# Terraforming Mars: By Aliens?


- Sometime movies are full of errors.
- But what can you do?

# Astronomy 330

This class (Lecture 26):
Space Travel

Last Class:
Visitations

HW 11 is due Sunday!

Music: Space Race is Over – Billy Bragg



# Final Papers

- Final papers due at BEGINNING of discussion class on May 6th.
- You must turn final paper in with the graded rough draft.
- Unless you are happy with your rough draft grade as you final paper grade, then don't worry about it.

# Final

- In this classroom May13th, 1330-1630.
- Will consist of
  - 20 question on Exam 1 material.
  - 20 question on Exam 2 material.
  - 40 questions from new material.
  - +4 extra credit questions
- A total of 210 points graded out of 200 points.
- A normal-sized sheet of paper with notes on both sides is allowed.
- I will post Exam1 and 2 online on class website.
- I will post a review sheet

# Online ICES

- ICES forms are available online.
- I appreciate you filling them out!
- Please make sure to leave written comments. I find these comments the most useful, and typically that's where I make the most changes to the course.
- So far 22/97, so fill them out!

# Question

Are you going to fill out an ICES form before the deadline?

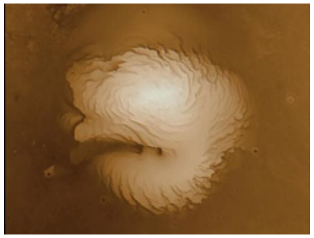
a) Yes
b) No
c) I don't like ice in my beverages.

# Outline

- Rockets: how to get the most bang for the buck.
- Some examples of possible rocket ships

# Wet Mars

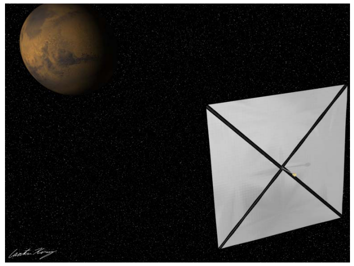
- There is clearly water on Mars frozen in the permanent ice caps or in icy deposits below the surface.
- Probably $10^{14}$ tons of ice in the caps, but how to melt it?
- Spread a layer of dark soil, which will sublimate the water to water vapor.
- Water vapor is a greenhouse gas, so eventually pressure and temperature goes up and liquid water can exist.
- Would take about 10,000 yrs to melt.



http://www.ucl.ac.uk/GeolSci/MITC/marsinfo/icecap.jpg

# Solar Mirror?

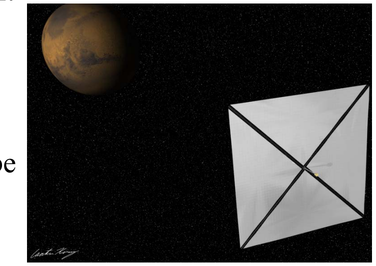
- Could build huge solar mirrors in space to add light to mars– size of Texas for 2% increase.
- Power needed to melt the icecap (remember only first step) is equivalent to 2500 yrs of the US energy output!



http://www.futurespace.de/gallery/pictures/sail-mars1.jpg

# Solar Mirror?

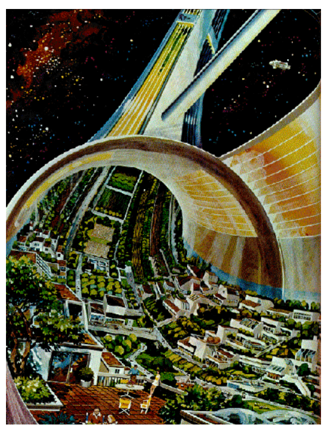
- A solar sail satellite (diameter of 125 km) above the pole should melt the icecap in 10 yrs.
- Other options: genetically engineered bacteria to add greenhouse gases, nanobots, etc.
- Bottom line, at this time it would be very costly and time consuming to terraform Mars.



http://www.futurespace.de/gallery/pictures/sail-mars1.jpg

# Space Colonies?

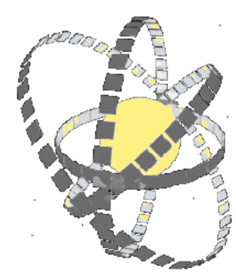
- Super-duper version of the Space Station.
- Collect materials from Moon, and make a large space structure.
- Artificial gravity from rotation– life could exist.
- But why?
- Hard to justify the expense.
- Maybe solar power collector– beaming microwaves back to Earth.



http://static.howstuffworks.com/gif/space-station-space-settlement.gif

# Dyson Spheres– Recap

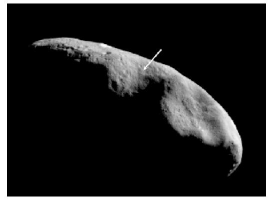
- Again, one could imagine a Dyson Sphere around the Sun to collect the sunlight.
- If other advanced civilizations built one, could we detect it?
- If at 1AU, the sphere would be about 300 K and emit in the IR.
- But if we detected it, we would think it was a star surrounded by dust-- a circumstellar disk of a young star or a blown out shell of dust from an old star.



