Interstellar Travel &
The Fermi Paradox
Maximum Speed Achieved

<table>
<thead>
<tr>
<th>Maximum Speed Achieved</th>
<th>% Speed of Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horse</td>
<td>0.000001%</td>
</tr>
<tr>
<td>Train</td>
<td>0.000010%</td>
</tr>
<tr>
<td>Automobile</td>
<td>0.000100%</td>
</tr>
<tr>
<td>Plane</td>
<td>0.001000%</td>
</tr>
<tr>
<td>Space Probes</td>
<td>0.100000%</td>
</tr>
<tr>
<td></td>
<td>1.000000%</td>
</tr>
<tr>
<td></td>
<td>10.000000%</td>
</tr>
<tr>
<td></td>
<td>100.000000%</td>
</tr>
</tbody>
</table>

YEARS BEFORE | YEARS AFTER
---|---
1000 | 1000
100 | 100
10 | 10
Now | Now
# Rocket Limitation

**Propellant Mass to send one canister past Alpha Centauri within 900 years**

<table>
<thead>
<tr>
<th>Propellant Type</th>
<th>Duration (sec)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical</td>
<td>500</td>
<td>$10^{137}$</td>
</tr>
<tr>
<td>Fission</td>
<td>5,000</td>
<td>$10^{17}$</td>
</tr>
<tr>
<td>Fusion</td>
<td>10,000</td>
<td>$10^{11}$</td>
</tr>
<tr>
<td>Ion/Antimatter</td>
<td>50,000</td>
<td>$10^{5}$</td>
</tr>
</tbody>
</table>

A BILLION
A THOUSAND
TEN

Not enough mass in the universe

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**Conclusion:** we need a Propulsion Breakthrough; NO PROPELLANT!
Some ideas for the future

There are plausible ideas to work on, but warp drive and worm holes may have to wait.
Interstellar Travel: Issues

1. How far do we have to go?
   To reach another star: $\alpha$ Centauri, 4.2 light years away.
   To reach a known planetary system: $\epsilon$ Eridani, 10 light years away
   To reach a planet like the Earth: who knows?

2. How long do we want to wait?
   Adult life: 50 years
   Multigeneration travel: 30 generations = 1000 years?
   (Linguistic & Cultural stability becomes an issue…)

3. How long will it take?
   At 30 km/s (solar sail, ramjet): 4.2 light years in 42,000 years
   At 3000 km/s (nuclear pulse): 4.2 light years in 420 years
   Near the speed of light (a-matter): 4.2 light years in 4.2 years
   Galactic Centre in 26,000 years
   Nearby galaxies in 2-10 million years

Note: Teleportation — remote reconstruction of matter at light speed — is not ruled out by the laws of physics. Quantum collapse of the wave function does not prevent it.
Why go fast?
Slow transport is possible, and the only option to carry any significant payload.

**Multigenerational craft or “space arks”:** carry an entire ecosystem and civilization.
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Stasis craft: carry crew in hibernation.
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**Clone craft:** carry just the genetic information to create a colony at the destination (and good enough androids to raise them!)

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Von Neumann Machine
Self Replicating Interstellar Probe
Average distance between Habitable planets?

How can we calculate this?

(1) Need to know how many Habitable Planets. Units: NONE

(2) Figure out volume of Milky Way. What is “shape” of Milky Way Galaxy? Units: lightyear$^3$
Average distance between planets?

Assume best estimates from Kepler of Habitable terrestrial planets:

~ 1 billion planets

Milky Way ~ pancake
R ~ 50,000 ly
H ~ 1,000 ly

Volume = $\pi R^2 H$
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(1) Need to know how many Habitable Planets.  Units:  NONE

(2) Figure out volume of Milky Way.  What is “shape” of Milky Way Galaxy? Units:  lightyear$^3$

(3) Calculate density of Habitable Planets : units  1 / lightyear$^3$
Average distance between HB planets?

Density = Number of planets / Volume

\[
\frac{1 \times 10^9 \text{ planets}}{\pi (50,000 \text{ ly})^2 (1000\text{ly})} \approx 1 \times 10^{-4} \text{ planets/ly}^3
\]
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(3) Calculate density of Habitable Planets: units 1 / lightyear$^3$

(4) Convert density into average distance assuming planets are evenly distributed in Milky Way

Avg. Distance ~ \((1 / \text{Density})^{1/3}\)

Convince yourself that the units work out!
Average distance between planets?

**Density = Number of planets / Volume**

If we assume the star systems are uniformly distributed, then the typical distance between them is:

$$\text{Distance} = \left(\frac{1}{\text{Density}}\right)^{1/3}$$

Distance $= \left(\frac{1}{1 \times 10^{-4}}\right)^{1/3} \sim 20$ ly
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**Galactic Colonization**

Depending on assumptions, ~1 billion habitable planets in Milky Way
Distance between suitable planets: about 20 lightyears
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Maximum speed of conceivable multigenerational craft: **0.001 to 0.01c**
Travel times are in the range **1,000 to 10,000 years**
How long to colonize?

Total time to span the Galaxy:

5000 hops x 1,000 years

= 5 million years
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If new craft are built and sent out soon after colonization, we’d span the Galaxy in ~5-50 Myr. Could any civilization do this? Will we?
"Where Are The Aliens?"
The Fermi Paradox

As originally phrased by Erico Fermi, it seems a reasonable proposition that:

• Our civilization and technology is very young; life forms with much more advanced technology could have remarkable capabilities.

• A modest extrapolation of current technology allows us mine asteroids or moons, and create probes that could create replicas of themselves and propagate through the galaxy.

• There are many likely sites for complex life, and plenty of time for technology to develop, billions of years before Earth formed.

"Where Are They?"
Some Solutions to Fermi’s Paradox

- We are alone
  - civilizations are extremely rare and we are the first one to arise
  - then we are unique, the first part of the Universe to attain self-awareness
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• Civilizations are common, but no one has colonized the Galaxy
  • perhaps interstellar travel is even harder or costlier than we imagine
  • perhaps most civilizations have no desire to travel or colonize
  • most civilizations have destroyed themselves before they could
  • we will never explore the stars, because it is impossible or we will destroy ourselves
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- **There is one or more Galactic civilizations**
  - it has deliberately concealed itself from us
  - we are the Galaxy’s novices, on the verge of a great adventure
PRIME DIRECTIVE: NEVER MESS WITH PRE-WARP CIVILIZATIONS

SHIPS NOT CAMOUFLAGED
Should We Be Trying to Contact?
So, let me get this straight. You’re going to fly this thing up to the Mother Ship and upload a virus?
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- We may know which solution is correct within the near future!