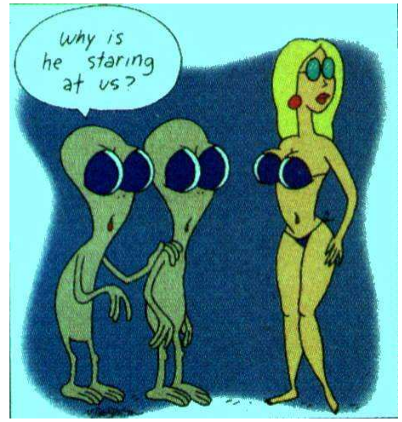
Carl Sagan Says

- "These are some of the things Hydrogen atoms do, given 15 billion years of evolution"
- "We are, in the most profound sense, children of the Cosmos"
- "We are star stuff contemplating the stars“
- “Tell a man that there are 100 billion stars in our Galaxy and he'll believe you. Tell him a bench has wet paint and he has to touch it.”

Warning, not really Carl Sagan quote.

Astronomy 230



This class (Lecture 27):
Travel

Next Class:
UFOs, Review, and ICES

Music: Rocket Man – Elton John

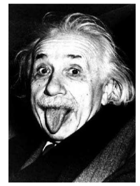
Outline

- Alternative fuels for space travel
  - Nuclear Fission
  - Nuclear Fusion
  - Antimatter
  - Solar Sails
  - Warp Drives?
    - General Relativity
  - Weird science?

Final

- Designed to be a 2-ish hour exam, but allowed 3 hours.
- Will consist of 40 multiple choice/ true-false questions (2 points each), 5 small essay questions (10 points each), and 2 large essay question (40 points each).
- A total of 210 points graded out of 200 points. So a large possibility of extra credit points.
- You can bring a normal-sized sheet of paper with notes on both sides.
- Multiple-choice is heavily weighted toward the last half of the course.
- Bring a calculator for easy math.

Special Relativity Summary



All motion is relative, except for that of light.
Light travels at the same speed in all frames of reference.

Objects moving close to the speed of light appear to shrink in the direction of travel.

Time appears to advance more slowly for objects moving close to the speed of light.

Objects moving close to the speed of light appear to have larger mass.

The future:

- May bring us closer to the speed of light
  - Right now we can travel through space at about c/25,000
  - Maybe fusion-powered crafts could in the near future reach 0.01c or maybe even 0.10c

Rocket Science

Momentum and Rockets

- Rockets are propelled by the same principle (on Earth or in space):
  - Rocket fuel releases tremendous energy.
  - The by-product is directed out the back of the rocket.
  - The rocket is pushed forward just like the "rocket" chair.
  - The high momentum is created by high velocity and a large mass of fuel ejected.

http://bagocrap.1accesshost.com/drawings/rocketwheelchair.gif

The Rocket Principle

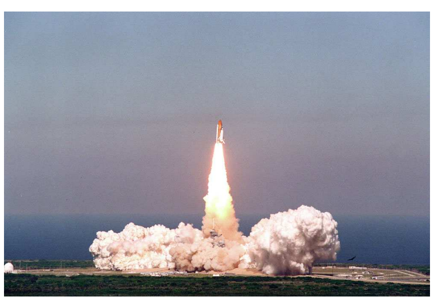
- Conservation of momentum (mass x velocity):
  - Sit in a chair with wheels and throw a heavy ball.
  - You and the chair will recoil in the opposite direction
  - This is the famous "action-reaction" mechanism. Newton's 3rd law.

The Rocket Principle

- Conservation of momentum (mass x velocity):
  - Your "rocket" chair would work by throwing a heavy ball
    - Achieving a high momentum with a large mass
  - Or, you could throw a light baseball, but very fast!
    - Achieving a high momentum with a large velocity
    - This is why a gun recoils when its fired.

Rocket Man: 4 Quantities

1. V_e : the exhaust velocity, usually in km/s.



Rocket Man: 4 Quantities

2. Thrust : force exerted by the exhaust (Newtons or pounds).

$$Thrust = \frac{mass}{\sec} \times V_e = Force = mass \times acceleration$$

Rocket Man: 4 Quantities

3. Mass Ratio :

$$R_M = \frac{M_{total}}{M_{payload}} = \frac{M_{fuel} + M_{payload}}{M_{payload}}$$

– This should be low: close to 1 is best. Of course, it depends on how fast you want to go & how efficient the fuel. And usually, the faster you go, the larger the R_m. But, the larger the R_m the more inefficient. Consequently, we need a fuel that produces more thrust per unit mass of fuel.

Rocket Man: 4 Quantities

4. Specific Impulse:

$$s.i. = \frac{thrust}{Fuel\ Rate} = \frac{\frac{mass}{s} \times V_e}{\frac{mass}{s}}$$

In metric $= \frac{Newtons}{\left(\frac{kg}{s}\right)}$

In British Engineering System $= \frac{Pounds}{\left(\frac{Pounds}{s}\right)} = seconds$

The units have traditionally been in seconds. But it is a little confusing, and has nothing to do with time.

It is a property of the fuel and engine design. Sort of like octane rating in gasoline–
a large s.i. is a good thing.

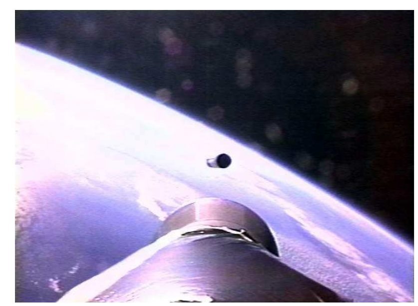
How's it work?

- For rocket to take-off, its thrust must be greater than its weight (force up > force down).
- In addition, the rocket needs to escape the Earth's pull.
- That means that the rocket velocity must exceed the Earth's escape velocity (11.2 km/s or 7 miles/s).
- Humans have never built a rocket that can do this!!!

http://www.eos.ucar.edu/mopitt/instr/rocket.jpg

What you talking 'bout Willis?

