Interstellar Flight:
Discovering the Limits of the Possible

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Contents

- The British Interplanetary Society
- Interstellar Studies
- The Institute for Interstellar Studies
BIS (from imagination to reality)

THE IMAGINATION WALL

BRITISH INTERPLANETARY SOCIETY (DOMAIN)

THE REALITY WALL

Ideas
Conjecture
Creativity
Concepts
Stories
Solutions
philosophy

Industry
Academia
Government
Inventions
Technologies
Spin-offs
careers

SPIN-IN

SPIN-OUT
BIS Projects (Imagination to Reality)

BIS Project Megaroc (1946)

NASA Project Mercury-Redstone (1960-61)
BIS Projects (Imagination to Reality)

H.G. Wells, “The First Men in the Moon”, 1901

J. Verne, “From Earth to the Moon”, 1865


NASA Project Apollo (1969)
Project KickSat is an initiative of Zac Manchester, Cornell University, USA and the BIS are launching a fleet of ChipSats or Sprites into Earth orbit.

RECRUITS NEEDED!!
BIS Project 2033 (NEW Launch)

What is the state of space exploration in the year 2033?
Are you the next visionary?
Send us your submission

RECRUITS NEEDED!!
Alpha Centauri Prize (New)

**Propulsion Option A**
(i.e. Solar Sails)

**Propulsion Option B**
(i.e. Laser Beaming)

**Propulsion Option C**
(i.e. Nuclear Fusion)

**Propulsion Option D**
(i.e. Antimatter)

Increasing TRLs & Design Performance Optimality

1st Interstellar Probe Design
The Alpha Centauri Prize

RECRUITS NEEDED!!
A project to design a 10 GW Solar Collector station in space capable of delivering energy to a space habitat at the L5 point.

RECRUITS NEEDED!!
"Imagining" Starships

Credit: David A Hardy
“I can never look now at the Milky Way without wondering from which of those banked clouds of stars the emissaries are coming...I do not think we will have to wait for long”. Sir Arthur C. Clarke
The Size of Space and Beyond

- Barred spiral galaxy
- 100-400 billion stars
- Oldest 13.2 billion years
- $1 \times 10^{12}$Msun
- 200 million years to rotate
- 27kLY to the centre from the Sun
- 1MLY Diameter
- 1kLY thick
- Even if we could travel at the speed of light, would take 27,000 years to reach Galactic centre and would take 1 millions years for any starship to cross entire galaxy, or 1,000 years to penetrate galactic thickness.
- Implications for Fermi Paradox: A statement on the apparent contradiction between our theoretical expectations for intelligent life in the Universe and our observations.
Voyager 1

- Launched 1977
- Currently at around 120 AU distance
- $1\text{AU} = 1.496 \times 10^{11}\text{ m}$, so Voyager at $1.795 \times 10^{13}\text{ m}$. Light travels at $3 \times 10^8\text{ m/s}$, so Voyager at 59,840 s, 997 minutes or 16.62 light hours away.
- Travelling at 17.4 km/s or 3.67 AU/year, which is 0.0058%c.
- So would take 74,138 years to reach Alpha Centauri if it was pointing that way.
- Conclusion: We need to go faster and further.
Interstellar Flight

L.R. Shepherd

The most significant factor in flight to the stars is the vast scale of distances involved. It would be possible, at least in principle, to construct a vehicle, drawing its power from known nuclear reactions, which would be capable of reaching the nearest stars in a period of time measured in centuries. Such a vehicle might achieve a maximum velocity of 5,000 to 10,000 km per second. One difficult problem would be the attainment of reasonable coefficients in conjunction with the necessary high subsonic velocities. An acceleration of 9.3 m/s² would be adequate but would involve an almost prohibitive rate of power dissipation.

Vehicles designed to achieve such velocities close to that of light would need to utilize sources of energy far more powerful than any known today. Nothing less than the complete conversion of matter into usable energy would be sufficient for this purpose. The efficiency of vehicles moving at such high velocities would have to be based upon the principles of special relativity. An important consequence of this would be the reduction of voyage travel times in the traveler’s system of reference. Even if one assumes the existence of power sources capable of giving vehicles velocities near to the speed of light, the attainment of such capabilities would be a formidable problem. Accelerations of the order of 1 g would be necessary to exploit fully the capabilities of such a vehicle and to take full advantage of the laser-detonation effect. A hypothetical vehicle propelled by phasers would require to develop a useful power rating of 3 billion watts per tonne of vehicle mass (a 1% extraction) to obtain a no-climb acceleration. If the phases were resolved from “solid body” surfaces, the temperatures involved would be of the order of 100,000°C.

