Project Icarus: Antimatter Catalyzed Fusion Propulsion For Interstellar Missions

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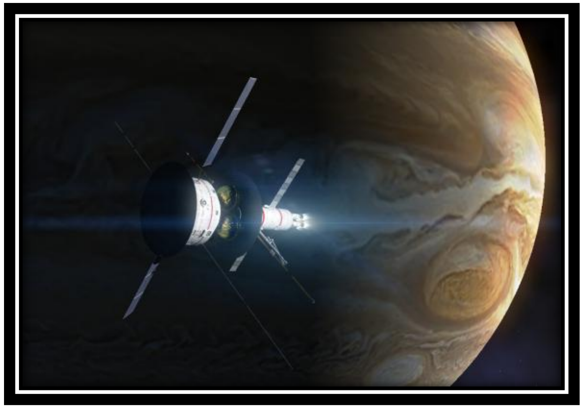
Overview

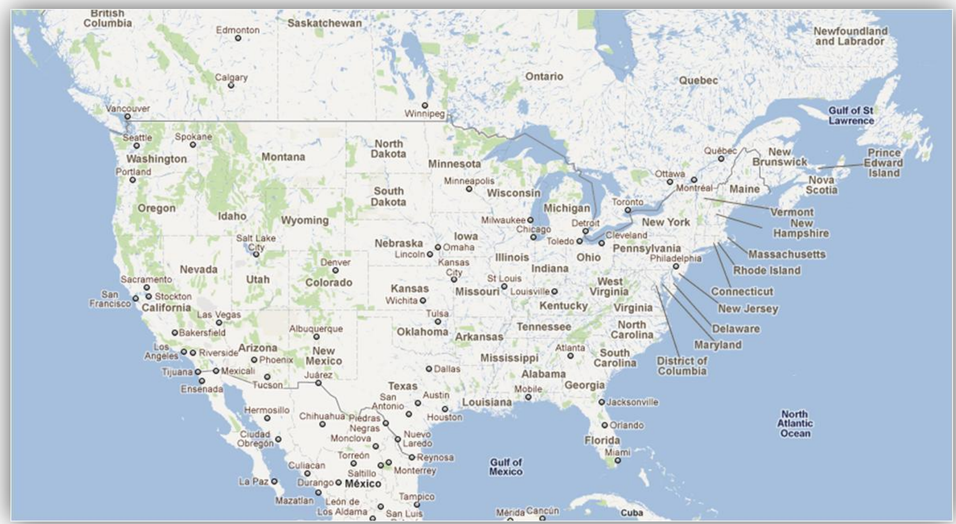
- Part 1: The Physics of Interstellar Travel
- Part 2: Project Icarus
- Part 3: Antimatter Catalyzed Fusion Propulsion For Interstellar Missions

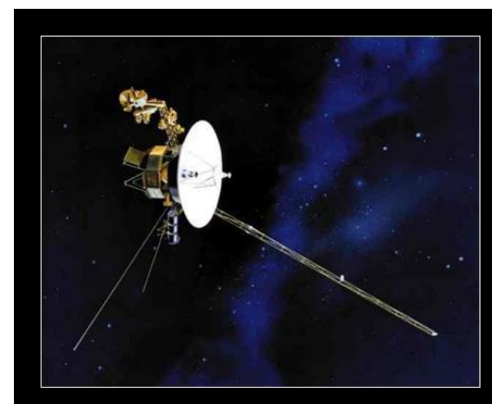


Interstellar Precursor Probe, "Icarus Pathfinder", designed by Project Icarus. Courtesy Adrian Mann

Part 1. The Physics of Interstellar Travel

- Currently four US spacecraft are travelling in interstellar space. These are the *Voyager* and *Pioneer* probes, travelling at speeds of 2.2 and 3.5 AU/year respectively.
- Voyager 1 is travelling at 17 km/s (38,000 mph) and is 116 AU from Earth.
- One of our closest neighbors, α-Centauri, is 272,000 AU from Earth.