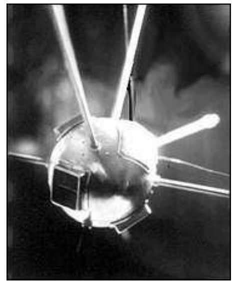
- Humans have never built a rocket that can escape the pull of Earth?
- No, that's why we have to use multistage rockets.
- Once the fuel from the first stage is spent, it's dropped.
- Then, the next stage is higher up, so the escape speed is less than from ground level.
- To escape the Earth's gravity many stages are necessary.



http://www.utahredrocks.com/stardust/launch6.jpg

Not Good

- Multistage rockets are wasteful.
- The Mass Ratio can be huge!
- The first US satellite was the Vanguard launched on March 17, 1958.
- 6.4 inch diameter with 2 radio transmitters.
- Weighed 6.3 lbs = 13.9 kg.
- Rocket mass was 36,000 kg.
- $R_M = \dfrac{36000 + 13.9}{13.9} = 2590 >> 1$



- Major ventures in space impossible with R_M this large.

http://www.bafsat.com/h3.html

Kiss and Make Better

- Can lower the mass ratio by increasing either the exhaust velocity or the specific impulse.
- Shuttle is **state-of-the-art**.
- Payload = 2.95×10^4 kg
- $M_{takeoff} = 2 \times 10^6$ kg
- $R_M = \dfrac{2\times10^6 + 2.95\times10^4}{2.95\times10^4} = 67.8$

Kiss and Make Better

- Shuttle thrust is 29×10^6 N with 80% from solid rocket boosters– they fall off at 40km.
- s.i. = 455 seconds
- Good, but not good enough to leave Earth's orbit
  (shuttle orbits @185 km)

Combustion Rocket Terminology

- A *fuel* is combusted, which means it 'burns', which means it reacts with oxygen.
- In space, there is no oxygen around, so the rocket must carry its own source of oxygen. Also known as an *oxidizer*.
- This forms a new waste compound called a *propellant* that is ejected out the back, thrusting the rocket forward by conservation of momentum.

Propellant-based

- Eject something backwards, you go forwards. **Newton's da man!**
  - Chemical : Burn fuel, exhaust is propellant
  - Nuclear : Reactor heats propellant
  - Electric/Ion : Ionize fuel atoms, push them out with electric fields
  - Anti-matter : Use energy from matter-antimatter annihilation to generate light thrust.

Fuels

- Look at the "octane" of various fuels available today.
- $H_2 + O_2 \rightarrow$ s.i. = 455 sec
- O_2 + hydrazine (N_2H_4) $\rightarrow$ s.i. = 368 sec
- H_2 + fluorine (F) $\rightarrow$ s.i. = 475 sec
  - But exhaust gas is hydrofluoric acid
- Note: No chemical fuel can achieve s.i. > 500 sec.

Rocket Combustion: Chemical Fuels

- Petroleum : Refined kerosene with LOX (liquid oxygen) oxidizer. *(Saturn V first stage)*
- Cryogenic : Ultra cold hydrogen fuel with LOX oxidizer. Propellant is…water! *(Space Shuttle Main Engines)*
- Hypergolic: A fuel and oxidizer that combust with no need for ignition. Fuel can be "monomethyl hydrazine" (MMH) and the oxidizer is "nitrogen tetroxide" (N_2O_4). *(Space Shuttle Orbital Maneuvering Subsystem)*
- Solid: Oldest form (like in model rockets), exists in solid form, hard to stop burning. Has oxidizer mixed together with fuel. *(Space Shuttle Boosters– SRBs)*

http://www-pao.ksc.nasa.gov/kscpao/nasafact/count2.htm

Rocket Combustion: Chemical Fuels

1. **Petroleum**
2. **Cryogenic**
3. **Hypergolic**
4. **Solid**

http://www-pao.ksc.nasa.gov/kscpao/nasafact/count2.htm

Petroleum rocket fuel in action

The mighty Saturn V 1st stage (launched Apollo 11).

http://vesuvius.jsc.nasa.gov/er/seh/movies.html#Saturn

http://www.hq.nasa.gov/office/pao/History/alsj/a16/ap16-KSC-72PC-184.jpg

Cryo fuel in action

The Shuttle's main engines!

http://www.slivka.com/Trips/ShuttleLaunch/pics/LOX_tank_750,000_gallons_at_launch_complex_39A_T.jpg

http://engineering.newport.ac.uk/StaffPer/StaffEngPer/DevansPer/Space-Shuttle.JPG

http://www.physicscurriculum.com/Photos/Space3.JPG

Shuttle Links

http://www-pao.ksc.nasa.gov/kscpao/shuttle/countdown/sts100/liftoffvideo.htm

http://science.ksc.nasa.gov/shuttle/missions/sts-90/vrtour/checkpoint.html

http://imedia.ksc.nasa.gov/shuttlesim/index.html

Hypergolic

Space shuttle orbital maneuvering system uses hypergolic fuel

Solid fuels:

Space shuttle launch uses solid fuel (like model rocket).

1.3 Mlbs at launch. The fuel for each solid rocket motor weighs approximately 1.1 Mlbs. The inert weight of each SRB is approximately 192,000 pounds.

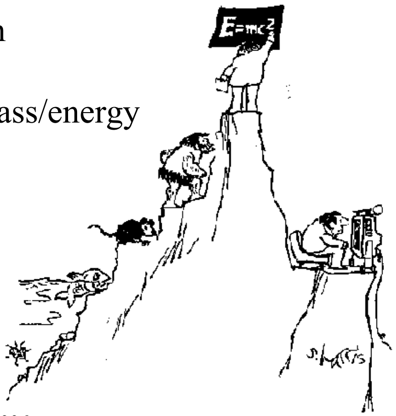
- Ammonium perchlorate (oxider)
- Aluminum (fuel)
- Iron Oxide (catalyst)
- Polymer (binder)

Fuel Efficiency

- To really think about interstellar travel or even going to Mars, we need the most bounce for the ounce:
  - Need to carry (probably MUCH) fuel
  - Must be very thrifty about efficiency
  - In other words, if we are going to carry fuel mass on a ship, we had better get as much energy from it as possible!

$E=mc^2$

- Can relate mass to energy, i.e. the most energy one can get from a piece of mass, no matter what you do
- A useful unit of mass/energy in particle physics is the "***electron volt***" or "eV"
- A proton "weighs" about 1 billion electron volts: 1GeV
- So a H atom is about 1 GeV of mass/energy



http://www.owlnet.rice.edu/~spac205/E=mc2.gif

Fuel Efficiency

- Chemical fuel (like burning wood or rocket fuel) one only gets a few eV of energy from each atom or molecule
  - In other words, only about 1 billionth of the total mass of the chemical agents gets converted into energy!
- Nuclear fission gives off a few MeV for each nucleus that fissions:
  - So, about one thousandth of the total mass gets converted into energy!
  - Better than chemical by a factor of a million!
- Nuclear fusion reaction can produce about 10MeV from a light nucleus
  - So, the efficiency is about one hundredth!
  - Getting better!