Interstellar flight would not provide a haven at vehicle velocities less than 100,000 km/s, but at near-light velocities, individual nuclei of the interstellar gas would penetrate through considerable thickness (11 cm) of solid metal and procedures would have to be taken to protect any people in the vehicle.

1. Introduction

Sometime in the near future, perhaps before the turn of the century, man will take his first step into space. He will do so in all probability, without being unduly concerned about the chain of events which will be setting into motion. The significance of the act may not have escaped him entirely, but he is not likely to be influenced by considerations of the ultimate importance of interstellar travel upon human affairs. Scientific curiosity and the love of adventure for its own sake will be sufficient motives for the first exploratory voyages.

Nevertheless there must be many of us amongst the apostles of space flight to whom these two motives are only a small proportion of the whole purpose. There must be many who cannot derive complete spiritual satisfaction from the picture of mankind spending its whole existence in one single infinitesimal planet with no contact with other species who may populate countless other worlds of the universe. Many who hold to a more materialistic outlook may see in man’s confinement to a single planet a factor reducing his probability of survival. Humanity dispersed over many worlds appears more secure than humanity crowded on one single planet.

We are going to examine the possibilities of interstellar flight. It is clearly possible that the human race establishing colonies in other stellar systems, always assuming that there are worlds suitable for mankind to be found in such systems. In other words we are concerned with the problem of getting small colonies across the almost endless interstellar gulfs, safely, but not necessarily in a short time. It is not necessarily a question of getting an individual from one stellar system to another, but rather a question of getting an adequate community to another system. It is important to observe this point because this profoundly affects our interpretation of what is possible and what is impossible. For if we interpret the problem of interstellar flight as the problem of transporting a man from one system to another during his lifetime, then it is a much more difficult problem than that set by the alternative interpretation.
Interstellar Books
Fundamental Requirements

- Energy: $10^{18} - 10^{20}$ J
- Power: 10s - 100s GW
- Cost: $billions - $trillions
- Mission Time: 50 – 100s years
- Cruise Velocity: 2,000 – 3,000 AU/year
- Exhaust Velocity: 8,000 – 10,000 km/s
- Acceleration: 0.01 < g < 1
- Distance: 4 < LY < 20

- Unmanned Robotic Flyby Probe
- Unmanned Robotic Flyby Return Probe
- Unmanned Robotic Orbital Probe
- Crewed Minimum Return Ship
- Crewed Small Colony Ship
- Crewed Large World Ship
Advanced Space Propulsion

- Electric
- Nuclear Electric
- Laser Thermal
- Solar Thermal
- Nuclear Thermal
- Plasma Drives
- EM Mass Drivers
- Particle Beamers
- Solar Sails
- Laser Sails
- Microwave Beam Sails
- Fission
- Fission/Fusion
- Fusion
- External Nuclear Pulse
- Antimatter Catalysed Fusion
- Interstellar Ramjets
- Negative Energy
- Space Drives
- Warp Drives
- Worm Holes
- Time Machines

The technology readiness maturity distinguishes between ‘imagination’ and ‘reality’, conjecture and application.

Physics ➔ Engineering ➔ Economics

√          √          √
Energy Sources for Starships

- Chemical: 0.000001 unit, ~13 MJ/kg
- Nuclear Fission: × 1 unit, ~82 million MJ/kg
- Nuclear Fusion: × 10 units, ~347 million MJ/kg
  - Nuclear Fission/Fusion
  - Antimatter Catalysed Fusion
- Antimatter: × 1,000 unit, 90 billion MJ/kg
- Propellantless Solutions
  - Solar Sails
  - Laser Sails
  - Interstellar Ramjets
- Space Drives & Metric Drives
  - Vacuum Energy
  - Dark Energy
  - Negative Energy
  - Warp Drives
The Physics of Nuclear Fusion

- Sun confines fusion plasma by gravitational field.
- Tokamak uses magnetic field to confine plasma.
- ICF uses inertial mass of material to confine plasma.
- Balance of compression & ignition to deliver fusion energy to engine.
- Ideal reactions: \( D(T,He4)n \) (radioactive) \( D(He3,He4)p \) (charged particle, minimal shielding required).