The Limitations of Chemical Rockets

- This challenge becomes more apparent if we consider one of the simplest equations that governs spaceflight; the Tsiolkovsky rocket equation.

$$R = exp(\Delta v / I_{sp} g_0)$$

- Plugging in the numbers relating to a chemical propellant fueled flyby of α-Centauri with a Δv of 10%c reveals that we would need more fuel than there exists mass in the known universe!

Propulsion Physics

- Classically, **chemical** reactions encompass changes that strictly involve the motion of electrons in the forming and breaking of chemical bonds.
- Only 13.6 eV of energy is required to ionize a Hydrogen atom.
- Contrast this with 200 MeV released from the fission of U-235, or the 17.6 MeV released during a DT fusion event.

Reaction	Specific Energy (J/Kg)	Specific Impulse (s)
Chemical	1.5 E7	~100
Fission	7.1 E13	~1000
Fusion	7.5 E14	10,000 - 1,000,000
Antimatter	9.0 E16	> 1,000,000

Energy Densities of Rocket Fuels

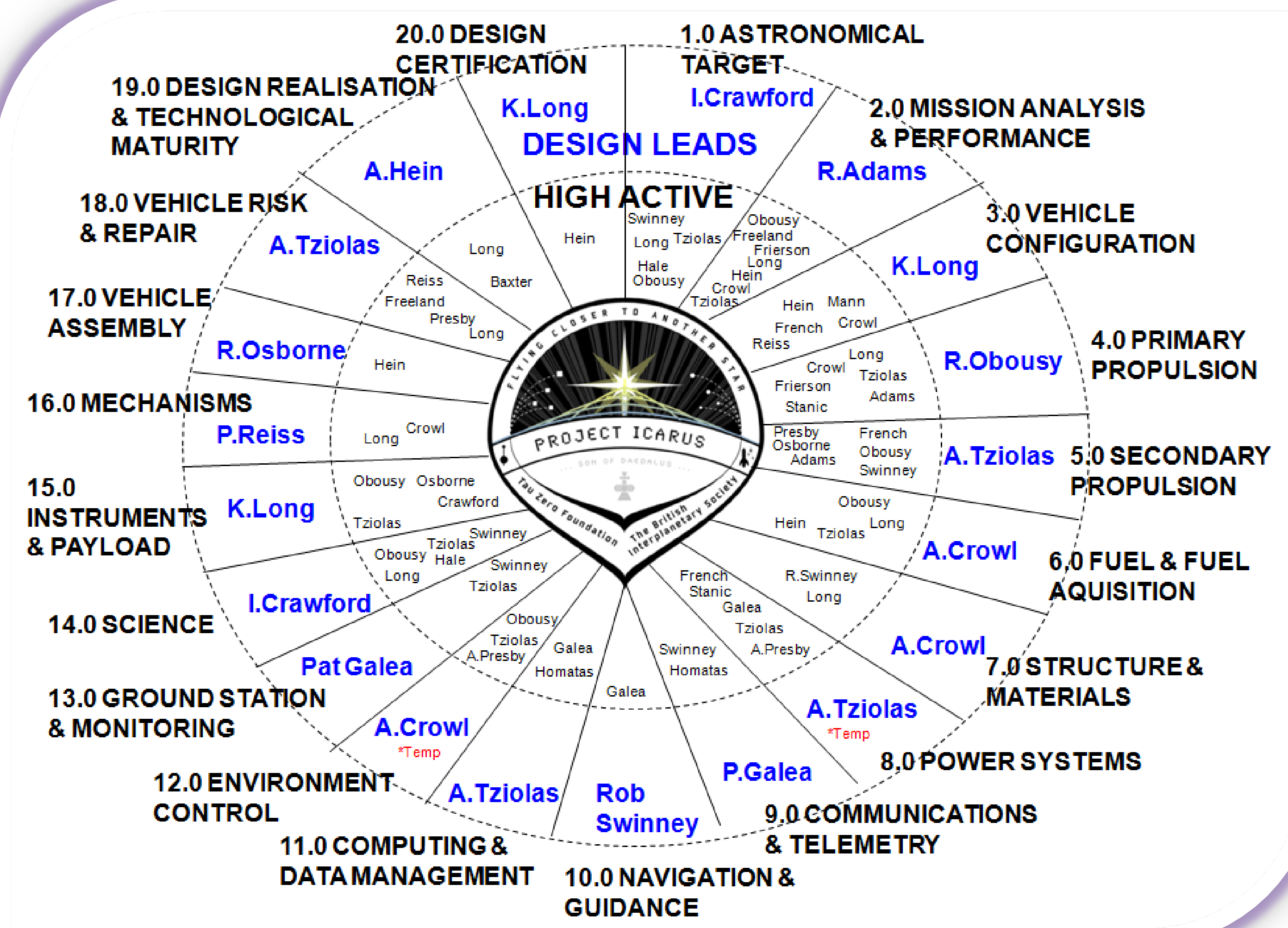
Part 2. Project Icarus and Icarus Interstellar

