thermonuclear explosion signalling. Assuming that a short series of bombs equal to the largest ever exploded could survive an 18 MY wait and be detonated (at a suitable distance behind the probe) while crossing the calculated AMiTe point and at timed intervals, what is the effective detection range?

The size and mass of thermonuclear warheads is surprisingly small and a few could be accommodated, eg W88 Warhead (Trident missile), mass <360 kg, size <2 m^3, yield $2x10^{15}$ Joules. The half-life of the U235 (fission primary) is >700 MY and so it seems reasonable that such explosions would be possible. The light curve (spectrum vs time) of a bomb in vacuum is not readily available information but some estimate can be made of the gamma-ray yield. According to [2] the strong electromagnetic pulse (EMP) that results has several components. In the first few tenths of nanoseconds, about a tenth of a percent of the weapon yield appears as gamma rays with energies of one to three mega-electron volts. In the case of the largest H-bomb trial in the 1950s which yielded $2x10^{17}$ Joules, if 0.1% of this was emitted as 1 MeV gamma rays, the photon yield would be $1.25x10^{27}$ photons. Such energetic particles yield multiple detection events and can be used to extract directional information (as happens eg in the Large Hadron Collider detector stations). However, this requires a lot of detector area electronics. The gamma photon yield is small when spread over eg a sphere radius 1 ly ($1.26x10^{33}$ sq m) and at least two explosions would need to be detected, with good directional data and same energy to distinguish from random cosmic events. If a ship only used explosive signalling at the AMiTe point then probabilities are increased as N (number of ships) rather than N^2. This at present seems unpromising and an example of the difficulty of isotropic signalling at light-year distances, the ‘wastefulness’ of this method coming from most energy being lost as the kinetic energy of an expanding sphere of gas. More consideration may be warranted if an estimate could be made of the light curve of the cooling sphere.

[1] Jocelyn Bell Burnell, *Discoverer of pulsars (aka Little Green Men) reflects on the process of discovery and being a female pioneer,* news.cornell.edu/stories/2006/07/jocelyn-bell-burnell-reflects-discovery-pulsars

[2] Fission bomb yields en.wikipedia.org/wiki/High-altitude_nuclear_explosion referencing *Electromagnetic compatibility (EMC) - Part 2: Environment - Section 9: Description of HEMP environment - Radiated disturbance. Basic EMC publication* webstore.iec.ch/publication/4141 (paywalled)

As mentioned, the AMiTe Line connecting the GCs terminates on the bright and extended areas of the galactic cores. M31 has an ‘Absolute Magnitude’ in the visible of –21.5 (at the notional 10 parsecs); the apparent magnitude at AMiTe would be +1.5 (using ½ way distance of 389 kpc, the inverse square law and taking logs to base 100 and applying to the ‘absolute’); compare this with +3.4 apparent magnitude at Earth’s surface on a fine autumn/winter’s night. Detailed photometric calculations would be needed to determine the effective range of a blue-shifted source at a particular power/divergence/pulse-length vs either the bright galaxy or the ‘sky’ around it. The bright nucleus visible with the naked eye on earth has an angular extent of about 0.5° and so would be around 1° from AMiTe. Any defect in the spaceships’ courses from the ‘perfect’ AMiTe Line would mostly remove them from optical overlap with the bright background galaxies, but these areas would be more ‘in view’ from further back in the interaction cylinder.