Project Orion

- A spacecraft powered by nuclear bombs– nuclear fission.
- Idea was sponsored by USAF in 1958
- Los Alamos group.
- You dropped hydrogen bombs wrapped in a hydrogen rich jacket out the rear of a massive plate.
- 0.1 kton bomb every second for take off, eventually tapering to one 20 kton bomb every 10 sec.

http://www.daviddarling.info/encyclopedia/O/OrionProj.html

Project Orion

- s.i. theoretically around 10,000 to one million seconds
- Limited to about 0.01c.
- But, it is a “dirty” propulsion system.
- A 1963 treaty banned nuclear tests in the atmosphere, spelled the end of "Orion".
- Still argued to be the best rocket we could build today.

http://www.daviddarling.info/encyclopedia/O/OrionProj.html

Project Daedalus

- Continuation/extension of Orion
- British Interplanetary Society project (1973-1978 planned)
- A robotic fly-by probe to Barnard’s Star
  - 2^{nd} closest star system to Earth, 6 lyr away
  - In human lifetime scale (chose 50 yrs)
  - Needs to reach 12% c.
- Idea was to also use nuclear pulsed power, but fusion.

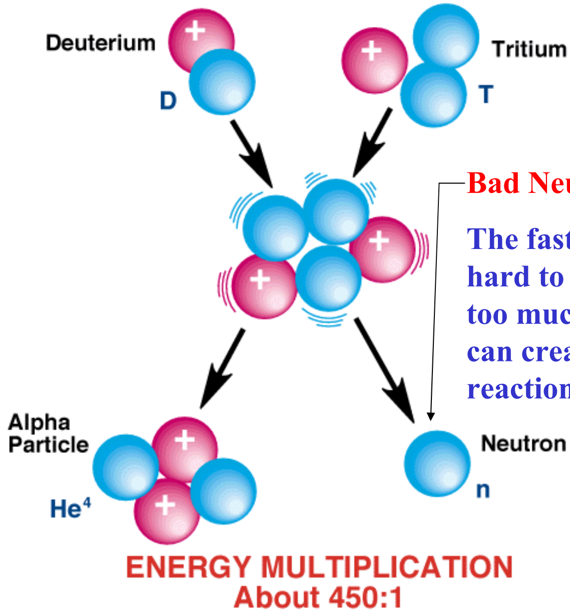
http://www.daviddarling.info/encyclopedia/D/Daedalus.html

Project Daedalus

- Good example of interstellar travel with foreseeable technology.
- Use fusion, like the stars.
- But, we have to use the more energy efficient part of hydrogen $\rightarrow$ helium.
- But there’s a problem.

http://www.daviddarling.info/encyclopedia/D/Daedalus.html

Deuterium–Tritium Fusion Reaction



Bad Neutron!

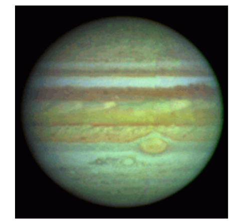
The fast neutrons are hard to stop, requires too much shielding. And can create extra reactions.

Project Daedalus

- Instead Daedalus would use:

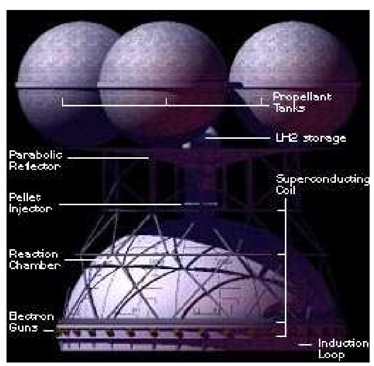
$$d + {}^{3}He \rightarrow {}^{4}He + p$$

- The by-products are normal helium and a proton.
- Both are positively charges and can be deflected with magnetic fields into an exhaust.
- Reasonably efficient, around 5 MeV.
- 1 MINOR problem. ^{3}He is very rare on Earth.
- Could be collected from the moon or Jupiter's atmosphere.



Project Daedalus

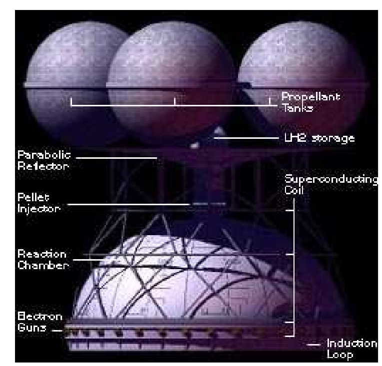
- Daedalus would accelerate for 4 years, then coast for 50 years to reach Barnard's star.
- At blastoff the mass would be 54,000 tons, of which 50,000 would be fuel.
- That's an $R_M = 12$.
- The fuel would be in pellets that enter the reaction chamber 250/sec.
- Sophisticated robots needed for repair.



http://www.daviddarling.info/encyclopedia/D/Daedalus.html

Project Daedalus

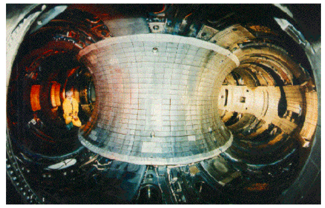
- For dust erosion at 0.12c, requires a beryllium erosion shield 7mm thick and 55 meters in diameter.
- Once it reached Barnard's star, it would disperse science payload that would study the system.
- Would transmit back to Earth for 6-9 years.
- So does not require a return trip.

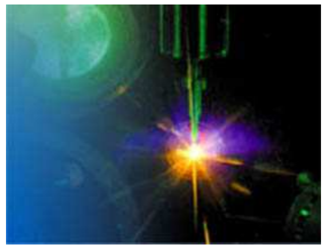


http://www.daviddarling.info/encyclopedia/D/Daedalus.html

Project Daedalus

- Still requires more technology.
- How to get the deuterium and ^3He close enough to fuse in the first place.
- This requires a hot, compressed collection of nuclei that must be confined for long enough to get energy out
  – It's like "herding cats"



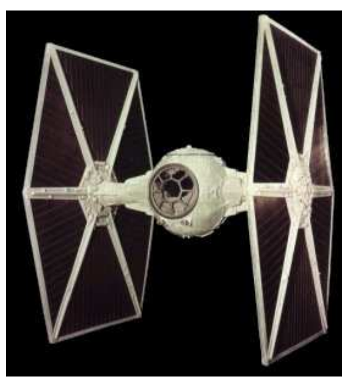


Fusion Rockets

- We are still not there.
- Fusion is not viable on the ground or in rockets at this time.
- Techniques are being worked on, but it can easily take decades before the technology is feasible.