- \( D + T \rightarrow He^4(3.52\text{MeV}) + n(14.06\text{MeV}) \)
- \( D + D \rightarrow T(1.01\text{MeV}) + p(3.03\text{MeV}) \)
- \( D + D \rightarrow He^3(0.82\text{MeV}) + n(2.45\text{MeV}) \)
- \( D + He^3 \rightarrow He^4(3.67\text{MeV}) + p(14.67\text{MeV}) \)
- \( Li^6 + n \rightarrow T + He^4 + 4.8\text{MeV} \)
- \( Li^7 + n \rightarrow T + He^4 + n - 2.5\text{MeV} \)
### Fusion Triple Product (Lawson Criteria)

\[ n \tau T \geq 10^{21} m^{-3} sKeV \]

For \( \sim 10\text{keV} \) plasma

\[ n \tau \geq 10^{20} m^{-3} s \]

<table>
<thead>
<tr>
<th>Confinement</th>
<th>( n )</th>
<th>( \tau )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inertial</td>
<td>( \sim 10^{23} \text{cm}^{-3} )</td>
<td>&lt;1ns</td>
</tr>
<tr>
<td>Magnetic</td>
<td>( 10^{-6} \text{cm}^{-3} )</td>
<td>( \sim \text{few sec} )</td>
</tr>
</tbody>
</table>

1. ![Image 1](image1.png)
2. ![Image 2](image2.png)
3. ![Image 3](image3.png)
4. ![Image 4](image4.png)
Neodymium glass laser
- Started operation 2009.
- 192 beams
- Deliver 1.8MJ to target.
- Potential output power 20MJ for ~ns but could be high as 45MJ.
- Achievable gains >10.
Project Daedalus (BIS, 1973-1978)

Project Daedalus (BIS, 1973-1978)
Project Longshot (1988)


Credit: Christian Darkin
Project Orion (1950s-1060s)

Dyson, F, Interstellar Transport, Physics Today, 21, 10, October 1968.
Enzmann Colony Starship (1960s)

World Ships (1980s)


Credit: Adrian Mann
Space Infrastructure (Skylon)

Credit: Adrian Mann and Reaction Engines Ltd
1963: Carl Sagan & Relativistic Flight

\[ m_{rel} = \frac{m_o}{\sqrt{1 - v^2 / c^2}} \]

<table>
<thead>
<tr>
<th>Fraction of light speed</th>
<th>Time measured by earth clock ΔT (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1c</td>
<td>20</td>
</tr>
<tr>
<td>0.5c</td>
<td>23</td>
</tr>
<tr>
<td>0.9c</td>
<td>46</td>
</tr>
<tr>
<td>0.95c</td>
<td>64</td>
</tr>
<tr>
<td>0.99c</td>
<td>142</td>
</tr>
<tr>
<td>0.999c</td>
<td>447</td>
</tr>
<tr>
<td>0.9999c</td>
<td>1,414</td>
</tr>
<tr>
<td>0.99999c</td>
<td>4,472</td>
</tr>
<tr>
<td>0.999999c</td>
<td>14,142</td>
</tr>
</tbody>
</table>

\[ t = \frac{2c}{a_n} \cosh^{-1}\left(1 + \frac{a_n S}{2c^2}\right) \]

Breakthrough Propulsion Physics (1994)
\[ ds^2 = -dt^2 + [dx - v_s(t) f(r_s(t)) dt]^2 + dy^2 + dz^2 \]

1996 - 2002

Three visionary breakthroughs were identified:

(1) Mass: propulsion that requires no propellant

(2) Speed: propulsion that circumvents existing speed limits

(3) Energy: breakthrough methods of energy production to power such devices.
Project Icarus Pathfinder (1,000 AU) and Starfinder (10,000 AU) Concepts
Building an Interstellar Society

• Political
• Economic
• Business
• Socio/cultural
• Philosophical
  • (e.g. religious)
• Psychological
• Legal
• Scientific
• Technological
The Emergence of “Interstellar Studies”

“To the Stars…”

“…but with a Plan”
A FUTURE (2111) WHERE BUILDING OF INTERSTELLAR SPACESHIPS IS POSSIBLE

THE ROADMAP TIMELINE

THE FUTURE

THE PRESENT

THE PAST

OUR JOURNEY SO FAR

WHERE WE ARE TODAY

THE FOUNDATIONS WE BUILD FROM

PROJECT ICARUS

PROJECT

PROJECT WORLDSHIPS

ORION

ENZMANN

STARWISP

PROJECT

DAEDALUS

LONGSHOT

VISTA

PROJECT

BUSSARD

RAMJET

PROJECT

PUBLICATIONS

TECHNOLOGY

LITERATURE

KNOWLEDGE

CAPTURE

INSTITUTE

SALARIES

AWARDS/GRANTS

TEACHING

EDUCATION

EXPERIENCE

TRAINING

POSITIONS

PROJECTS

DEVELOPMENT

CONCEPTS

DESIGN

BLUEPRINTS

STRATEGIES

TECHNOLOGY

ROADMAP

TECHNOLOGY

SCIENCE

CODES

KNOWLEDGE

ANALYSIS

PHYSICS

ENGINEERING

PUBLICATIONS

WEB FORUMS

COMMUNICATION

NETWORKS
The seeds of an Idea

INTERSTELLAR INSTITUTE FOR AEROSPACE RESEARCH
A CONCEPT PROPOSAL

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This paper was originally a response to a US DARPA solicitation announcing the Interstellar sails, called INTERSTELLAR INSTITUTE FOR AEROSPACE RESEARCH.