Consider the area illuminated by a low divergence cone. This is really very small compared with the possible cross-sectional ‘uncertainty area’ of a 5 ly disk. At 4.3 light-years, the spreading of ‘Longshot’ (2 m send lens) signals results in a footprint radius of 13.4 million kilometres, or 8.9% of an Astronomical Unit (AU). With 10 m receive optics, this would still support a bandwidth of over 100 bit/sec, plenty for LGM signalling. 10 m send optics could, of course, be defocused to give the above divergence angle, or greater. Assuming the radius of 9% of an AU at 4.3 ly (~10% of AU at 5 ly) this represents a tiny fraction of a 5 ly disk (3.6×10^{-15}) or about 10^{-13} of a 1 ly diameter disk. If it takes a ship around 60 years to cross the volume, the average crossing time of two anti-parallel ships would be 30 years, about 10^{9} one-second timeslots over a 60° full-angle cone if the beam could be scanned/rastered, and assuming wide-angle defocused receiving optics. However, even this number of time-slots and area coverage over the whole area to scan, we fall short of covering the full target area by a factor of 10k to 250k. The N- squared factor of (eg) 10^{10} would therefore be needed to improve the odds. Higher spreads with weaker signals would also do this, limited by S/N performance, but should still allow reception of an unmistakeable LGM signal by a ship in the cone (and possibly up to twice or more the distance down the chain). There are many variables in signalling, search and trajectory patterns and it may be up to the optical SETI (O-SETI) research community to suggest a more considered approach to give a higher probability of any pair of ships communicating.

High energy pulse signalling may also be an option with ships starting to send high energy pulses as soon as they are on the interaction line, ie at AMiTe - 50 kly. At ~4 ly spacing along a 100 kly line, there would be of the order of 25,000 ships all sending high energy pulses forward, at low repetition rate, but with identical Doppler shifts which could have considerable range (remembering the maximum range calculated by Hippke of up to 3 kpc (~10,000 ly), in ideal filtered conditions).

After Contact: What Next?

This can mainly be left to the imagination. Once initial detection had been made within the interaction zone, trajectories would be calculated and passed up and down the line. Remaining fuel would be used to achieve closer approach and higher bandwidth communication at a precisely defined and filtered wavelength. 'Conventional’ SETI thinking, AI and machine learning would establish communications protocols which would enable data downloads to commence. Once all on-board data had been exchanged, some ships might use remaining fuel to divert towards suitable home systems in the target galaxy, enabling recovery (and possible artefact transfer) by separate, later launched ‘docking’ missions.

Project Counterparts

The ‘Treffpunkt’ concept relies on other civilisations drawing the same conclusions about the merits of AMiTe as a unique meeting point and, following long study and practical experience, arriving at a broadly similar mission profile. Absolute details such as probe velocity and spacing may be influenced by home-system details eg orbital periods of suitable gas giants and availability of He-3. Missions from both galaxies can be considered as equally likely and most probably from the ‘approaching quadrants’; lengths of mission (we propose 59 MY) may be influenced by favourable/unfavourable position in the approaching quadrant.

It is not impossible that ships approaching from M31 Type IIb civilisations may already have perfected the techniques having had previous success. After all, they have the advantage of the much nearer and more convenient M33 Triangulum galaxy (3rd largest in Local Group), which defines a ‘Tri-And’ Point at their mid-point. This would require much less time and energy to reach, improving the odds thereby. A single contact at the AMiTe point might therefore not only be with a single species but with a trans-galactic ‘community’ stretching back possibly billions of years.

Summary and Future Work

Mission Profile: Saturn, in a 5:2 orbital resonance with Jupiter, may be a convenient He-3 mining and jump- off point for ‘Daedalus-class' starships. Returning to the same relative positioning with Jupiter every 59 years (two orbits), the best conditions for accomplishing a Jupiter Oberth manoeuvre (if useful) and launching along the same trajectory as previous ships would pertain. Future analysis may choose Jupiter but we use the 59 year interval which hopefully would give enough time to extract the He-3 portion of the fuel, and for the construction of the spaceship, eg on the Moon, Titan etc (see Daedalus concept, Figure 6).