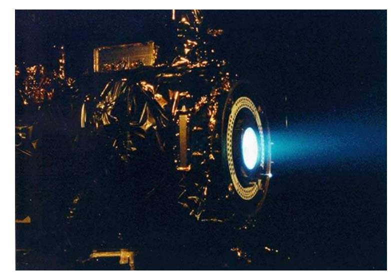
Ion Drives

- These are not science fiction.
- A propellant system: "stuff" is thrown backwards propelling the ship forwards.
- They eject a beam of charged atoms out the back, pushing the rocket forward
  – Kind of like sitting on a bike and propelling yourself by pointing a hairdryer backwards



Ion Drive

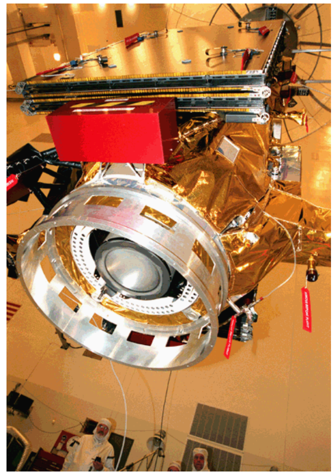
- First successful used in Deep Space 1, which took the closest images of a comet nucleus (Comet Borrelly).
- The engine worked by ionizing xenon atoms, then expelling them out the back with strong electric fields.
- The only waste is the propellant itself, which can be a harmless gas like xenon.
- But, requires energy input to power electric field which pushes the ions out the back
  – Solar cells usually provide power.



http://antwrp.gsfc.nasa.gov/apod/ap030720.html

DS1

- DS1 only used 81.5 kg of xenon.
- Thrust of engine is only about as strong as the weight of a piece of paper in your hand!
  - If you keep pushing lightly, you will keep accelerating, so after time you can build up speed
  - DS1 eventually reached velocity of 4.5 km/s (10,000 mph!)
  - Remember fastest space vehicle is Pioneer, which is still going about 12km/s
- Not useful for missions that need quick acceleration
- But, more efficient than chemical
  - Can achieve 10 times greater velocity than chemical!



http://nmp.jpl.nasa.gov/ds1/img/98pc1191.gif

Our Problem

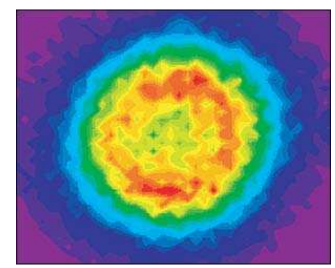
- For interstellar travel with any propellant, you must carry with you the stuff that you eventually shoot out the back
  - Fine for Saturn V rocket and "short" lunar missions
  - Bad for interstellar travel
    - Maybe even prohibitive
- But, it is unlikely that the methods discussed up to now will enable us to reach the stars in any significant manner.
- It is unlikely, therefore, that ET civilizations would use these methods
- We may do better, though…with the biggest bang for the buck.

Antimatter

- The most energy you can get from a hunk of mass is extracted not by
  - Chemical Burning
  - Nuclear fission or fusion
  - Pushing it in an ion drive
- The most efficient way to get energy from mass is to annihilate it!
- When they annihilate all of their mass is turned into energy ($E=mc^2$), eventually photons.
- $V_{ex} = c$

Anti-(Anti-matter)

- But, antimatter does not normally exist.
- We have to make it.
- We can make small quantities in giant particle accelerators, but total amount ever made is on order of a few nanograms.
- Would take 200 million years at current facilities to make 1kg!



Anti-Hydrogen from CERN.

http://news.bbc.co.uk/2/hi/science/nature/2266503.stm

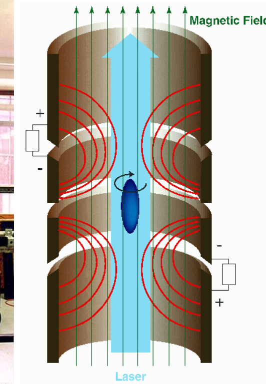
Anti-(Anti-matter)

- The amount of antimatter made in Illinois at Fermi-Lab in 1 day can provide energy to light a 100 W light bulb for ~3 seconds. If 100% efficient.
- And right now it takes about 10 billion times more energy to make antiprotons than you get from their annihilations.

http://news.bbc.co.uk/2/hi/science/nature/2266503.stm

Storage Issues

- Antimatter can be like a battery– storing energy.
- But antimatter ***must*** not touch matter!
- So, you have to store it without touching it
- Can be done by making electromagnetic "bottle" that confines particles with electric and magnetic force fields
  - "Penning trap"



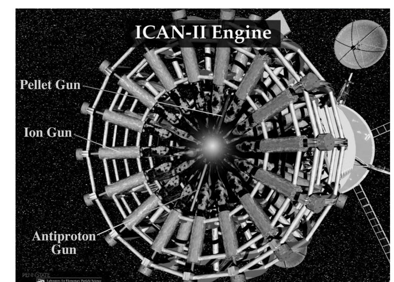
http://www.engr.psu.edu/antimatter/

Nonetheless

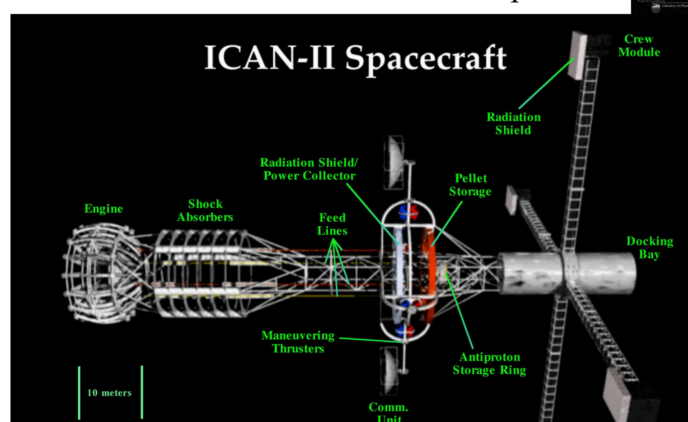
Propulsion	Specific Impulse [sec]
Chemical	200 - 450
Electromagnetic	600 - 3000
Nuclear Fission	500 - 3000
Nuclear Fusion	5000 - 10000
Antimatter	1000 - 100000

- Antimatter has potential to be about 1000 times more powerful than chemical combustion propulsion
- Antimatter propulsion has potential to be about 10 times more powerful than fusion

