Astronomy 330:

Extraterrestrial Life

This class (Lecture 27):

Communication/Travel

Last Class!!!:

Visitations

2 x 2 page pdf articles due tonight

Music: *Aliens Exist*– Blink 182

Drake Equation

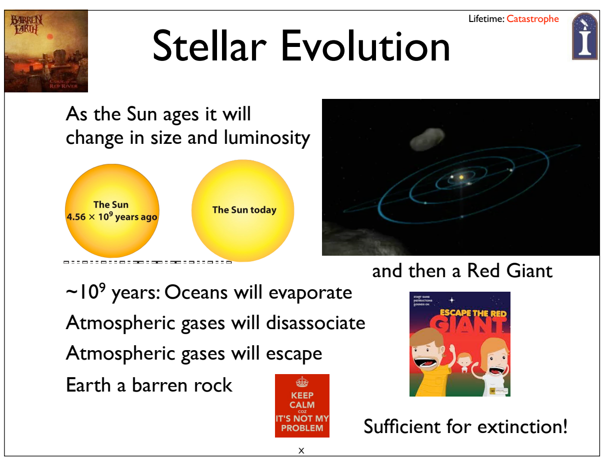
That's 2.56 Communicating life/year

Frank Drake

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	30 stars/yr	0.8 systems/star	4 x 0.47 = 1.88 planets/system	0.2 life/planet	0.3 intel./life	0.95 comm./intel.	yrs/comm.

Feb 15, 2013 over Chelyabinsk Russia a huge fireball.
A 41,000 mph it was brighter than the Sun!
~20 meters in size and 10,000 tons, most of the energy absorbed in the atmosphere-- 20-30 times Hiroshima!

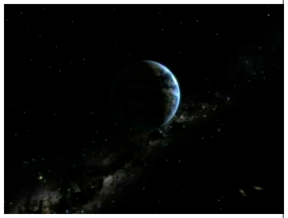


Lifetime: Catastrophe

Rogue Cosmic Object

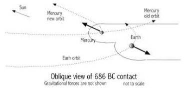
Earth's location in habitable zone could be disrupted

Rogue Black Hole
White Dwarf
Hypervelocity Star



Earth's orbit could be disrupted

Mercury
Jupiter



Earth's could be disrupted!

Sufficient for extinction!

Lifetime: Catastrophe

Galactic Smackdown

Galaxies collide

Milky Way
versus
Andromeda

Who will win?

Will we live?

Sufficient for extinction!

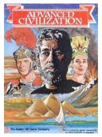
Lifetime: Catastrophe

Death from the Skies

1) Impacts
2) Solar Evolution
3) Supernovae
4) Gamma-Ray Bursts
5) Rogue Black Holes
6) Rogue Stars
7) Galaxy Collisions
8) Cosmology
9) Quasars
10) Aliens

ASTR 150
Killer Skies: Astro-Disasters
Credit: 3 hours.

Lifetime



Time an advanced civilization will communicate

Averaged over time

Averaged over species

What if aliens take a break?

What if aliens give up?

What if aliens are terminated?

What if aliens run out of resources?

Cheap Energy

L

What can we confidently state?

We have been communicating for ~75 years
sort-of-kinda

so a lower limit of 100 seems reasonable.

Is there an upper limit?

- Disease
- War
- Nature/Cosmos

Civilization Reboots

And we need to average over species and time L = ????

Drake Equation

That's 2560 advanced civs!!!

Frank Drake

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	30 stars/yr	0.8 systems/star	4 x 0.47 = 1.88 planets/system	0.2 life/planet	0.3 intel./life	.95 comm./intel.	1000 yrs/comm.

= 2.5 x 10^{11}

Communicating Civilizations

Drake Equation For Optimist

62.5% of all stars in our Galaxy.

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact	Rate of formation of Sun-like stars	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	50	**1**	**1**	**1**	**1**	**1**	**5 x 10^9**

Birthrate of 50/year!