http://www.homoexcelsior.com/omega.db/datum/megascale_engineering/dyson_sphere/

# Asteroid Living and…

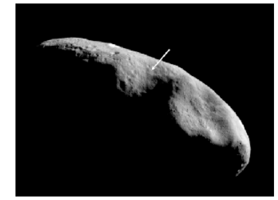
- Mining the Apollo (near Earth) asteroids for metals is a possible economical driver for life in space.
- But all of this requires moving machines, humans, or material around the solar system.
- Today, if there were piles of gold laying on the Moon, it would not be cost effective to go get it.



http://apollo-society.org/images/near_arrow_sm.jpg

# Asteroid Living and…

- But, remember to date human space travel has cost 10 times as much as remote “robot” travel.
- Probably devise ways to mine remotely.
- Efficient mining requires more and more intelligent robots.
- What if they get too smart?
- Still self-replicating space probes could be result of such advances.



http://apollo-society.org/images/near_arrow_sm.jpg

# Space Probed

- A single probe is constructed and dispatched to a nearby star system
- It surveys the system in an intelligent and exhaustive manner
- After which, the probe uses the energy and available raw materials of the system to reproduce itself .

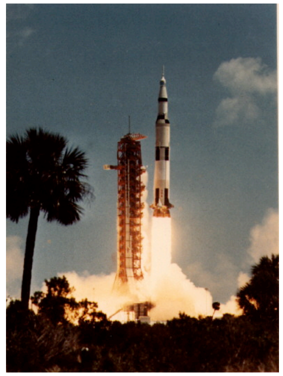
# Neumann Space Probed

- Dispatches its “children” onwards to repeat its mission in other star systems
- The parent probe is then able to choose whether it wants to stay in the system or not, depending on what it found
- Still need a way to get to other worlds.

http://www.biochem.wisc.edu/wickens/meetings.html

# Energy into Propulsion

- For any type of space travel, we need an energy source to propel the vehicle.
- The basic idea is to convert some stored energy into *energy of motion* for the spacecraft
- Two ways basically:
  1. Process some sort of fuel
     - Carried onboard
     - Collected from space and processed
  2. Other, non-fuel-like energy source:
     - Solar (if near a star)
     - Gravity (using an astronomical body's gravity field to propel a ship)



# We got a speed limit!

- No matter what we do, we can not go faster than the speed of light!
- That naturally occurs when one demands that the speed of light *must* be the same regardless of who measures it.
- This is completely counter-intuitive!
- Basis of Einstein's Theory of Special Relativity.

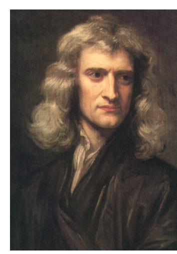

http://www.rpi.edu/dept/phys/Dept2/APPhys1/optics/optics/node4.html

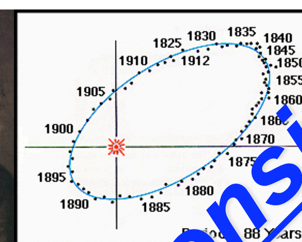
# How Fast is Light?

- The speed of light is $c = 3\times10^8$ m/s (186,000 miles per second)!
- How fast is that?
  - Around the Earth over 7 times in a second
  - From Earth to the Moon in under 2 seconds (it took the astronauts 2 weeks)
  - From the Sun to the Earth in a little over 8 minutes
  - From the Sun to Pluto in about 5½ hours
  - From the nearest star to Earth, about 4 years


# *Two Threads of Thought in Physics up to 1900*

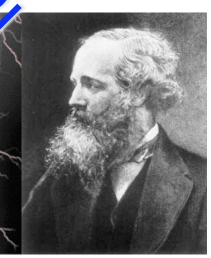
**Mechanics**
(Newton's Laws)






All motion is relative
No speed is special

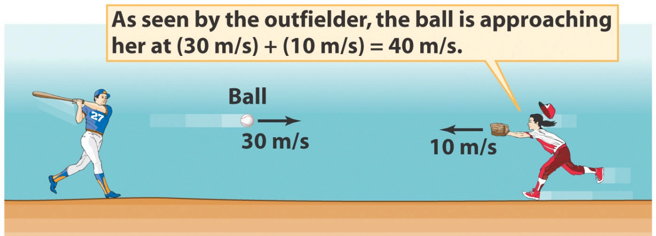
**Electromagnetism**
(Maxwell's Equations)



The speed of light is the **same** for all observers

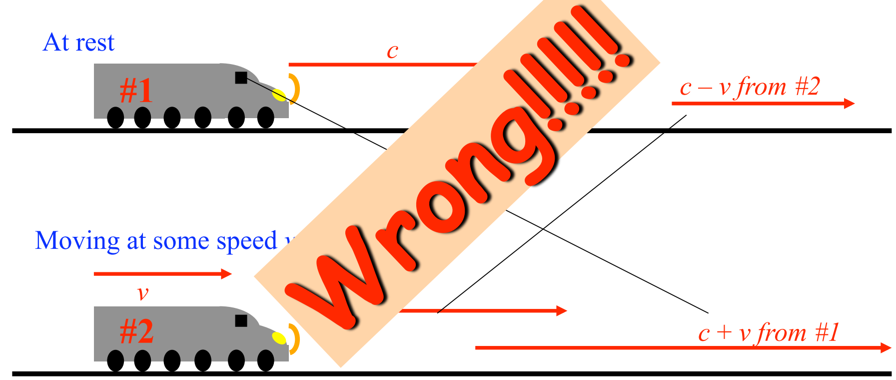
Inconsistent!