ICAN



- Ion Compressed Antimatter Nuclear
  - Designed at Penn State for Mars Mission
- Mixture of antimatter and fusion pellets.



http://www.engr.psu.edu/antimatter/

Interstellar Problem

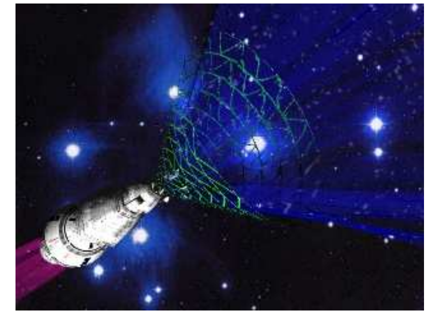
- Still for interstellar trips, we got a problem with carrying around the fuel.
- Edward Purcell thought about antimatter interstellar travel and found even that to be lacking!
- The lightest mass U.S. manned spacecraft was the Mercury capsule– the "Liberty Bell". It weighed only 2836 pounds (about 1300kg) and launched on July 21, 1961.
- It would still take over ***50 million kg*** of antimatter fuel to get this tin can to the nearest star <u>and back</u>.

http://lsda.jsc.nasa.gov/images/libertybell.jpg

http://www.craftygal.com/archives/september/table0900.htm

Lose the Fuel, Fool

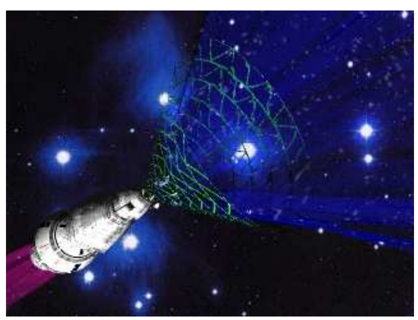
- What if we didn't have to carry all the fuel?
- One option is the Bussard ramjet.
- The spacecraft collects its own fuel as it moves forward.
- But, in interstellar space there is only 1 atom/cm3.



http://www.sternenreise.de/weltraum/antrieb/bussard.htm

Lose the Fuel, Fool

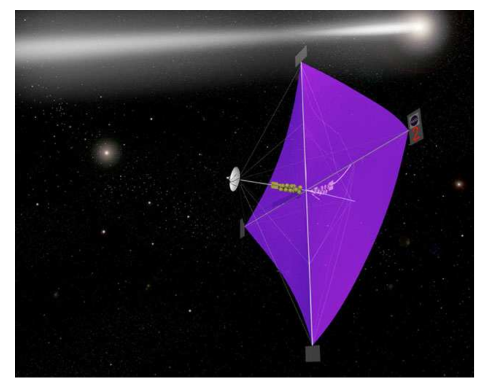
- The scoop would have to be 4000 km in diameter (size of US).
- Or magnetic fields to collect the material.
- But would mostly be low-grade hydrogen fuel, so it is a technological step ahead of what we already discussed.
- Could reach speeds close to 0.99c.



http://www.sternenreise.de/weltraum/antrieb/bussard.htm

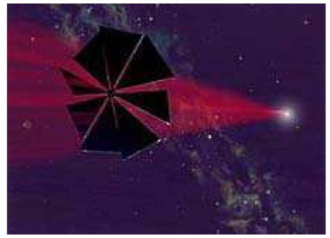
Light Sails

- Imagine a space sailboat but with photons of light hitting the sails and pushing it forward.
- No need to carry propellant, distant laser could be used to illuminate sails.
- Photons have energy but no rest mass.
- But, they do carry momentum!
  - It is related to the energy such that $p = E / c$
- So, such a craft is not propelled by solar winds!
- But by light bouncing off, like a mirror.



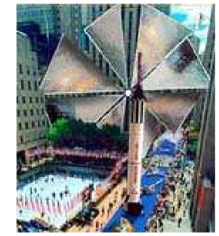
COSMOS 1

- First solar sail spacecraft (and private!) launched from a Russian nuclear submarine on June 21, 2005!
- Unfortunately, the first stage of the Volna never completed its scheduled burn, and the spacecraft did not enter orbit.
- Built in Russia at Babakin Space Center
- Had 8, 15m sails
  - 100kg payload (small, but first step!)
- The planetary society is going to try again, if they can raise the money.

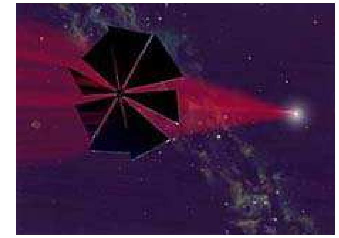


- http://www.planetary.org/solarsail/animation.html

COSMOS 1

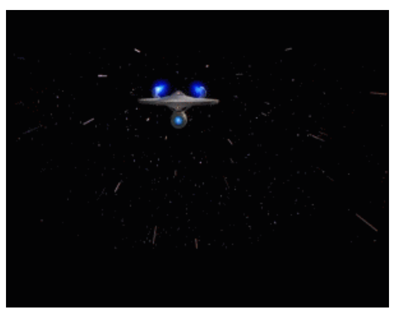


- It would take about 1,000 years for a solar sail to reach one-tenth the speed of light, even with light shining on it continuously.
- It will take advanced sails plus a laser power source in space that can operate over interstellar distances to reach one-tenth the speed of light in less than 100 years.
- So probably not useful for interstellar travel.



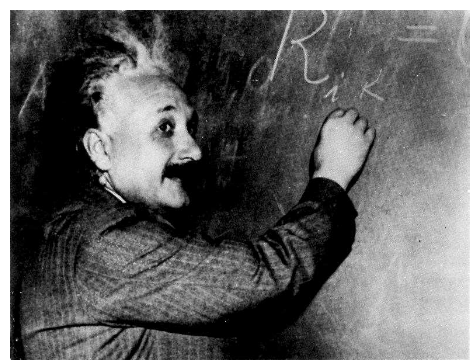
Warp Drives

- Again, science fiction is influencing science.
- Due to great distance between the stars and the speed limit of c, sci-fi had to resort to "Warp Drive" that allows faster-than-light speeds.
- Currently, this is **impossible**.
- It is speculation that requires a revolution in physics
  - **It is science fiction!**
- But, we have been surprised before…
- Unfortunately new physics usually adds constraints not removes them.



http://www.filmjerk.com/images/warp.gif

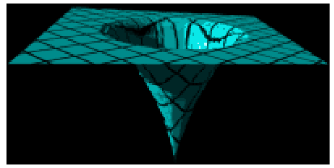
Einstein Is Warping My Mind!