= 7.5 x 10^{-6}

Communicating Civilizations

Drake Equation For Pessimist

Must wait 10^7 years for one!

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact	Rate of formation of Sun-like stars	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	5	**0.1**	**0.15**	**0.01**	**0.01**	**0.01**	**100**

Birthrate of 7.5 x 10^{-8} / year!

= 930,000

Communicating Civilizations

Drake Equation For Average

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact	Rate of formation of Sun-like stars	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	10	**0.5**	**0.89**	**0.5**	**0.7**	**0.6**	**1x10^6**

Birthrate of 0.93 /year!

= 1,800

Communicating Civilizations

Drake Equation
For me

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact	Rate of formation of Sun-like stars	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	10	0.8	1	0.5	0.5	0.9	1000

Birthrate of 1.8 /year!

What does this Mean?

Given the state of our knowledge

All answers are valid!

Birthrate of *1 per year*: Most life we contact would likely be much older

Cosmic Infants

Given other typical values Lifetime ~ 1 years, at least two life forms for class.

Empty Space

Our total number is 2560 advanced civilizations.

Professional View

http://www.seti.org/drakeequation

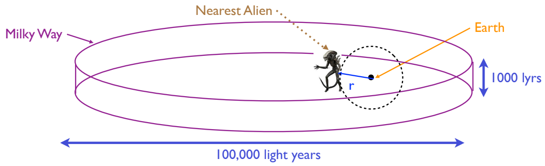
x

Dad, how much farther?

Assume large N

Alien density = $\frac{\pi r_g^2 h_g}{N}$ Search volume = $\frac{4\pi r^3}{3}$

$$r = \left(\frac{3}{4}\frac{r_g^2 h_g}{N}\right)^{1/3} \approx \frac{1.2\times 10^4 \text{ lyrs}}{N^{1/3}}$$



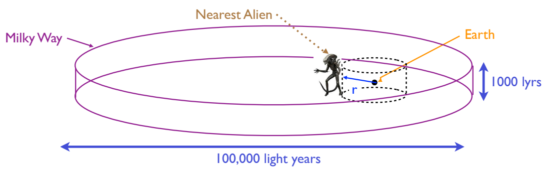
N>5200

Dad, how much farther?

Assume low N

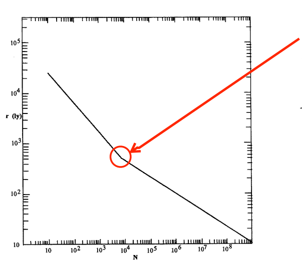
Alien density = $\frac{\pi r_g^2 h_g}{N}$ Search volume = $\frac{\pi r^2 h_g}{1}$

$$r = \frac{r_g}{\sqrt{N}} = \frac{5\times 10^4 \text{ lyrs}}{N^{1/2}}$$



N<5200

How far are the Aliens?



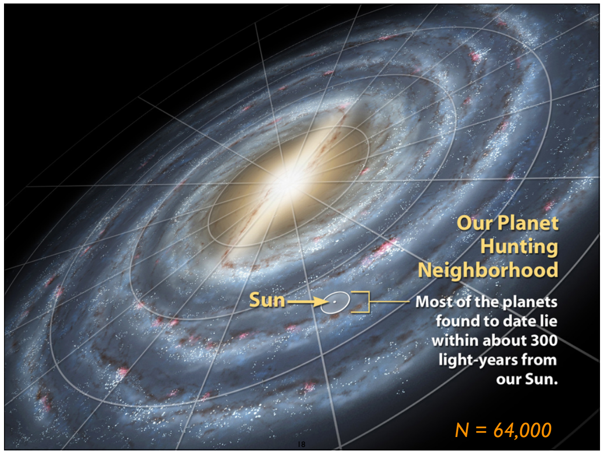
Equate two radii to get break point

$$N = \left(\frac{50}{12}\right)^6 \approx 5200$$

$N \approx 1000 \rightarrow$
$r \approx 1600$ lyrs

$N \approx 2.5\times 10^{11} \rightarrow$
$r \approx 2$ lyrs

For N= 2560 (low N), r = 988 light years



64000 needed for life to be that close.. 300 years for them to hear from us and still 300 years to hear back from them! That's 600 years total.