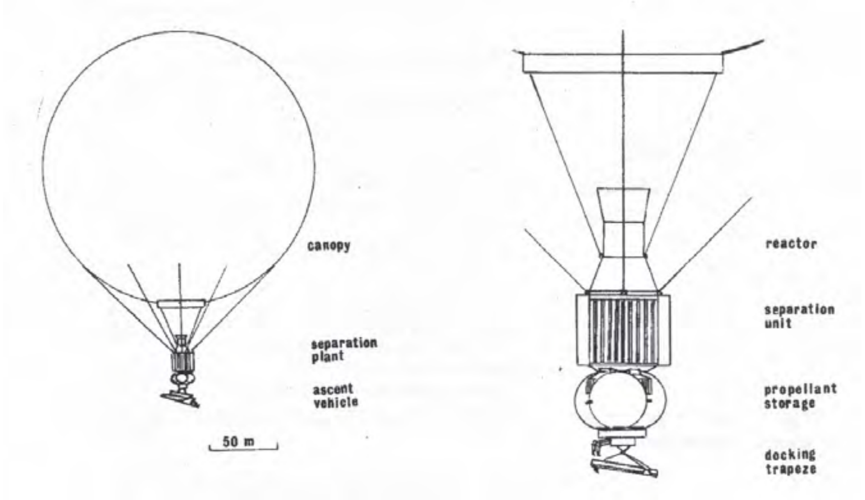


Fig 6. Daedalus Study: Proposed He-3 mining

(Original caption: Fig. 2. Jupiter aerostat factory
(a) overall scheme, with the ascent, vehicle docked
(b) detail of the factory complex)

Credit: *Project Daedalus: Propellant Acquisition Techniques* RC Parkinson

BIS *Project Daedalus - Final Report*, pp. S83-889, 1978.

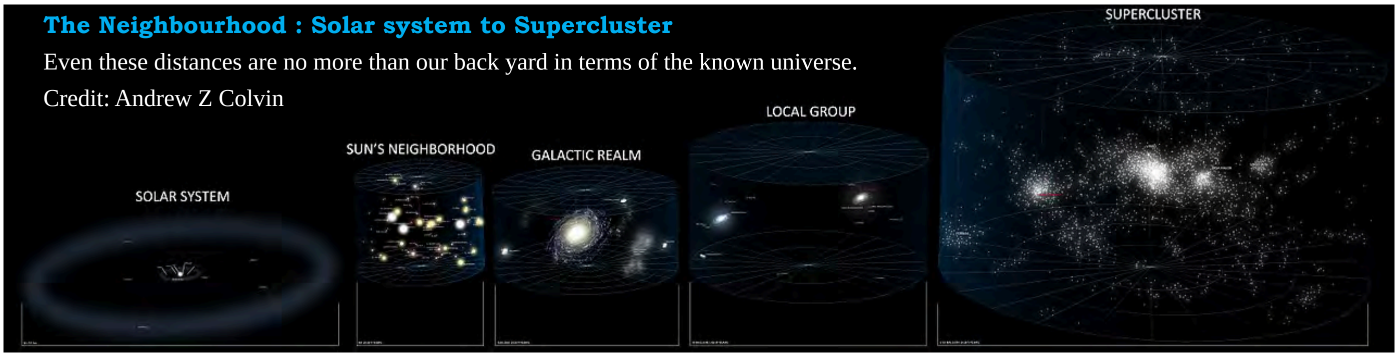
Ships would be launched every 59 years and attain a speed of 0.045c (Longshot) in the galactic disk, relaying navigational information and being tracked back along the line. Hopefully, a ‘free trajectory’ could be established outside the disk and then an acceleration to a cruise at 0.071c, in energy saving mode, towards a point at AMiTe minus 50 kly. At this point a final burn would occur to correct the vector along the GC-AMiTe-GC line, using latest data of AMiTe position passed up the line from Earth. Communication attempts could begin.

Note, the number of proposed ships at 1 million is not in itself extravagant compared with the number of automobiles in existence; this includes 200 million SUVs at the time of writing. The critical resource is assumed to be He-3 as has been noted elsewhere. Even the extremely long timescale is less that some of the proposals for L in the Drake equation and so AMiTe could be considered even by very long lived Kardashev IIa civilisations if other means had not been met with success.