- Einstein's General Relativity around 1918
- Space and time were re-interpreted
- No longer were they seen as immutable, constant properties
- Space itself can be "warped" by mass.

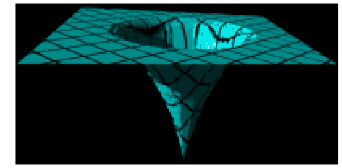
General relativity

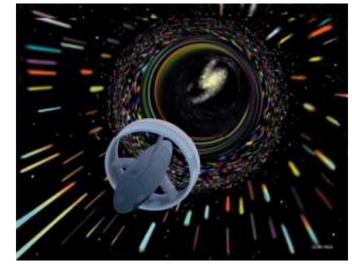
- Gravitational fields can also change space and time
  - A clock runs more slowly on Earth than it does in outer space away from any mass, e.g. planets.
- Einstein revealed that gravity is really 'warped' space-time.
- A black hole is an extreme example.



General relativity

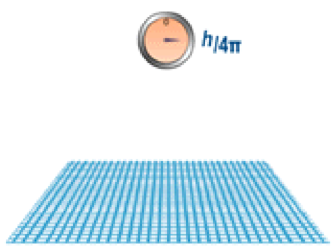
- Rotating black holes may form wormholes to "elsewhen" but they are thought to be short-lived.
- Researchers are considering stabilizing them with exotic matter.
- What if it were possible to create a localized region in which space-time was severely warped?
  - A car has a speed limit on a road, but what if you compress the road itself?





Quantum field theory

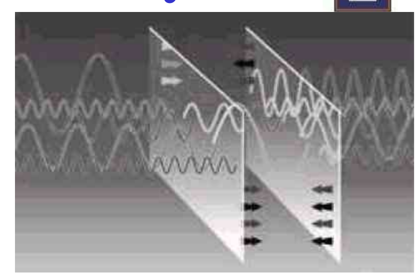
- The subatomic world is not a world of billiard ball-like particles
- "Empty space" is full of waves/particles popping in and out of existence
  - Like a choppy sea, "virtual particles" are born and interact for an allowed window of time
- This sea of "virtual particles" that inhabits space-time can be a source of energy
  - This is real physics, not Sci-fi

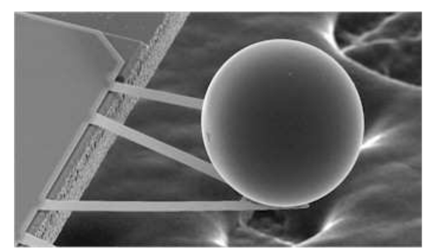


http://zebu.uoregon.edu/~js/glossary/virtual_particles.html

Quantum field theory

- In 1948, Hendrik Casimir predicted a weak attraction between two flat plates due to the effect of the sea of virtual particles.
- Two 1 meter plates placed a micron apart, would have 1.3mN of force. This is like a weight of 130 mg.
- But it is force from nothing!
- Maybe this effect can create a subtle propulsion system?





Dark Energy

- Imagine harnessing the power of dark energy (which seems to occupy all space) to form an anti-gravity generator?
- It is crucial to investigate new ideas with open minds and freedom.
- Right now, we really don't have a firm idea for any new propulsion system (space warp-driven propulsion, etc.).
- But, be patient – a long wait may be ahead
  - Hundreds of years?
  - Thousands of years?
  - Remember that the civilization lifetime can be millions of years!

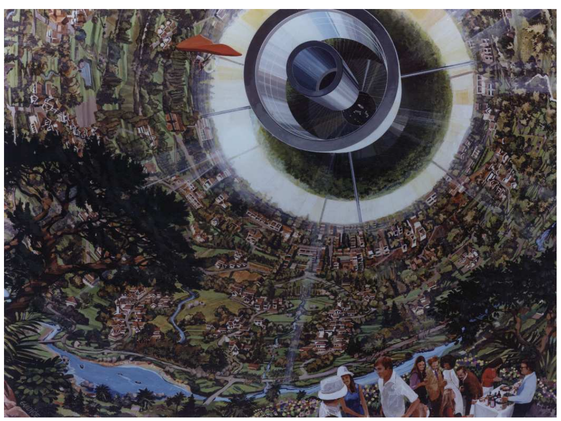
ET's Spacecraft?

- We really don't know yet how to get to the stars realistically, so we don't know what advanced civilizations might use.
- But it is
  - Smarter
  - Cheaper
  - Still very informative and
  - Realistic

  to send an unmanned probe into stars first
  - Lighter payload!
- Self-replicating probes?

Long Haul Space Travel

- Spacecraft that we can envision easily would take a lifetime to get to the nearest star.
- Colonizing missions would be multi-generation missions.
- Space colonies with propulsion systems would slow down things, so maybe it would take 1000 yrs.
- How many of you would sign up today?



Nikolai Kardashev: Civilization Types

Type 0: Not in complete control of planet's energy
Understand the basic laws of physics
Chemical and nuclear propulsion, solar sails

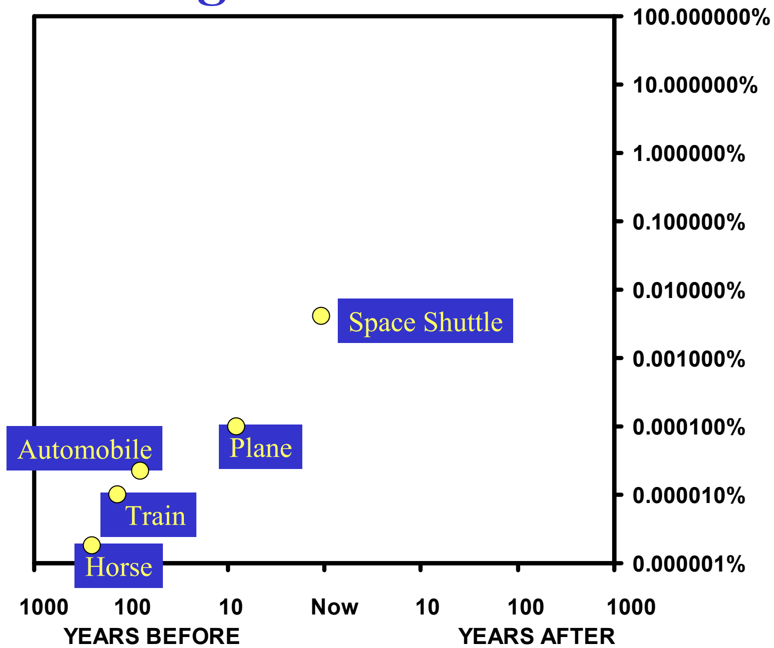
Type I: Harnesses energy output of an entire planet.
Laser sails.