Talking Points

Assumptions:

- Uniform density of civilizations
- Cylindrical Galaxy
- Uniform stellar density

These underweight Galactic Center

r is an average distance, should make a PDF

Hey man, that's a probability!

r is better defined than N

$r \sim N^{1/2}$ (Low N)

$r \sim N^{1/3}$ (High N)

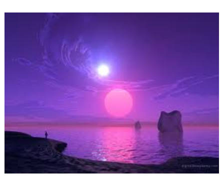
What if communication time is longer than L?

1. We assumed uniform density of civilizations.
   - Underweights the galactic center, but maybe that's okay– supernovae.
2. Distance away is the <u>average</u>.
   - Could be closer, but unlikely to be much closer.
3. Note that r is better defined than N.
   - R depends on $N^{1/2}$ or $N^{1/3}$.
   - If we are wrong in N by a factor of 100, then only off in r by factors of 10 or 4, respectively.
4. For communication, it may be that the distance there and back is longer than L.

How Many Stars?

- How many stars in our distance?
- Let's use an average of 1 star/pc^3
  - 988 light years is 309 parsecs
- So $4/3\ \pi\ (309)^3 =$ 123M stars
- But, about 50% of stars are multiple, so we need to correct for that.
- 123M + 123M/2 =

  185 Million stars!!!!!



3.2 parsecs per light year

How to Communicate?

- We are relatively a young civilization, with radio technology for only a hundred years.
- Right now, we are mostly a passive "lurker" civilization.
- Okay, so what will an advanced civilization use?
- Hard to figure out.. They are aliens!

Can you hear me?

Long distance relationship?

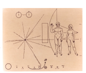
At best light travel is ~4 years

8 years round trip!

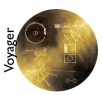
What do you say?

Morse Message (1962)

Pioneer



Voyager



Arecibo Message (1974)

Cosmic Call 1 (1999)
Teen Age Message (2001)
Cosmic Call 2 (2003)
A Message from Earth (2008)
Across the Universe (2008)
Hello from Earth (2009)
Wow! Reply (2012)

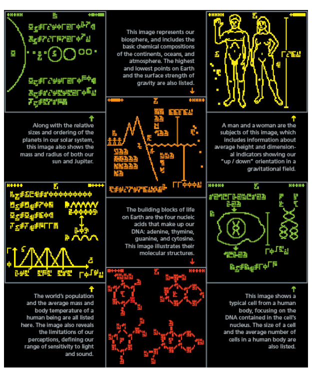
First message to ET: MIR, LENIN, SSSR (toward HD 131336). Messages set out irregularly—– not sending out specific messages every day. Too expensive, and telescopes are better used for astronomy.

Active SETI

Interstellar Rosetta Stone

Canadian scientists Yvan Dutil and Stephane Dumas

Included in both Cosmic Call Messages



Is Active SETI the right approach?

Who is listening?

Active SETI is a big question.. not a clear answer yet

Hold your Horses!

The First SETI Protocol: *What to do if an Alien talks*!

The Second SETI Protocol: *How to contact an Alien*!

Who decides *Active SETI* is a good idea?