## *Why Newton and Maxwell Can't Both Be Right*

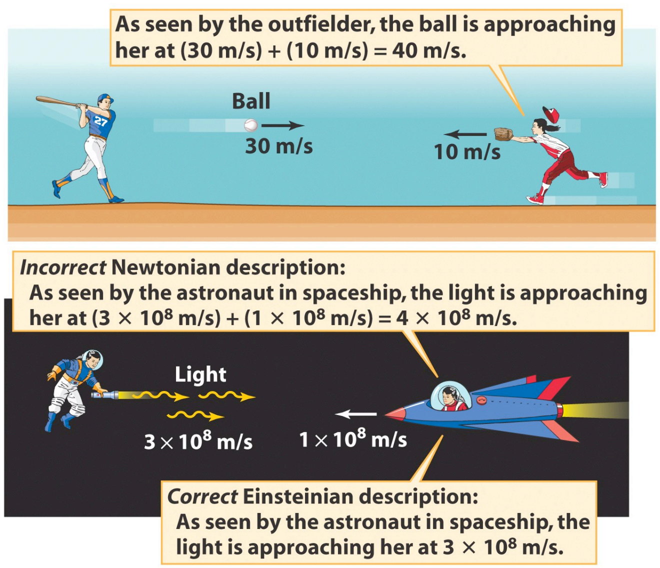



## *Why Newton and Maxwell Can't Both Be Right*

Consider two locomotives emitting light from their headlamps:




## *Why Newton and Maxwell Can't Both Be Right*




## **Why Newton and Maxwell Can't Both Be Right**

So the speed of light can't be the same for everyone if Newton – and our intuition – are right. But Maxwell says it is constant!

Something must happen. And what must happen for Newton and Maxwell to be both right, is that there is a modification of time and distance. Remember

$$speed = \frac{dist}{time}$$

Distance and time become relative to the observer.

# Approaching the "c"

- The clocks on a ship accelerating to "c" would stop completely from someone at rest.
- The ship would be infinitely thin in length along its direction of motion.
- The mass of an object as it approaches "c" becomes infinite
  - So does its kinetic energy– requires more power.

http://www.richard-seaman.com/ Travel/Japan/Hiroshima/ AtomicBombMuseum/ IndividualArtifacts/

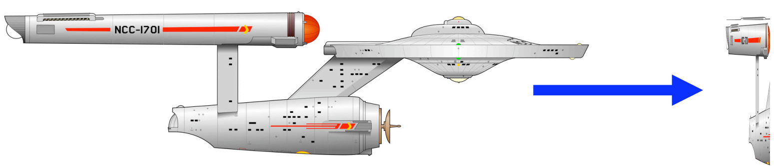
# *Gamma*

The factor by which all of these changes occur is called "gamma"

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

# *Counterintuitive Result #1*

***Moving objects are shorter in the direction of relative motion (<u>Lorentz contraction</u>)***




| Fraction of the speed of light | % of original length |
|---|---|
| 0.00 | 100% |
| 0.001 | 99.99995% |
| 0.01 | 99.995% |
| 0.1 | 99.5% |
| 0.5 | 86.6% |
| 0.9 | 43.6% |
| 0.99 | 14.1% |

# *Counterintuitive Result #1*

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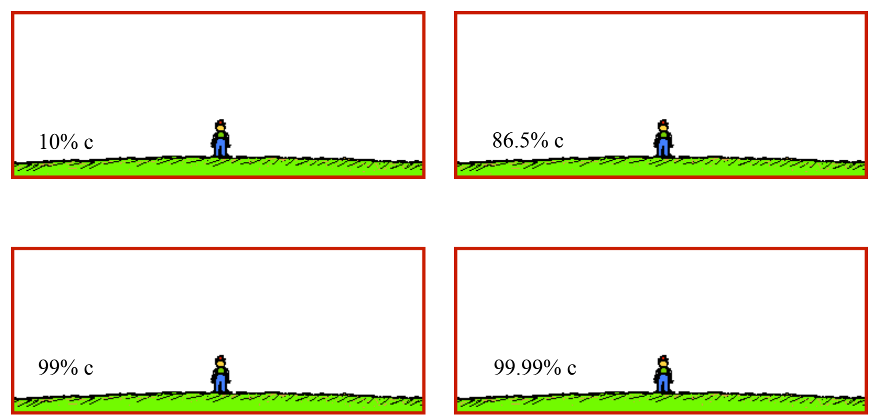



http://www.physicsclassroom.com/mmedia/specrel/lc.html

# Length Contraction

- This effect has some benefits:
  - Outside observers will measure that the length of the spaceship has shrunk.
    - This doesn't really help or harm us
  - But, from the astronaut point of view, the entire universe outside their window has shrunk in the direction of motion, making the trip shorter!
- It's all relative.