Type II: Harnesses entire output of their host star.
Dyson Sphere–can provide a trillion times more energy than we use on the Earth now. Antimatter drives?

Type III: Colonizes and harnesses output of an entire galaxy
Use a trillion times the energy of Type II civilizations
Use a trillion trillion times the energy of Type I civilizations

http://www.unm.edu/~astro1/ET109/types/types.html

Going Interstellar!

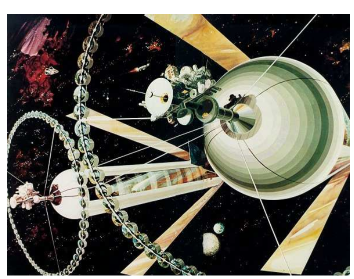


Problems to Overcome?

1. Space is Big.
   – Nothing we can probably do about this one.
2. Time.
   – Because of #1, interstellar travel would take a lot of time.
   – But arguably do-able.
     • Maybe lifetime is expanded, generation ships, suspended animation, or intelligent robots.
3. Cost
   – Right now, colossal budget of a few trillion dollars. Impossible now, but in the future?
   – Medieval blacksmiths could have made an oil tanker, but too costly. 500 years later, piece of cake.
   – In future, cost of interstellar travel may also go down.

1000 Years?

- So in 1000 years from now, we should be able to travel to other stars. But will we?
- It would be nuts to speculate on what will motivate our descendents (if any) 1000 years from now. But if interstellar travel really is easy and cheap, surely someone will give it a go?



Getting Out of Here

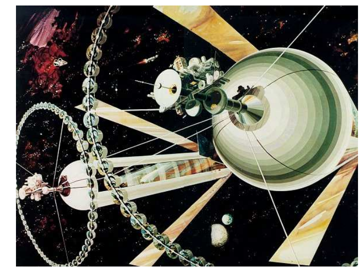
- Distances between stars are much greater than we can imagine– freaky big distances, plus difficult environment and time consuming makes interstellar travel hard to conceive.
- SciFi books and movies have dramatized space travel to make it <u>seem</u> possible
  – But, interstellar travel may never happen
- Even the Voyager spacecraft (one of the fastest ever flown) travels at only 20 km/s through space - not even 1% of the speed of light. They would take 60,000 years to reach even the nearest star.
- In our discussions, we argue that with foreseeable technology 10% the speed of light is possible.
- Is that enough to expect to see aliens on Earth?

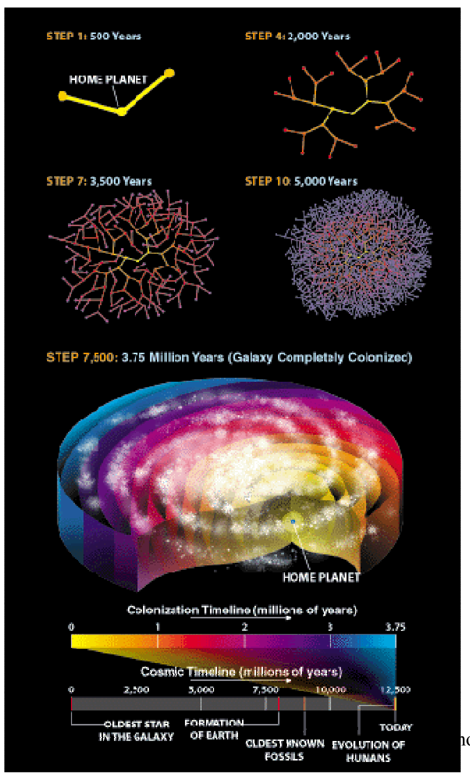
Galaxy Colonization

- If our Drake equation estimate is roughly right, there should be civilizations that are 1 billion years old!
- Think of the accomplishments.
- Even if interstellar travel is limited to 0.1c, civilizations with advanced telescopes could send colonizing craft to new planets.
- That group regenerates for 500 yrs and sends out another craft.
- An advanced civilization could colonize the entire galaxy in maybe only 5 million yrs!

How long to colonize the Galaxy?

- With 0.1c, we can travel 10 light years in 100 years
- We can reach the nearest star in 43 years
- Allow each new colony 50 years to duplicate the technology
- Colonies could spread out about 50 light years every 3,000 years