- Project Icarus is a five year theoretical design study for an interstellar mission using current and near term technology.
- Project Icarus was inspired by Project Daedalus which was a British Interplanetary Society Project that was conducted over 1973 - 1978.
- Our team is international and works primarily via electronic collaboration.

Terms of Reference for Project Icarus

- To design an **unmanned probe** that is capable of delivering useful scientific data about the **target star**, associated planetary bodies, solar environment and the interstellar medium.
- The spacecraft must use **current or near future technology** and be designed to be launched as soon as is credibly determined.
- The spacecraft must reach its stellar destination within as fast a time as possible, **not exceeding a century** and ideally much sooner.
- The spacecraft must be designed to allow for a **variety of target stars**.
- The spacecraft propulsion must be **mainly fusion based**.
- The spacecraft mission must be designed so as to **allow some deceleration** for increased encounter time at the destination.

Project Icarus Research Modules



Project Icarus has a fourfold purpose:

1. To motivate a new generation of scientists in designing space missions that can explore beyond our solar system.

2. To generate greater interest in the real term prospects for interstellar precursor missions that are based on credible science.

3. To design a credible interstellar probe that is a concept design for a potential mission in the coming century.

4. To provide an assessment of the maturity of fusion based space propulsion for future precursor missions.

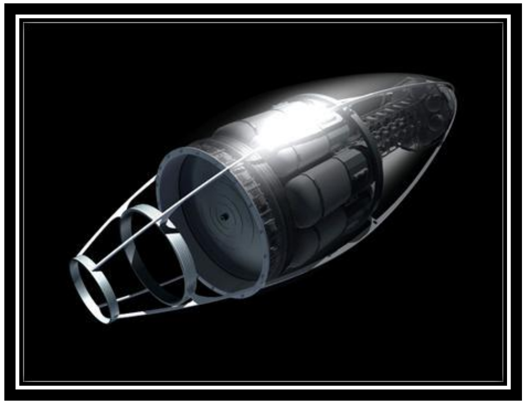
Recent Publications

- K. F. Long. "Project Icarus: Astronomical Considerations Relating to the Choice of Target Star", **JBIS**, Vol64. No.4/5. (2011).
- I. Crawford. "Project Icarus: Astronomical Considerations Relating to the Choice of Target Star ", Accepted for **JBIS** Publication (2011).
- K.F.Long, M.Fogg, R.Obousy, A.Tziolas, A.Mann, R.Osborne, A.Presby. Project Icarus: Son of Daedalus - Flying Closer to Another Star. **JBIS**, 62 No. 11/12, pp403-416 Nov/Dec 2009.
- S. Baxter, "Project Icarus: The Challenges of Mission Longevity", Accepted for publication in **JBIS** (2011).
- S. Baxter, "Project Icarus: Three Roads to the Stars", Accepted for publication in **JBIS** (2011).
- K.F.Long, "Project Icarus: The first unmanned interstellar mission, robotic expansion & technological growth", **JBIS** (under review).
- I. Crawford, "Project Icarus: A review of local interstellar medium properties of relevance for space missions to the nearest stars", **Acta Astronautica**, Accepted Oct 16th 2010.
- K.F.Long, R.K.Obousy, A.Hein, "Project Icarus: Optimisation of nuclear fusion propulsion for interstellar missions", **Acta Astronautica**, 68, pp. 1820-1829, (2011).