# *Counterintuitive Result #2*

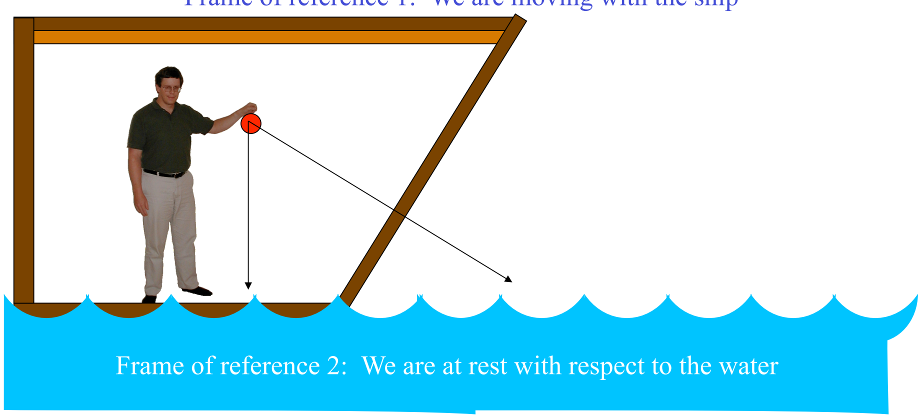
***Clocks on Moving objects slow down***


*"Try not to watch the clock. It only makes the day go slower."*

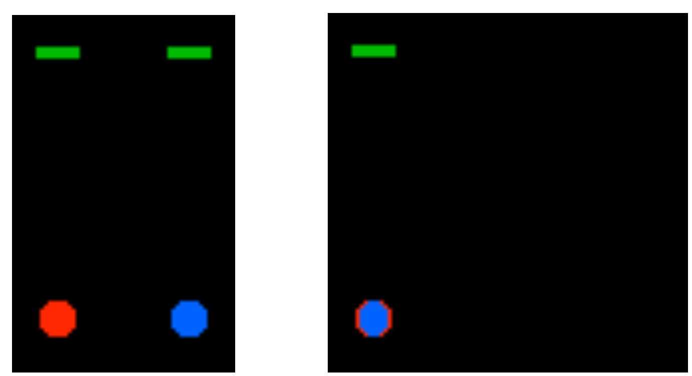
# *Galileo's ship thought experiment*

No experiment within the ship's cabin can detect the ship's motion if the ship moves in the same direction at a constant velocity. This is still true, even when considering the speed of light.

Frame of reference 1: We are moving with the ship



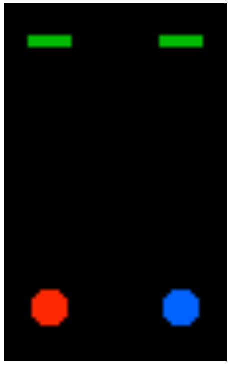

# *If the Ball is light?*



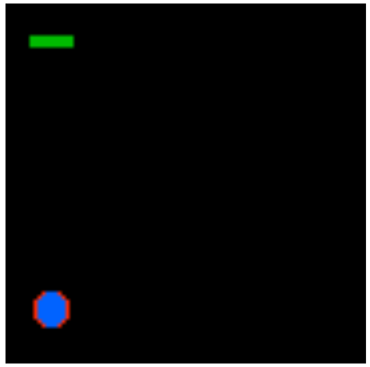
A. Hamilton (Colorado)

## *Counterintuitive Result #2*

***Time advances more slowly for moving objects (<u>time dilation</u>)***



Red & blue at rest



Blue moving to right

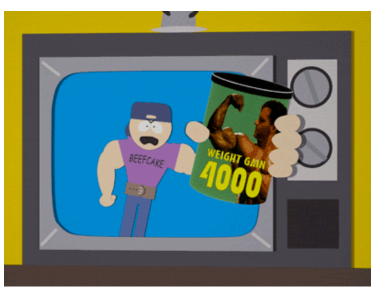
A. Hamilton (Colorado)

# Time Dilation

- The effects of time dilation are curious but not prohibitive for space travel
  - Astronauts will age less than the Earth-bound folks waiting for the return. Can spoil the homecoming celebrations.
  - The faster you go, the bigger difference between astronaut time and Earth time
- Example: Trip to the center of the Galaxy and back. Accelerate at 1g for the first half and decelerate for second half and you can go 30,000 ly in 20 years! But more than 30,000 years has elapsed on Earth!