METI

Active SETI =
Messaging to Extra-Terrestrial Intelligence

The San Marino Scale

Value	Potential Hazard
10	Extraordinary
9	Outstanding
8	Far-reaching
7	High
6	Noteworthy
5	Intermediate
4	Moderate
3	Minor
2	Low
1	Insignificant

SMI = I + C

I = Log(Signal/Sun)

C = Information Content

http://lifeboat.com/ex/shouting.at.the.cosmos

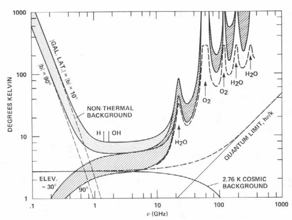
x

Passive SETI

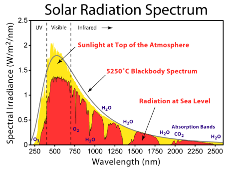
Where do we look?

How do we look?

Radio



Solar Radiation Spectrum



Optical

Aliens can shoot a laser backwards through telescope

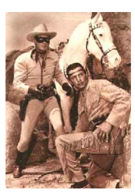
24

Radio is probably best. Dust extinction is reduced. Lower frequency means less energy/photon, so cheaper. There is a natural dip from about 1 to 10 GHz in the radio where the atmosphere and the galaxy are the quietest.

Still, 1-100 GHz or even 1-10 GHz is a lot of frequency to search. Remember, we have to tune to the proper "radio station". What's the right channel size? Many argue that we should use 1 Hz channels, then in the 1-10 GHz band there are 9 x 10^9 channels! Is there a magic frequency that advanced civilizations would choose?

Does ET Love Lucy?

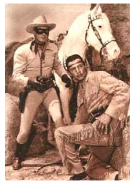
- One solution is to look for unintentional leakage signals.
- We can not currently detect this, but maybe other civilizations can.
- What leakage do we have? TV, FM Radio, radar (military)
- Television transmission exceeds 10^7 watts (10 MW).



ET would be unable to really distinguish individual stations due to the rotation of the Earth. To detect early carrier signals at 50 lyrs, need 3000 acres of antenna. To watch the TV show, need antenna the size of Colorado. It is possible? Still Earth would produce a regular 24 hour pattern for the last 60 years. Military radar is more promising. Highly focused and powerful. Only requires a 1000 foot antenna.

Does ET Love Lucy?

- We've had leakage signals for ~60 years.
- As radio travels at speed of light, our leakage signals have reached the nearest 20,000 stars!
- Still, this is way **too few** for most estimates.
- It is unlikely that a civilization is within 60 lyrs. → $N_{required} = 10^7$
- So probably ET does not love Lucy, at least yet.



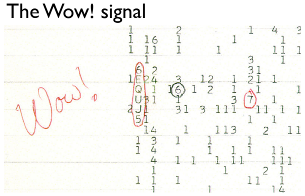
Passive SETI

Has anything been seen?

Big Ear Radio Telescope (OSU)

Looking in Constellation Sagittarius

The Wow! signal



Narrowband signal detected in 1979

Subsequent searches negative.

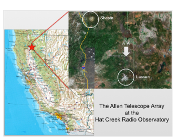
In 1973 by F. Dixon and D. Cole. Used Ohio State radio telescope for a continuous survey of sky. Not steerable- so cuts a swath through the sky: A Sky Survey Searched overhead for signals. 1.42 GHz with 50 channels of 10 kHz. But not just looking at stars. Could only detect extremely strong transmissions. Land was sold to a golf course development. Aug. 15, 1977, Jerry Ehman was looking through the data when he recorded the Wow! signal. A major signal in the telescope- 30σ detection! Stayed around for >72 seconds. Unlikely to be noise, but never seen again.

"Even if it were intelligent beings sending a signal, they'd do it far more than once."