This initial proposal is consistent (on the whole) with numbers published in previous proposals (Daedalus, Longshot) and reasonably foreseeable technologies. Further assessment is required especially on propulsion and power-plant aspects and also on mission profile. Even if the numbers derived from Daedalus still look ‘optimistic’, there may be a way of closing the gap (more fuel, more mass). At its core, the problem reduces to, “can a 2-way communications package with a nominal 4.3 ly range be accelerated to 5-7%c with enough convertible energy to last ~20 million years?”. Practical experience of missions to nearby stars over the next few centuries would test the technology. The communications requirements appears consistent with current O-SETI proposals but in this case we propose a new challenge: finding a needle in a 5 ly haystack. This aspect could clearly benefit from more analysis.

The proposal has been careful not to draw on any radically new technologies requiring the capabilities of an ‘advanced civilisation’, eg antimatter confinement. If such things are possible then we should consider studying the AMiTe point for signs that ET has long-since established a communications station there.

The desirability of the project is a moot point; it may only become attractive in the far-future as ‘the last one standing’ after other methods have been considered. Like many SETI proposals, it has a timescale longer by far than a human lifetime, or indeed the lifetime of any extant human civilisation, but the tantalising possibility that other civilisations have already used this method may prompt further study and perhaps alternative proposals.


The Neighbourhood : Solar system to Supercluster

Even these distances are no more than our back yard in terms of the known universe.

Credit: Andrew Z Colvin

Further reading

This supplements earlier footnotes.

ESA

ESA Advanced Concepts Team: Interstellar Workshop 20-21 June 2019
www.esa.int/gsp/ACT/news/2019-02-04-interstellar_exploration_workshop/

Michael Hippke

ui.adsabs.harvard.edu/search/q=author%3A%22Hippke%2C%20Michael%22&sort=citation_count%20desc%2C%20bibcode%20desc

Interstellar Communication Network. I. Overview and Assumptions / II. Deep space nodes with gravitational lensing.

Interstellar communication. I. Maximized data rate for lightweight space-probes / III. Optimal frequency to maximize data rate / IV. Benchmarking information carriers / V. Introduction to photon information efficiency (in bits per photon) / VI. Searching X-ray spectra for narrowband communication / VII. Benchmarking inscribed matter probes / VIII. Hard limits on the number of bits per photon / IX. Message decontamination is impossible.

Civilisation lengths

The Lancet: Global population in 2100 www.thelancet.com/infographics/population-forecast

BIS Project Daedalus

A Bond & A R Martin, "Project Daedalus – Final Report", British Interplanetary Society, 1978 - bis-space.com/shop/product/project-daedalus-demonstrating-the-engineering-feasibility-of-interstellar-travel/

Project Longshot

Spacecraft Systems: 3.4 Communications System Design
en.wikisource.org/wiki/Project_Longshot/Spacecraft_Systems#3.4

Doppler calculations

Georgia State University, Physics & Astronomy - *Hyperphysics* - hyperphysics.phy-astr.gsu.edu/hbase/index.html

Low Speed Doppler Shift / Doppler Expression Expansion / Doppler Calculation
hyperphysics.phy-astr.gsu.edu/hbase/Relativ/reldop3.html

About The Author

David F Gahan is a physicist, engineer and tech-entrepreneur, graduating from Imperial College London in 1984 (BSc Physics). He is the co-inventor of the world's highest temperature commercially available pressure/temperature sensor (1,000 Celsius, fibre-optic based), and was the Founder and CEO of Oxsensis Ltd (oxsensis.com/), which developed the sensor for gas-turbine aero and power applications and worldwide deployment. He has been CEO/CTO and occupied senior commercial positions in a number of companies and specialises in the development of technical/business opportunities in the physics based industries, from start-ups to major international enterprises in UK, France and USA. Sectors including energy, telecoms, displays and semiconductor equipment.

He now consults in technology development, innovation, change management, visioning, and company and process development. He has a side-line in classical composition, based on the writings of Charles Darwin, which led to a string-quartet performance at the Oxford Museum of Natural History in 2015.