## *Counterintuitive Result #3*

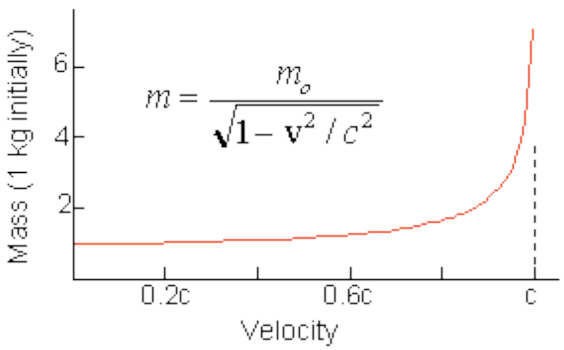
***Mass increases for moving objects***




# Mass Increase

- The increase of effective mass (and kinetic energy) with velocity makes acceleration and deceleration more difficult if you intend to travel close to “c”
  - This translates to very costly starflight in terms of required energy.
  - And now the interstellar dust that you strike at relativistic speeds appears as larger mass.
  - For 99% speed of light travel, 5.5 meters of shield would erode every year.

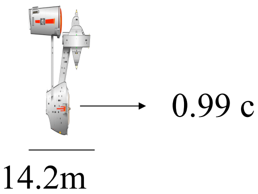
# The gamma factor and mass:




Infinite Mass!!!!

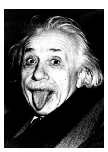
# So, what does that mean?

- If you're on a 100m spaceship going near the speed of light (.99 c), the spaceship measures100m long, but someone on the Earth would measure the spaceship to only be 14m long.
- As you speed by the Earth your clock would tick 1 second, and an observer would tick about 7 seconds– $\gamma = 7$.




Paul's Twin brother (on the Earth) is 7 seconds older for ever second.

And Paul's mass increased by a factor of 7.



## 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 shrink in the direction of travel.**

**Time advances more slowly for objects moving close to the speed of light.**

**Mass of the moving object rapidly increases as objects move close to the speed of light.**

# Question

You are on a spacecraft moving near the speed of light toward our nearest star. What happens to the distance of your journey?

a) Nothing
b) It only appears longer.
c) It only appears shorter.
d) It is longer.
e) It is shorter.

# 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:

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

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

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

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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.**

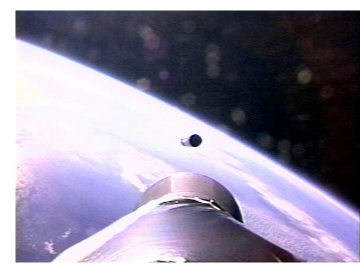
# How's it work?

- 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

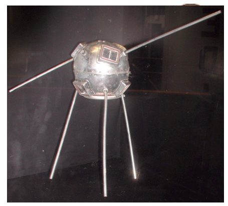
# What you talking 'bout Willis?

- 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.

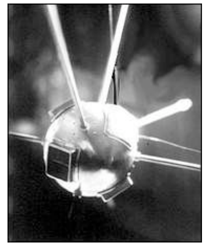


http://www.utahredrocks.com/stardust/launch6.jpg

# Not Good



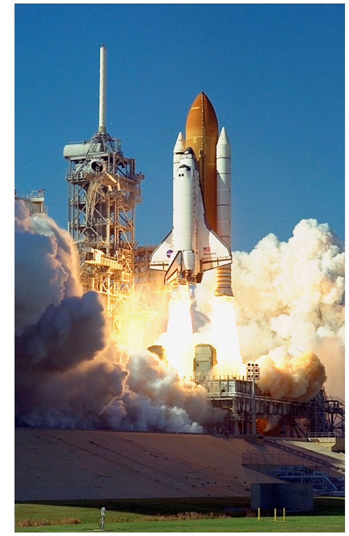
- Multistage rockets are wasteful.
- The Mass Ratio can be huge!
- The first US satellite was the Vanguard launched on March 17, 1958. (Still in orbit!)
- 6.4 inch diameter with 2 radio transmitters.
- Weighed 3 lbs = 1.4 kg.
- Rocket mass was 36,000 kg.
- $R_M = \dfrac{36000 + 1.4}{1.4} = 25{,}715 >> 1$
- 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 = $2.95 \times 10^4$ kg
- $M_{takeoff} = 2 \times 10^6$ kg
- $R_M = \dfrac{2 \times 10^6 + 2.95 \times 10^4}{2.95 \times 10^4} = 67.8$



# Kiss and Make Better

- Shuttle thrust is $29 \times 10^6$ 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

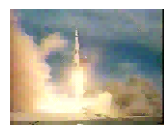
- Look at the "octane" of various fuels available today.
- $H_2 + O_2 \rightarrow$ s.i. = 455 sec
- $O_2$ + hydrazine ($N_2H_4$) $\rightarrow$ s.i. = 368 sec
- $H_2$ + fluorine (F) $\rightarrow$ s.i. = 475 sec
  - But exhaust gas is hydrofluoric acid
- **Note: No chemical fuel can achieve s.i. > 500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

# Rocket Combustion: Chemical Fuels

1. Petroleum : Refined kerosene with LOX (liquid oxygen) oxidizer. *(Saturn V first stage)*
2. Cryogenic : Ultra cold hydrogen fuel with LOX oxidizer. Propellant is…water! *(Space Shuttle Main Engines)*
3. 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)*
4. 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)*