Icarus Propulsion System

- The Project Icarus Primary Propulsion module is examining a number of possibilities for the main engine propulsion system including:

  - ICF I - Internal Pulsed
  - ICF II - External Pulsed
  - MCF
  - Magnetic target fusion
  - Polywell
  - Long pulse laser beam
  - Electron beam
  - Ion beam
  - Short pulse laser beam
  - gamma-ray laser beam
  - Di-positronium laser
  - Fusion Propulsion I: Z-Pinch
  - Fusion Propulsion II: Dense Plasma Focus
  - Antimatter I: Antimatter Initiated MicroFusion
  - **Antimatter II: AMCF**
  - Colliding Beam
  - Fusion-boosted fission hybrid (Mini Mag Orion)



Icarus concept vehicle, courtesy of Adrian Mann.

Part 3. Antimatter Catalyzed Fusion Propulsion For Interstellar Missions

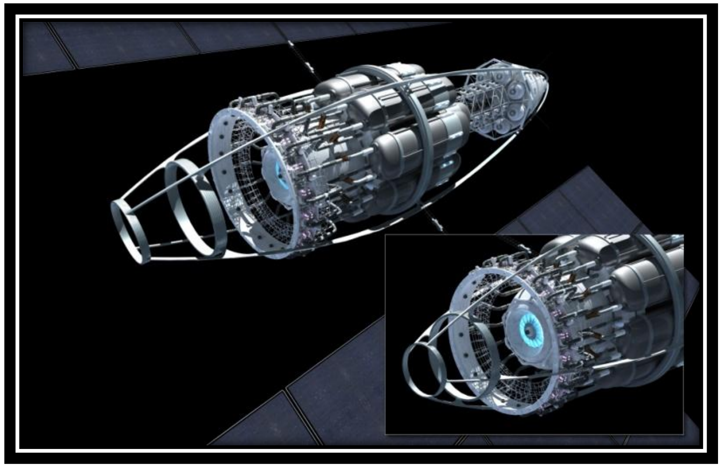
Antimatter

- Paul Dirac predicted the existence of antimatter in 1928.

- Positron discovered in 1932.
- Antiproton discovered in 1955.

- No known reaction yields more energy than matter antimatter annihilation.

- Main issues; creation and storage of antiparticles.



Antimatter concept craft created for Obousy courtesy of Adrian Mann.

- Penn State Universities Mark 1 trap can store 10 billion antiprotons for about a week.
- Global production is 1-10ng per year.
- Est costs $100B per mg

Electron Positron Annihilation

Antimatter Rockets

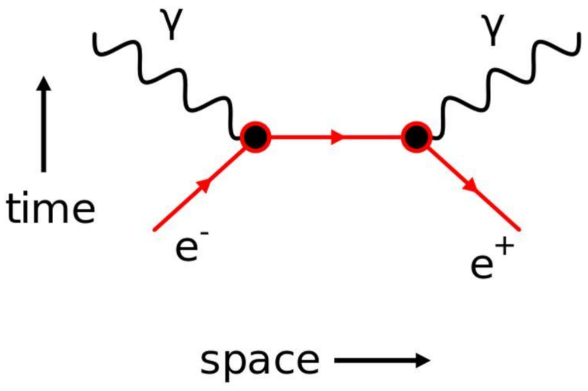
- Theoretical models for positron/electron and proton/antiproton propulsion engines exist in the literature.