SETI Institute

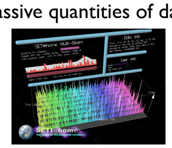
Today Passive SETI

Allen Telescope Array



Radio surveys generate massive quantities of data

SETI@HOME

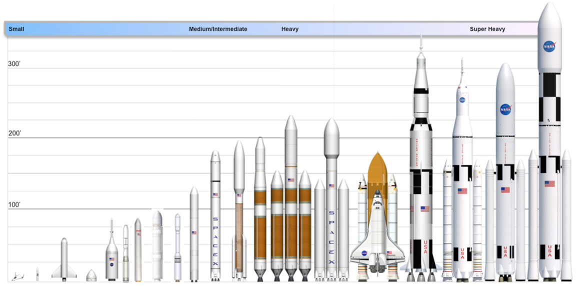


AAT has money problems

"In 1993, Nevada Democratic Senator Richard Bryan successfully introduced an amendment that eliminated all funding for the NASA SETI program. The cost of the program was less than 0.1% of NASA's annual budget, amounting to about a nickel per taxpayer per year. The Senator cited budget pressures as his reason for ending NASA's involvement with SETI." Just beginning to recover from this— so nearly all SETI work has been privately funded.

He said: "The Great Martian Chase may finally come to an end. As of today millions have been spent and we have yet to bag a single little green fellow. Not a single Martian has said take me to your leader, and not a single flying saucer has applied for FAA approval."

Rocket Science

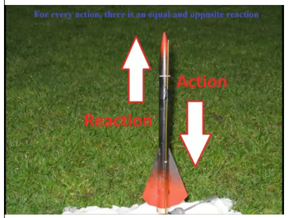


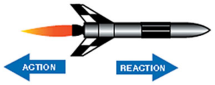
The distances are freaky huge! Nearest star is 4.3 ly away or around 4 x 10 km! 40,000,000,000,000 km! 40 TRILLION km!!!
Voyager (our fastest spacecraft to date) would take 100,000 years

Rocket Science

Basic principle (Newton's 3rd law)

- Rocket expels propellent backwards
- Rocket is pushed forward





Action-Reaction

Rocket Science

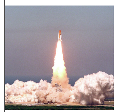
Conservation of momentum

- High Exhaust Velocity
- High Mass Ejected

So either use a big mass at lower velocity
or a small mass with high velocity

Rocket Man

Four Quantities of Interest



1. V_e: the exhaust velocity.
   Bigger is better!
2. Thrust: force exerted by the exhaust.
   Bigger is better!
   $$F = ma = \frac{d(M_{Total} V_e)}{dt}$$
3. Mass Ratio: payload size
   Close to unity!
   $$R_M = \frac{M_{Fuel} + M_{Payload}}{M_{Payload}}$$
4. Specific Impulse: burn time
   Bigger is better!
   $$\text{s.i.} = \frac{\text{Thrust}}{\text{Burn Rate}} = \frac{d(M_{Total} V_e)}{d(M_{Fuel})}$$

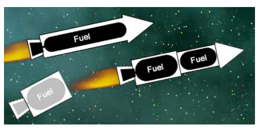
Take Off, Man

Force Down (Gravity) < Force Up (Thrust)

Escape Velocity = 11.2 km/s (7 miles/s) (Earth's Surface)

Humanity has never achieved this!

Solution: multi-stage rocket



Stages are dropped when fuel is exhausted

Next stage ignites higher up

Escape velocity is lower than from Earth's surface

What's the Problem?

Multistage Rockets are wasteful *Recycling?*

Multistage Rockets can have a huge mass ratio!

Vanguard 1 (Launched March 17, 1958)

Still in orbit

Payload = 1.4 kg

Rocket Mass = 36,000 kg

$$R_M = \frac{36000 + 1.4}{1.4} \approx 2.6 \times 10^4 \gg 1$$

Practical Space exploration impossible in this manner

Multistage Rocket

The mighty Saturn V (Apollo 8).

What can we do?

Must lower Mass Ratio

- Increase exhaust velocity
- Increase specific impulse

Shuttle **was** *state of the art*

- Payload = 2.95×10^4 kg
- Rocket Mass = $2. \times 10^6$ kg

$$R_M = \frac{2 \times 10^6 + 2.95 \times 10^4}{2.95 \times 10^4} \approx 68$$

Solid boosters fall off at 40 km

- s.i. = 455 seconds

Good, but not enough to leave Earth's gravity (~185 km)

Rocket 101

Propellent: What is ejected out the back!