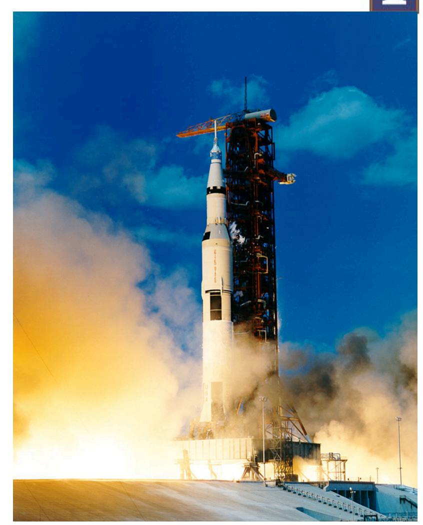
http://www-pao.ksc.nasa.gov/kscpao/nasafact/count2.htm

# Petroleum rocket fuel in action



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

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

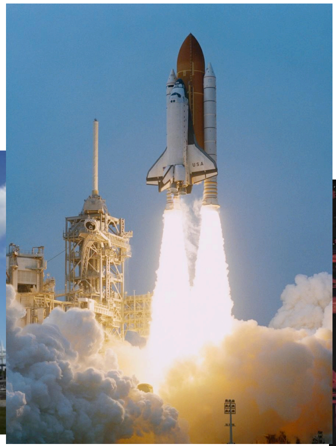


http://www.hq.nasa.gov/office/pao/History/alsj/a16/ap16-KSC-72PC-184.jpg

# 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.

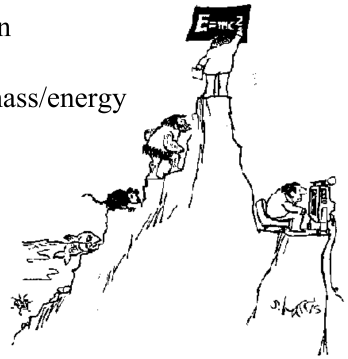
- Ammonium perchlorate (oxider)
- Aluminum (fuel)
- Iron Oxide (catalyst)
- Polymer (binder)

# 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



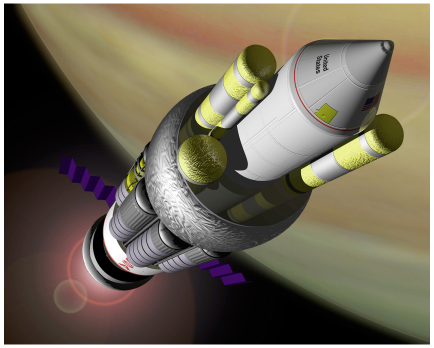

http://www.owlnet.rice.edu/~spac205/E=mc2.gif

# 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

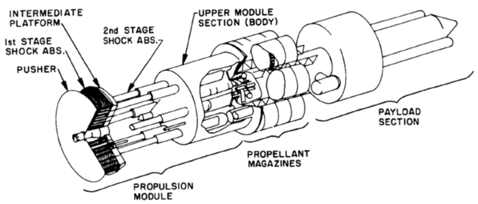
- A spacecraft powered by nuclear bombs– nuclear fission.
- Idea was sponsored by USAF in 1958
- Physicist Freeman Dyson took a year off from Princeton to work on idea
- Sounds crazy now… but a real project



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

# 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.

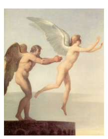



http://en.wikipedia.org/wiki/Project_Orion_%28nuclear_propulsion%29

# Project Orion

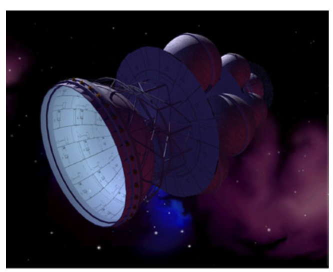
- s.i. theoretically around 10,000 to one million seconds
- Limited to about 0.01c.
- But, it is a “dirty” propulsion system.
- A 1963 treaty banned nuclear tests in the atmosphere, spelled the end of "Orion".
- Still argued to be the best rocket we could build today.

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

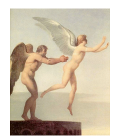


# Project Daedalus

- Continuation/extension of Orion
- British Interplanetary Society project (1973-1978 planned)
- A robotic fly-by probe to Barnard’s Star
  - 2nd 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.