- Sanger rocket

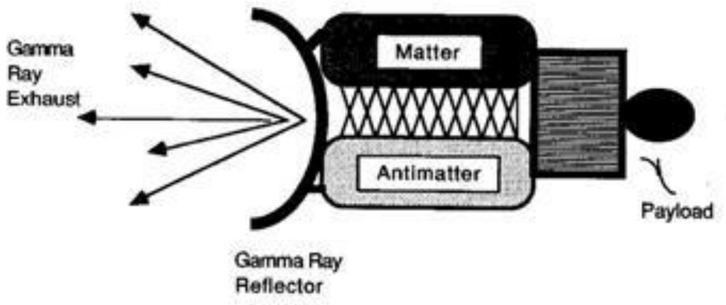
To generate thrust a way needs to be found to channel the gamma rays into an exhaust stream.

http://arxiv.org/abs/1111.3608
The Refractive Index of Silicon at Gamma Ray Energies
D. Habs, M.M Günther, M. Jentschel, W. Urban
(Submitted on 11 Nov 2011) Max Planck Inst. For Quantum Optics

Gamma ray optics?



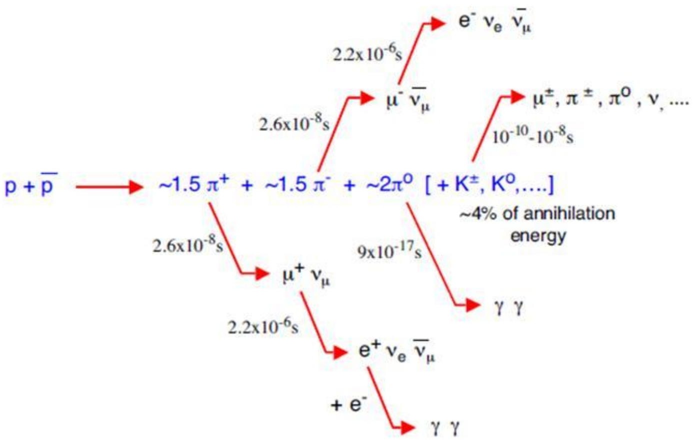
Electron positron annihilation generates gamma ray photons. Process must satisfy all conservation laws (charge, linear and angular momentum, energy).



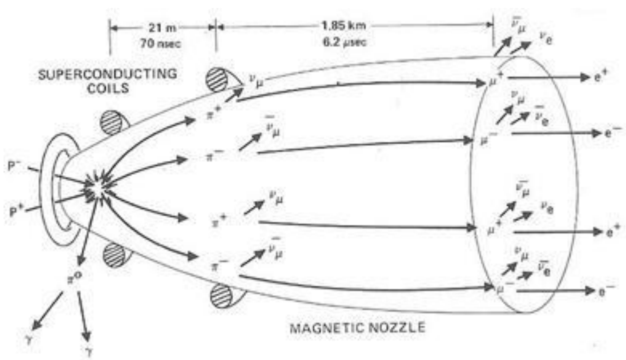
Sanger Photon Rocket. Image courtesy The Starflight Handbook

Proton Antiproton Annihilation

Antimatter Rockets



- The annihilation of antiprotons is a strong interaction process that takes place at the level of the quark structure of the nucleus.
- For annihilation of protons a rest 1.88GeV of energy is produced.
- Charged Pions account for ~64% of KE



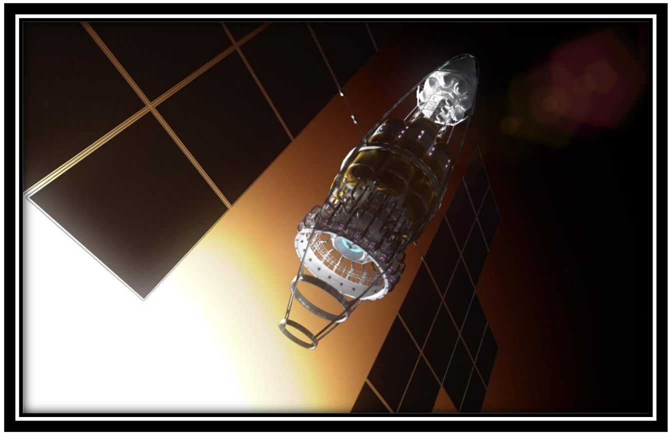
Proton Antiproton Annihilation Rocket – Image courtesy Robert Forward.

