Interstellar Travel

Why Interstellar Travel

Where Can We Go?

How Can We Get There

What Would an Interstellar Civilization Might Be Like
Interstellar Travel: A Major Undertaking.

Journey times in years.

Astronomical Energy requirements

Zetajoules (ZJ)
Zeta = $10^{21}$
Joule = 1 Watt-Second

≈ Present World Energy Use
1 ZJ

0.5c Starship
14 ZJ
cold sleep
1000 mT
0.5 c
small crew

0.87c Starship
90.4 ZJ
1000 mT
0.87 c
gamma = 2
time dilation
cold sleep
small crew

0.05c "Generation Ship"
112 ZJ
1,000,000 mT
0.05 c
Flying biosphere2, about 10 aircraft carriers or big cruise ships
≈ 2 centuries to alpha Cen.

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Why Interstellar Travel?

Provide realtime human guidance to exploration robots.

Entertainment value for actual and vicarious participants

Commerce? Unique artifacts?
- Extrasolar artwork by aliens or human colonists?
- Archeological SETI exhibits for Earth museums

Not for...

Resources--much cheaper to mine or make in the solar system
Extrasolar Colonies for More Living Room?

Short term:

--Isolation.

Some folks just can't get along

...or are tired of putting up with idiots.

--Empire building

No room on Earth for this antisocial occupation, but go grow your own?

Long term:

--External disasters we can't cope with otherwise? (When Worlds Collide)

we know Jupiter-sized rogue planets exist...

--Our habitable zone is moving out as the Sun ages and expands;

we might buy a few billion years with sunshields or moving Earth...

BUT red dwarfs last for around a trillion years.

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## Nearby Star Destinations

<table>
<thead>
<tr>
<th>Name</th>
<th>Spectrum</th>
<th>Luminosity</th>
<th>Distance</th>
<th>&quot;AU&quot;</th>
<th>&quot;year&quot;</th>
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Gliese 876 and its planets and moons
After Merlis and Schneider, 2010
Orbital Period Chart: Sol, Jupiter, and Some Extrasolar Systems

Orbital Frequency (mean motion) in cycles per century

Current (2006)
Single Planet Observational Limit

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Resonances can allow stable orbits near giant planets.

5 times apoastron continuum

1/5 periastron distance continuum

2:1 Resonance band

1:1 (Trojan) Resonance Orbits

1:2 Resonance band

3:2 Resonance

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Habitable or Terraformable Moons?
Star travelers may make their own worlds from local resources.
HOW DO WE GET THERE?

--ROCKETS

--SAILS
Interstellar Flight: Energy, Velocity, Time

\[ KE = m \ c^2 \left( \gamma - 1 \right) \]
\[ \gamma = \sqrt{\frac{1}{1 - v^2/c^2}} \]

\( KE = \) Kinetic Energy \quad \( \gamma = \) Lorentz factor \quad \( m = \) mass \quad \( v = \) velocity

For constant acceleration \( a \) in the spaceship frame

\[ s = \frac{c^2(\gamma - 1)}{a} = \frac{KE}{m^*a} \]
\[ \Delta t = \frac{v}{a} + \frac{v^*s}{c^2} \]

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Interstellar Flight: Accelerate, Coast, Decelerate

Decelerate for 0.5 Y

Coast time

Accelerate for 0.5 Y

Distances:
- Coast Distance: 3.8 LY
- Total distance: 8.1 Y

Velocities:
- Initial velocity: $v = 0.5 \cdot c = 1.5 \times 10^8 \text{ m/s}$
- Final velocity: $v = \sqrt{v^2 + KE/m} = \sqrt{(1.5 \times 10^8)^2 + (7.5 \times 10^{21})}$

Energy:
- Total work: $4.3 \times 10^{19} \text{ J}$
- Total world electric energy consumption in 1996: $4.3 \times 10^{19} \text{ J}^*$

Time:
- Total trip time: 9.1 Y

* (Time world almanac)

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Interstellar Flight: Minimum Acceleration

Deceleration time 25 years

Acceleration time 25 years

Acceleration, .00688 g

TIME

4.3 Light years

DISTANCE

\[ v = 0.172 \, c = 1.5 \times 10^8 \text{ m/s} \]

KE \[ m = 1000 \, \text{Mg} \]

\[ = 1.36 \times 10^{21} \, \text{J} \]

Total world elect. energy consumption in 1996:

\[ 4.3 \times 10^{19} \, \text{J} * \]

*(Time world almanac)

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THE PROBLEM WITH ROCKETS IS MASS RATIO:

\[ \Delta v = v_x \ln(MR) \]

MR = Mass Ratio = Initial Mass/Final Mass

Mission Velocity / Exhaust Velocity.

exponential feedback!!