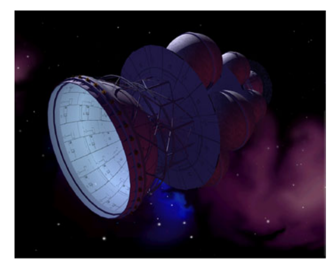


http://www.daviddarling.info/encyclopedia/D/Daedalus.html

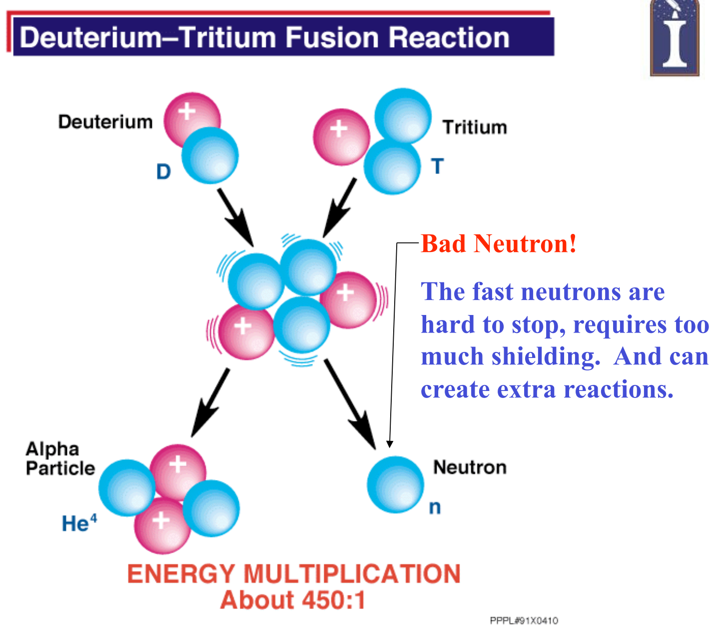


# Project Daedalus

- 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 → helium.
- But there’s a problem.



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

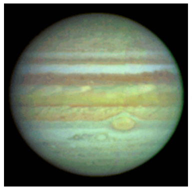



# Project Daedalus

- Instead Daedalus would use:

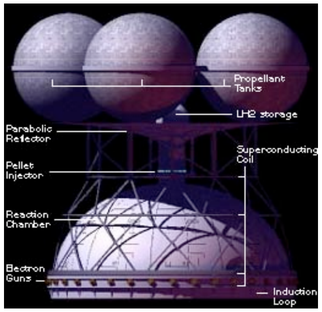
$$d + {}^{3}He \rightarrow {}^{4}He + p$$

- 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

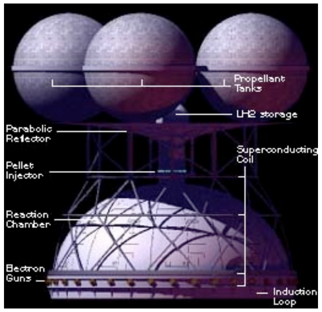
- Daedalus would accelerate for 4 years, then coast for 50 years to reach Barnard's star.
- At blastoff the mass would be 54,000 tons, of which 50,000 would be fuel.
- That's an $R_M = 12$.
- The fuel would be in pellets that enter the reaction chamber 250/sec.
- Sophisticated robots needed for repair.




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

# Project Daedalus

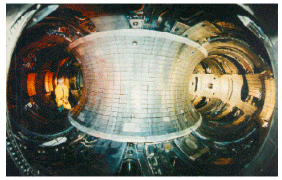
- For dust erosion at 0.12c, requires a beryllium erosion shield 7mm thick and 55 meters in diameter.
- Once it reached Barnard's star, it would disperse science payload that would study the system.
- Would transmit back to Earth for 6-9 years.
- So does not require a return trip.

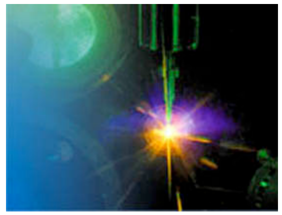



http://www.daviddarling.info/encyclopedia/D/Daedalus.html

# Project Daedalus

- Still requires more technology.
- How to get the deuterium and $^{3}$He 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"



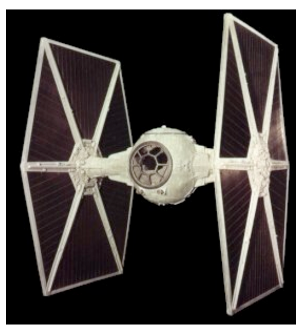


# Fusion Rockets

- 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.

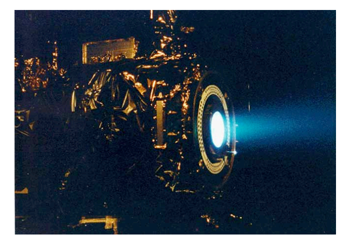
# Ion Drives

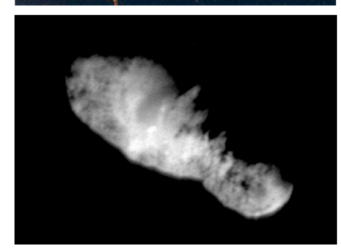
- These are not science fiction.
- A propellant system: "stuff" is thrown backwards propelling the ship forwards.
- They eject a beam of charged atoms out the back, pushing the rocket forward
  - Kind of like sitting on a bike and propelling yourself by pointing a hairdryer backwards