1. INTRODUCTION
The possibility of interstellar flight has been the subject of many speculative fiction works (e.g., in fantasy, science fiction and poetry). Despite this, the community has generally believed that interstellar flight is speculative in nature, and that no practical method for achieving interstellar flight has been demonstrated. In 1959, the concept of interstellar flight was first proposed by Dr. L. G. Kippen, who later developed the concept of interstellar flight into a practical method. In 1959, the concept of interstellar flight was first demonstrated by Dr. L. G. Kippen, who later developed the concept of interstellar flight into a practical method. In 1959, the concept of interstellar flight was first demonstrated by Dr. L. G. Kippen, who later developed the concept of interstellar flight into a practical method.

The second step towards the development of a working model was the development of a working model. This was done by the designer of the theoretical spacecraft, a concept that has been referred to as a "starship" (or "spacecraft"). By 1963, the concept of interstellar flight was first demonstrated by Dr. L. G. Kippen, who later developed the concept of interstellar flight into a practical method. In 1959, the concept of interstellar flight was first demonstrated by Dr. L. G. Kippen, who later developed the concept of interstellar flight into a practical method.

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“Scientia ad sidera”
Knowledge to the Stars
Mission & Vision

• **Mission Statement:**
"The mission of the 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 Statement:**
"We aspire towards an optimistic future for humans on Earth and in space. Our bold vision is to be an organisation which is central to catalysing the conditions in society over the next century to enable robotic and human exploration of the frontier beyond our Solar System and to other stars, as part of a long-term enduring strategy and towards a sustainable space-based economy."
Web Sites

www.I4IS.org  www.interstellarindex.com
Educational Academy

• **Purpose:** To build the knowledge and people capability

• 3 internal students

• 4 ISU Msc students:
  • James Harpur, “design of 100 kg interstellar probe”
  • Piotr Murzionak, design of an 550-1000 AU interstellar precursor mission”
  • Wei Wang, Review of deceleration options for an interstellar probe”
  • Eric Franks, “Agricultural methods for microgravity environments”.
Purpose: To conduct the fundamental research, solve the problems, derive solutions, insights and designs.

- CATSTAR
- OAKTREE
- Bussard
- SENTINEL
- Quantum Light
- Unruh
- BAIR
- Casimir
- GeV
Purpose: To develop and spin-out the technology developments as innovations, business or enterprise.

Similar to the Stanford University model of the 1940s and 1950s when dean of engineering Frederick Terman encouraged faculty and graduates to start their own companies, e.g. Hewlett-Packard, Varian Associates...Silicon Valley
OAKTREE (Observations And Knowledge with Targeted Reconnaissance of Earth-like Exoplanets)

- Goal: To characterise all nearby star systems within twenty light years and enhance observational programs.
Project Bussard

Bussard

- Goal: To research the history, physics and engineering issues associated with the Bussard interstellar ramjet.
SENTINEL (SEarch for Non-Terrestrial Intelligence Near Earth Light-years)

- Goal: to use scientifically rigorous methods and techniques to address the possibility, and thereby purpose, for extraterrestrial intelligence, or associated artifacts, being within light years distance of Earth as a means to creating pathways to solving the Fermi Paradox.
Quantum Light

- Goal: To define quantum neurogenic light speed controllers
Unruh

- Goal: To test quantized inertia experimentally, and to determine whether we can affect inertia by interfering with Unruh radiation and devise ways to test its prediction of faster than light travel.
Project BAIR

BAIR (Black Hole Applications for Interstellar Ramjets)

- Goal: to investigate the application of black hole physics to spacecraft propulsion.
Project Casimir

Casimir

- Goal: To investigate macroscopic Casimir energy as a possible power source for interstellar flight
Goal: To investigate high energy 1GeV generator technology for applications to high specific impulse spacecraft propulsion.
1. **Physics Principles Understood**  
   (~$100s)

2. **Physics Principles Validated**  
   (~$10,000s)

3. **Engineering Ground Demonstration**  
   (~$100,000s)

4. **Orbital System Demonstrator**  
   (~$1,000,000s)

5. **Mission Application**  
   (~$10,000,000s)

**Goal:** To design concepts and build missions cheaply which can demonstrate interstellar related technologies using CubeSat and smaller devices, related architectures.

**CubeSat Architecture Tests for Space Technology And Readiness**

CATSTAR PROGRAM
“Travel to the stars will be difficult and expensive. It will take decades of time, GW of power, kg of mass-energy and trillions of dollars...interstellar travel will always be difficult and expensive, but it can no longer be considered impossible”.
Dr Robert Forward, 1996.