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Magnetically Confined Continuous Fusion

Well Studied for power production

Potential Exhaust Velocities up to \( \approx 0.1 \) c,

High mass ratio means \( \approx 0.15 \) c cruise velocity

"Magnetically confined fusion is about twenty years in the future..."
(...and always will be? )
NUCLEAR PULSE

Exhaust velocities ≈ 0.01-0.1c
Alpha Centauri trip in decades
May use to decelerate
Still working on pellet detonation....

Micropulse fusion vehicle (after Hyde)

Toroidal life support area
Superconducting magnet rings
Fuel pellets
Pellet detonation
Magnetic field lines act as nozzle and "wind of passage" deflector
Exhaust plume

Radiation-absorbing shadow shield ring
Particle, Laser, or Antiproton beams
Antimatter

About 1% of quarks form antiprotons

Start with high-energy collision

\[ \bar{u}, \bar{d}, \bar{u} \rightarrow \bar{p} \]

Add positrons to make antihydrogen

Cool atoms

\[ \bar{H} + \bar{H} \rightarrow \bar{H}_2 \]

Antihydrogen ice

Keep in Perfect Vacuum!

With Electric and Magnetic Fields

\[ T < 2K \]
Antimatter Rockets And Generators

Rocket Mass = Payload Mass + (Engine Mass + Structure Mass) + Propellant Mass

Antihydrogen storage

Normal matter

magnetic nozzle

Annihilation makes radiation

Gamma rays

Neutrinos

Escape Energy lost.

Used as Rocket exhaust or output Goes to MHD Generator

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Antimatter-Powered Electric Rocket

Robot Transforms Ship in Flight

Empty tanks & structure used as fuel and reaction mass

Power Generators

Liquid droplet Radiator

Ion beam generator

Accelerator stages
Interstellar Ramjets

- Concept: Scoop up protons and atoms and fuses them.

"Free" Reaction Mass and Energy

But Thrust and Acceleration are Low

To get 1 kg/s at .2c, ($\approx$60 Mm/s)
Scoop Radius = 1,782 km

Proton fusion is difficult.

Drag may limit scoop to a few tenths of c

About 1 atom per cubic centimeter

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Beam Supported Propulsion

Leaves much propulsion mass at "rest"

--but beam must go to spacecraft!

Beam Powered Rockets

Photon Sails: Sun, Lasers, Microwaves

Mass Beam Riders
Beamed power rockets

- High exhaust velocity
- Still mass ratio-limited

Light or Microwaves are beamed to spacecraft

The energy received is used to accelerate propellant

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Photon Sails

PHOTONS ARE EASY TO MAKE

Arrays collect many times the spacecraft kinetic energy

Reflected Photons Lose Energy

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Mass Beam Propelled Spacecraft

Solar power stations power mass beam drivers

Beam drivers shoot pellets at spacecraft with the right velocity

Pellets steer themselves to beamrider

Lasers turn pellets into plasma
Plasma reflected by magnetic mirror

Reflected left almost motionless relative to beam projectors.

Deceleration with pellet trail, pulsed fusion, or by some other means.
RELATIVITY: NO LIGHTSPEED BARRIER FOR TRAVELERS*

Star-map velocity as a multiple of the speed of light

Kinetic energy in units of $mc^2$

Relative velocity as a multiple of the speed of light.

* But the calendars will show many years gone.
Life on a Starship

Power

Gravity?

Provisioning

Recycling

Cold Sleep?

Elbow Room
REGENERATIVE LIFE SUPPORT - INPUTS AND OUTPUTS


<table>
<thead>
<tr>
<th>INPUTS</th>
<th>kg/person/day</th>
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<tbody>
<tr>
<td>Oxygen</td>
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<tr>
<td>Dry Food</td>
<td>0.62</td>
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<tr>
<td>Water in Food</td>
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<tr>
<td>Food Preparation Water</td>
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<tr>
<td>Drinking Water</td>
<td>1.61</td>
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<tr>
<td>Oral Hygiene Water</td>
<td>0.36</td>
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<tr>
<td>Hand and Face Wash Water</td>
<td>1.81</td>
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<tr>
<td>Shower Water</td>
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<td>Clothes Wash Water</td>
<td>12.47 *</td>
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<tr>
<td>Dish Wash Water</td>
<td>5.44</td>
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<td>Urinal/Commode Flush Water</td>
<td>0.49</td>
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Total: 31.0 kg/person/day