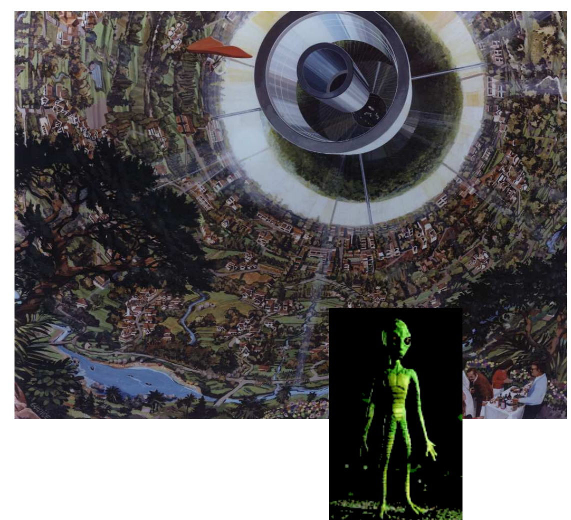
Optimistic

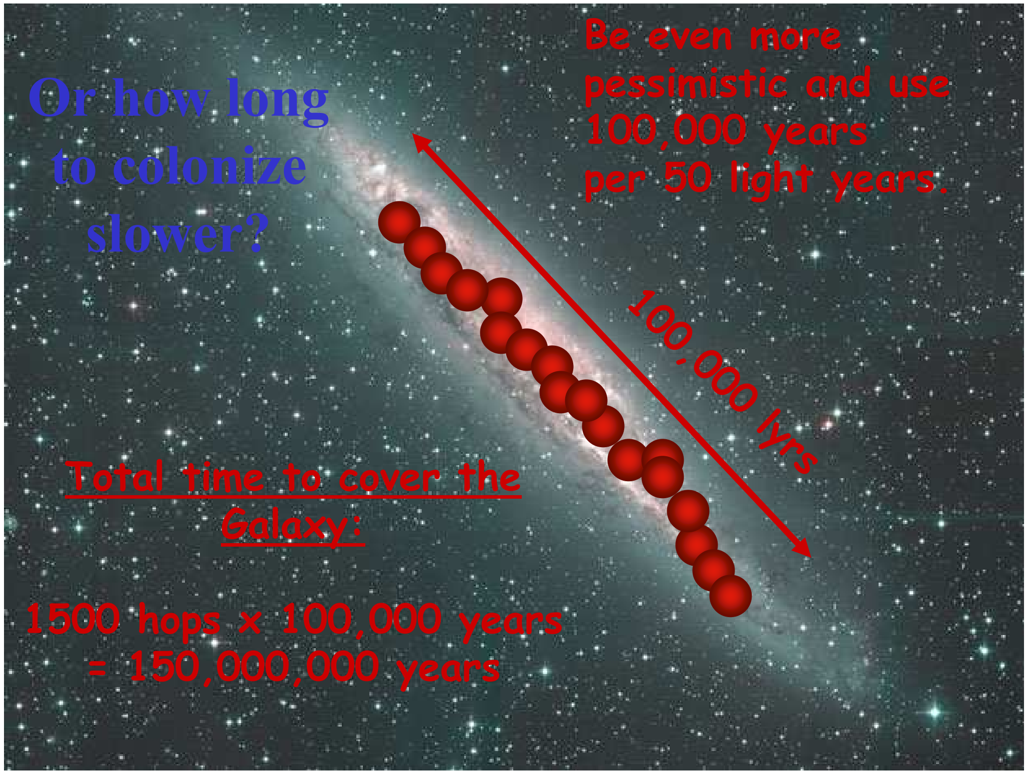
Every 500 years, the colonization craft makes it to the next suitable solar system– small delay.

Then, it only takes about 4 million years!

Slow Long Haul Space Travel

- Spacecraft that we can envision easily would take a lifetime to get to the nearest star.
- Colonizing missions would have to be multi-generation missions.
- Space colonies with propulsion systems would slow down things, so maybe it would take 1000 yrs for each trip.
- How many of you would sign up today?





The Fermi Paradox

The Drake Equation – Even for a few hundred technical civilizations.

Only 150 million years to colonize the Galaxy.

WHERE IS EVERYBODY?????

The Fermi Paradox

- Our estimate for communicable civilizations was around 12,000.
- Given such a large number, one of them must have developed earlier than we did.
- So "Where are they?"
- Even if interstellar travel is very slow and difficult, there has been <u>a lot</u> of time to do it.
- Furthermore, many of the objections to interstellar travel do not apply to artificial intelligence (intelligent robots.)

Life on Earth is of One Type?

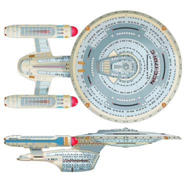
- Life got started on Earth pretty quickly. To some, this suggests that life forms easily, whenever conditions are right.
- So why are all creatures on Earth descended from the same microbe?
- You can tell from the similarities in our DNA and cells that all living things come from the same ancestors. Why?
- The average time needed to spread over the Earth was much less than the average time to evolve. Not true for the Galaxy.

Timescales

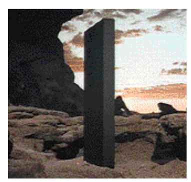
- For pessimist: 150 million years to colonize the Galaxy.
- For optimist: 4 million years to colonize the Galaxy.
- This may seem like forever, but it is actually pretty tiny compared to the time it takes evolution (about 0.1%).
- So, if we believe our condition, there should only be one intelligent family of species in our galaxy - whoever reached intelligence first should have spread everywhere before anyone else reaches intelligence.
- This is the main point of the Fermi Paradox.
- Where are they?

Limits

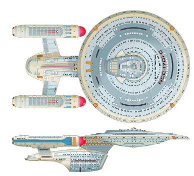
- So, if we go back to two alternatives - a galaxy packed with billions of intelligent life-forms, and a cold and lonely empty one, Fermi is suggesting that the truth lies closer to the second alternative.
- Does this seem reasonable?
- There may be a few (or a few hundred) intelligent species out there.
- But if there really were billions, we would have surely have been visited?



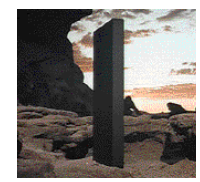
Where is Everyone?



- **They are around, but we can’t tell yet**
  - They are too advanced or alien to recognize or detect
  - They don’t bother with us (or traveling or broadcasting)
  - Do civilizations hide to avoid a “galactic scourge?”
  - They are keeping us “quarantined” (the “zoo” or prime directive hypothesis)
  - They’ve been here (or are here), and we don’t know it
  - They are not “technical” in a way we can understand.



Where is Everyone?



- **They are not around**
  - Some factors in Drake equation may be much smaller than we believe – life, or intelligent life, is very rare
  - They wipe themselves out too quickly
  - Other factors wipe them out too quickly
  - Life hardly ever develops technical civilizations
  - There is very little life out there
  - We are among the first to develop

Or…

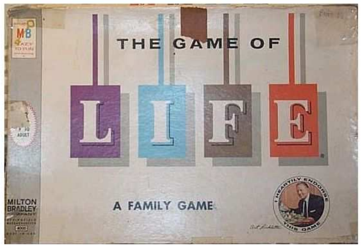
- There is no ET life on Earth, so there are only 5 possible explanations (according to Michael Hart):

1. Space travel is not feasible.
2. Other civilizations have chosen not to colonize.
3. Other civilizations have not had time to colonize the Galaxy.
4. The Earth has been visited in the past, but we do not observe any visitors now.
5. There are no other advanced civilizations in the Galaxy.

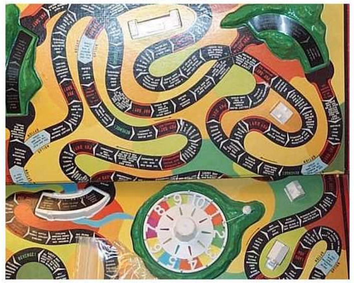
Hart argues against all but #5. He is saying that our Drake Equation result is wrong!

Maybe Life is Hard

1. Maybe colonization is much more difficult than we assume. Might expect robotic probes first, which slows down the process.
2. Maybe travelers prefer to explore more than colonize. Overpopulation is not the issue.
3. Are planets suitable for life? If one of the 20 amino acids is missing in that life system, food is a problem.
4. By colonization timescale, the space creatures may prefer to stay in space– weightlessness evolution. Comfy clothes.



1960 edition. Art Linkletter-endorsed. Shucks, that's all I need to see!



http://www.wesclark.com/am/life.jpg