Chemical: Burn fuel, exhaust is propellent

- Fuel Efficiency: one billionth of the total mass

Nuclear: Reactor heats propellent

- Fission Efficiency: one thousandth of the total mass
- Fusion Efficiency: one hundredth of the total mass

Ion: Ionize fuel, eject with electric fields

Antimatter: Thrust from matter-antimatter annihilation

Rocket 101

Mankind has currently focused on chemical fuels

Fuel is combusted, or burned, this requires Oxygen

Oxidizer is required in space, which is a vacuum

Waste product, or the *propellent*, is expelled out the back

Four types of chemical fuels:

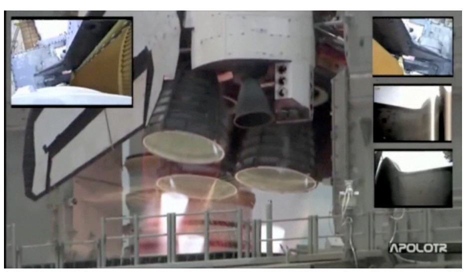
- Petroleum: Refined Kerosene with LOX (liquid Oxygen)
  - Saturn V first stage
- Solid: Oldest form, Oxidizer mixed with Fuel
  - Space Shuttle Boosters
- Cryogenic: Ultra cold H with LOX (propellent is H_20)
  - Space Shuttle Main Engines
- Hypergolic: Fuel plus oxidizer that combusts with no ignition
  - Space Shuttle Orbital Maneuvering Subsystem

1. Fuel can be "monomethyl hydrazine" (MMH) and the oxidizer is "nitrogen tetroxide" (N_2O_4).

Cryo fuel in action

The Shuttle's main engines!

Shuttle Launch



Shuttle Atlantis Final Launch

Fission Rockets: Project Orion

Initial Plan: Use Nuclear Bombs!

Physicist Freeman Dyson (1958)

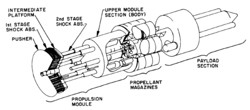
Project Orion (USAF)

Surfing the *blast wave*

or an atomic *pogo-stick*

s.i.: 10,000 to 1,000,000

Limited to ~ 0.1c



Eject H bombs

Detonate 60m away

0.1 kt bomb/sec (takeoff)   20 kton/10 sec afterwards

Terminated with 1963 Test Ban Treaty

Project Orion: You dropped hydrogen bombs wrapped in a hydrogen rich jacket out the rear of a massive plate.
Detonate 60 meters away, and ride the blast-- an atomic pogo stick.
0.1 kton bomb every second for take off, eventually tapering to one 20 kton bomb every 10 sec.

Fusion Rockets

Project Daedalus

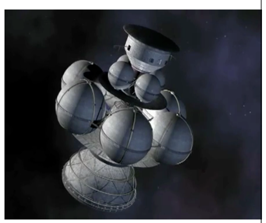
Continuation of Project Orion

British Interplanetary Society

Robotic Flyby of Barnard's Star

2nd closest star (~6ly)

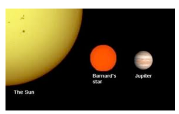
Need .12 c to get there in 50 years



Disperse science payload at destination

Transmit information for 6-9 years.

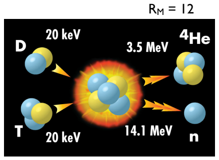
One way ticket!

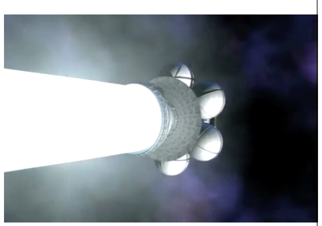


Fusion Rockets

Nuclear Fusion via pulsed power

$R_M = 12$





By-products are He and H nuclei

Positively charged so can be vented as exhaust

Reasonably efficient (5 MeV)

But ^{3}He is rare on Earth   Jupiter's atmosphere?