<table>
<thead>
<tr>
<th>OUTPUTS - kg/person/day</th>
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<tr>
<td>Carbon Dioxide</td>
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<tr>
<td>Urine Solids</td>
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<tr>
<td>Sweat Solids</td>
</tr>
<tr>
<td>Fecal Solids</td>
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<tr>
<td>Water vapor from skin and lungs</td>
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<td>Urine</td>
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<tr>
<td>Feces Water</td>
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<td>Hygiene Waste Water</td>
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<td>Urinal and Commode Flush Water</td>
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</table>

Total: 31.0 kg/person/day

If we have complete water recycling, expendable supplies per person per year of active time are about 500 kg © G. Nordley 2001
Life support strategy depends on technology available, and mission length

- a. fully awake no recycling (31 kg/day about 10 mT per year)
- b. fully closed life support mass
- c. freeze and deliver (least long trip mass)
- d. mixed cold sleep and recycling

Trade between life support closure and suspended animation.
Generation ship vs smaller, faster ship.

Energy available: 100 ZJ (1E23)

Generation ship: 1,000,000 tons
velocity: .04 c

Beamrider: 1000 tons
velocity 0.84 c

Going 12 LY?
Generation Ship takes 300 years
Beamrider takes 14.3 years
1000 - 10000 Mg
Depends on shielding need

radiator area,
debris deflection

Ship spins for artificial gravity

2 m H2O

Solenoid loops for reflector field

Floor are level under thrust, spin, or both

Spin g
resulting g

© G. Nordley 1998
Some personal conclusions:

No "generation ships." (Lifetime extension, propulsion advances)

Starships with human crews won't be launched until relative velocities of 0.3 to 0.5 c are achieved.

Interstellar Journeys will take a few years to a few decades (Solar System time)

Robotic systems will explore and prepare systems for humans.
To Proxima Centauri with a 1000 ton ship

3 g, 0.95 reflection, 0 residual velocity

Peak power required $\approx 40,000$ TW

Coasting velocity = .886 C

Acceleration time:
200 d Earth-frame
152 d spaceship

Transit time
$\approx 5.33$ years Earth
$\approx 3$ years, spaceship

20% Efficiency, Arrays to ship $\text{KE} = 565 \times 10^{21}$ J
Turning Asteroids Into Solar Power Stations
Exponential Growth

1 Year
2 Factories
2 GW power

2 Years
4 Factories
4 GW power

Energy

1 kW

1.1 kW

Beamed Power To Star Base

6 048, 576 GW

About 30 times current Earth use!

A million times fast!
Self Replicating Factories

Asteroid

1 Year

1 GW

© G. Nordley 2012
Self Replicating Factories → Asteroid

1 Year → 4 Factories

2 Years → 3 GW
Self Replicating Factories → Asteroid

1 Year

2 Years

3 Years

8 Factories

7 GW

© G. Nordley 2012
Self Replicating Factories

1 Year

2 Years

3 Years

4 Years

Asteroid

16 Factories

© G. Nordley 2012

15 GW
Self Replicating Factories

1 Year

2 Years

3 Years

4 Years

5 Years

Asteroid

32 Factories

31 GW

© G. Nordley 2012
Self Replicating Factories → Asteroid

1 Year
2 Years
3 Years
4 Years
5 Years
6 Years

64 Factories
63 GW
2^{n-1}

© G. Nordley 2012
Self Replicating Factories

1 Year
1 GW

2 Years

3 Years

4 Years

5 Years

6 Years

...........

20 Years

Asteroid

$2^{n-1}$

1,048,576 Factories

1,048,575 GW

$\approx$ 1 petawatt (PW)

1 PW-year = 33 ZJ

© G. Nordley 2012
Array width: 10,000 km
Array length 55,000,000 km
Array area 55 E 15 m²
arc length 30 deg
Fraction of a Dyson sphere: 3.75 E-6
Power collected 550 E6 TW
Starships powered to 0.86c: 36,000
Needed to build: 40 Y
Radius of raw material asteroid ≈300 km
THOUGHTS ON INTERSTELLAR CIVILIZATION

Divergent human cultures with common heritage

---Slow paced, but not totally isolated

--extended life, robot labor, large scale

Trade (if any) in unique artifacts

--robots will build what is needed from local material

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Star travelers of different intelligences

--could form their own culture

--biological impulses subordinate to intelligence

--same physical laws, similar engineering achievements
  cultural interchange

--so, cultural convergence among different species

This may already have happened....
Interstellar Travel Summary:

The energy requirements for human interstellar flight are huge.

Given energy, relative velocities approaching c are possible.

The important technologies are robotics and space access.

Biotech advances make it easier.

Starfaring may be like Early Seafaring; long journeys seldom import.
Ad Astra