Antimatter Catalyzed Fusion

AMCF

• Antiprotons are an alternative to conventional fusion ignition schemes.
• An Antiproton beam offers 90MJ/μg and holds a major advantage over laser, particle beam and other fusion ignition schemes for space propulsion.
• Antiproton driven fusion ICF falls into the following ignition schemes:

- Volumetric Ignition
- Hotspot Ignition
- Fast Ignition



Antimatter concept craft created for Obousy courtesy of Adrian Mann.

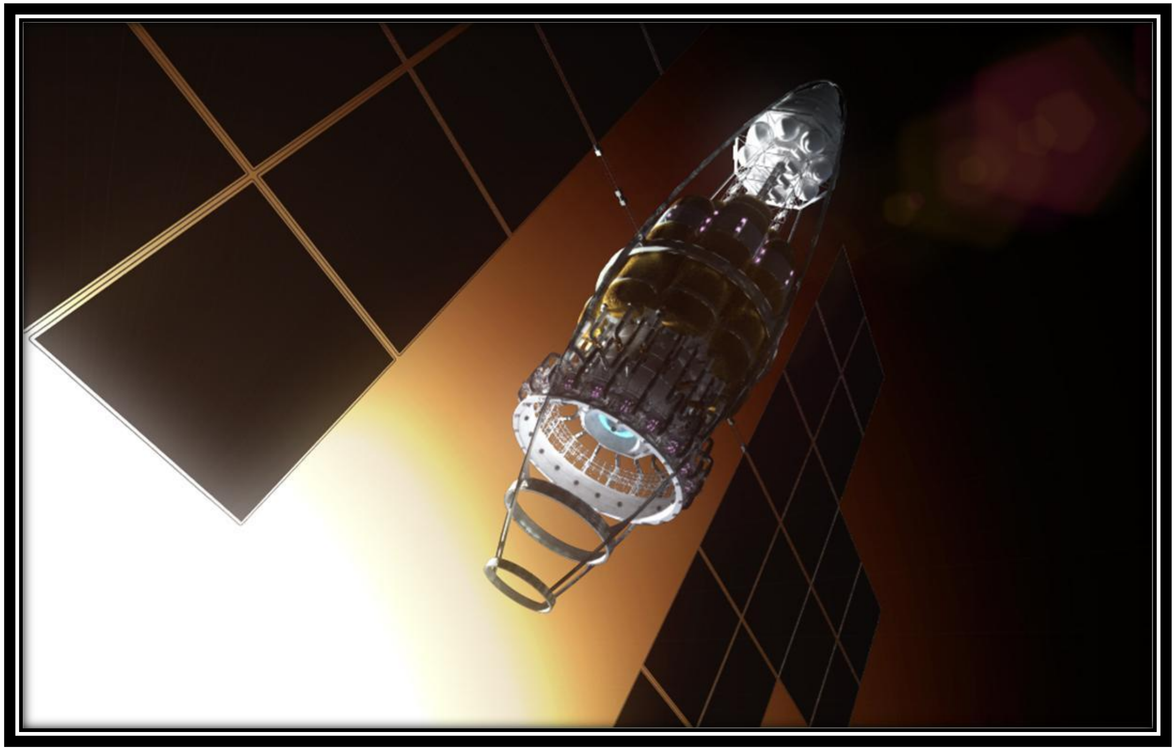
• NIF, a conventional ICF driver delivers 1.3MJ of energy to a DT pellet. Total mass of the facility is 100k tonnes.

Advanced Concepts

AIMStar

- Antimatter Assisted Microfusion Starship
- Penn State Initiative
- D/He3 fuel mixes with antiprotons confined in Penning trap
- U238 also injected
- Antiprotons induce fission which then induces fusion
-

The End



“All of this seems an incredible undertaking, but if we are to tackle the problem on the astronomical scale, then we must attempt to visualize solutions to suit.”

Dr. Anthony Martin,
Project Daedalus