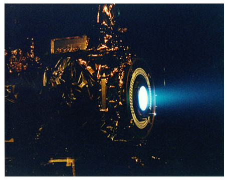
- Daedalus would accelerate for 4 years, then coast for 50 years to reach Barnard's star.
- At blastoff the mass would be 54,000 tons, of which 50,000 would be fuel.
  - Built in space though.
- That's an R_M = 12.
- The fuel would be in pellets that enter the reaction chamber 250/sec.
- Sophisticated robots needed for repair.
- For dust erosion at 0.12c, requires a beryllium erosion shield 7mm thick and 55 meters in diameter.
- Once it reached Barnard's star, it would disperse science payload that would study the system.
- Would transmit back to Earth for 6-9 years.
- So does not require a return trip.

Ion Drives

Eject beam of charged atoms

Ride a bike using a hairdryer backwards!

Deep Space 1 (Comet Borrelly)



- Ionized *Xenon* atoms (81.5 kg)
- Propelled via *Electric Fields*
- Waste is Propellent (Xe)
- Thrust balance *paper on your hand*
- DS1 eventually reached 4.5 km/s

Requires power source

- Solar Cells?
- Fusion generator?

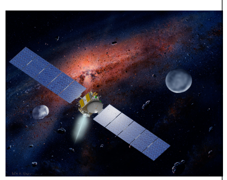
4.5 km/s = 10,000 mph
Darth Vader's Tie uses Ion Drive.

Ion Drives

Dawn spacecraft: Launched Sep. 2007

- 3 Heritage DS1 engines the size of basketballs

Vesta (2011) & Ceres (2015)



- Thurst of 90 N (Weight of paper)
- 0-60 mph in four days!
- 5 years: 23,000 mph
- Powered by 10 kw solar array
- Vesta (275 kg Xe) & Ceres (110 kg Xe)

Ion more efficient than chemical

- Can achieve ten times greater velocity than Chemical
- But not useful for quick accelerations

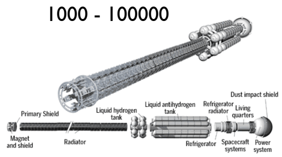
Propelled by three DS1 heritage xenon ion thrusters (firing only one at a time).
s.i. = 3100 s Dawn spent 270 days using less than 72 kg of fuel to change its velocity by 1.81 km/s (4050 mph)!

Antimatter Drives

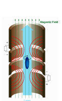
Antimatter Engines can be very efficient

Propulsion	Specific Impulse [sec]
Chemical	200 - 450
Electromagnetic	600 - 3000
Nuclear Fission	500 - 3000
Nuclear Fusion	5000 - 10000
Antimatter	1000 - 100000

Problems:



- *Where do you get the antimatter?*
- *How do you store the antimatter?*



Penning Trap

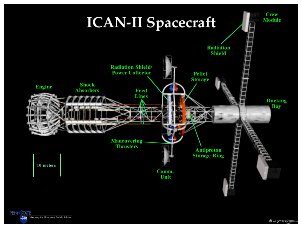
Can be done by making electromagnetic "bottle" that confines particles with electric and magnetic force fields

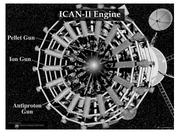
In an antimatter rocket, a dose of antihydrogen would mix with an equal amount of hydrogen in a combustion chamber. The mutual annihilation of a half pound of each, for instance, would unleash more energy than a 10-megaton hydrogen bomb, along with a shower of subatomic particles called pions and muons. These particles, confined within a magnetic nozzle similar to the type necessary for a fission rocket, would fly out the back at one-third of the speed of light. That fast exhaust would translate to a top speed of 66 percent of the speed of light. "This is by far the most powerful rocket we can make," Frisbee says.

A two-stage antimatter rocket to Alpha Centauri would need some 900,000 tons of fuel and would arrive in about 41 years. A four-stage version (two to speed up, two to slow down) on a longer voyage would show the advantages of antimatter to better effect. According to Frisbee's calculations, it would need 38 million tons of antimatter fuel, but it would cut the trip to 55 Cancri, 41 light-years away, to an almost manageable 130 Earth years. The same trip would take 400 years using a fusion engine.

Antimatter Drives

Ion Compressed Antimatter Nuclear (ICAN)





Designed at Penn State

Mixture of Antimatter & Fusion Pellets

We still have the M_{Fuel} problem

All made up at this time, but interesting...

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We have a Problem

For interstellar trip, we need a lot of fuel!

Mercury Capsule: Lightest US manned spacecraft

Weight: ~ 1300 kg

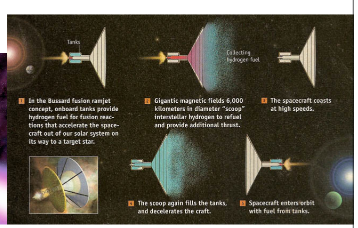
Imagine a roundtrip to Alpha Centauri

- 40,000 Trillion km
- Require over ***50 million kg*** of antimatter fuel

The situation is even worse for more realistic manned spacecraft.

Lose the Fuel, Fool

Scoop fuel as you go!

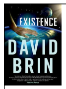


Bussard Ramjet

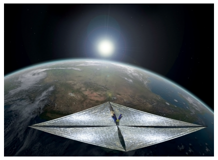
- Magnetic Fields collect stray H atoms
- H is compressed and used in Fusion reaction to propel starship (~0.99c)
- Problems:
  - Must be accelerated via other means first
  - Interstellar Space ~1 H atom/cm^3

This digital image shows a venerable design for an interstellar vehicle. Magnetic fields would collect stray hydrogen atoms and draw them into the funnel in the front. There they would be compressed and used to fuel a fusion reaction to propel the starship at relativistic speeds. The ship would have to be accelerated to a high speed by some other means before the ramjet could even begin to work. Also H not the best option for fusion— not H3+

Lose the Fuel, Fool



Catch the light fantastic



Sail collects photons

Photons have no mass

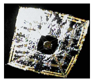
Photons have energy

Photons have momentum   P = E/c

Distant laser could illuminate sails

Planetary Society

COSMOS 1: June 21, 2005	Russian launch rocket failed
IKAROS (20m with Japan)	First successful solar sail
LightSail 1 ($32 m^2$)	Waiting on funding



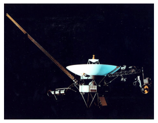
Why not visit?

Space is Frickin Huge!

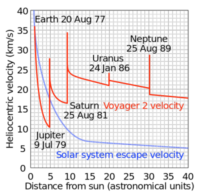
Nearest Star System: Alpha Centauri is 4.37 lyrs

Hosts an Earth like planet?

~40,000,000,000,000,000 km!



Voyager 2   ~17 km/s



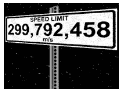
100,000 years!   ***Fugetaboutit!***

Future Trends

Newer technologies might approach the speed of light

Now:	c/25,000
Short-term?	Fusion: 0.01c - 0.1c
Long-term?	Ramjets: .9c - 0.99c

How long will our civilization last?



The ultimate speed limit

Basis of special relativity

Speed of light ($c = 3\times10^8$ m/s) is the same for everyone

Sun to the Earth in a little over 8 minutes!

Question

You are at the back of a jet traveling at 400 mph. You shine a laser toward your friend in first class. What speed does your friend measure for the laser light?

a) c+400 mph

b) c-400 mph

c) c

d) c/400 mph

e) $c/(c^2-400^2)$ mph

Where c is the speed of light.

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