# 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.

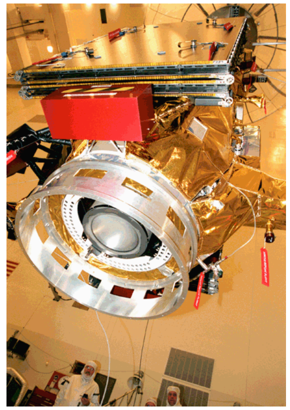




http://antwrp.gsfc.nasa.gov/apod/ap030720.html

# DS1

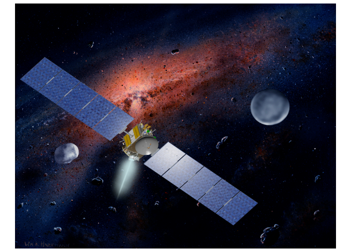
- DS1 only used 81.5 kg of xenon.
- Thrust of engine is only about as strong as the weight of a piece of paper in your hand!
  - If you keep pushing lightly, you will keep accelerating, so after time you can build up speed
  - DS1 eventually reached velocity of 4.5 km/s (10,000 mph!)
  - Remember fastest 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

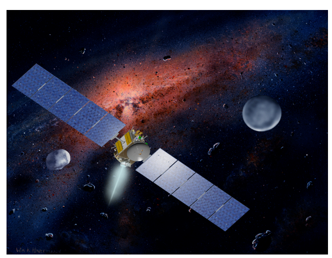
# The New Dawn

- Propelled by three DS1 heritage xenon ion thrusters (firing only one at a time).
- s.i. = 3100 s
- Thrust of 90 mN (weight of a sheet of paper on Earth)
- 0-60 mphs in 4 days!
- In 5 years = 23,000 mph!
- Powered by a 10 kW solar array
- Each engine the size of a basketball (weighs 20lbs)



# The New Dawn

- To get to Vesta will use 275 kg Xe
- To get to Ceres will use another 110 kg Xe
- NASA's first purely exploratory mission to use ion propulsion engines



# Our Problem

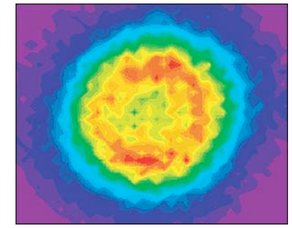
- For interstellar travel with any propellant, you must carry with you the stuff that you eventually shoot out the back
  - Fine for Saturn V rocket and "short" lunar missions
  - Bad for interstellar travel
    - Maybe even prohibitive
- But, it is unlikely that the methods discussed up to now will 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

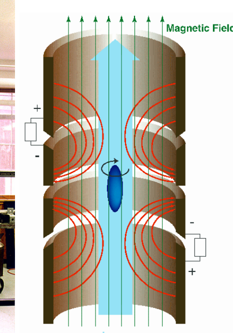
# Anti-(Anti-matter)

- 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"



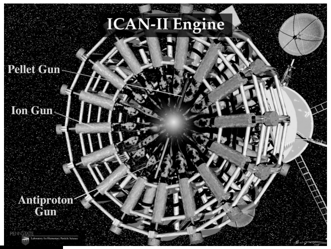

http://www.engr.psu.edu/antimatter/

# Nonetheless

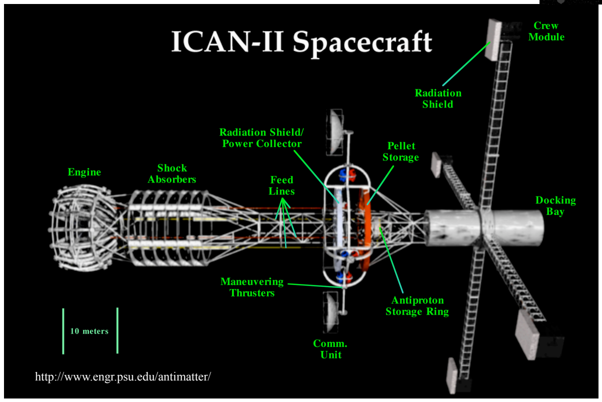
| **Propulsion** | **Specific Impulse** [sec] |
|---|---|
| Chemical | 200 - 450 |
| Electromagnetic | 600 - 3000 |
| Nuclear Fission | 500 - 3000 |
| Nuclear Fusion | 5000 - 10000 |
| Antimatter | 1000 - 100000 |

- 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.



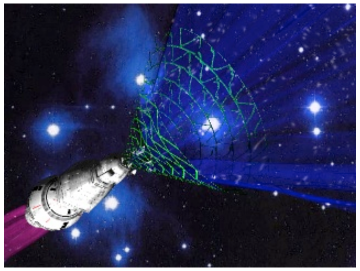

# Interstellar Problem

- 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 and back.

http://lsda.jsc.nasa.gov/images/libertybell.jpg
http://www.craftygal.com/archives/september/table0900.htm

# Lose the Fuel, Fool

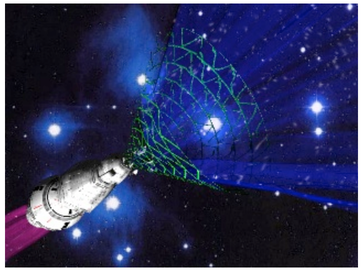
- What if we didn't have to carry all the fuel?
- One option is the Bussard ramjet.
- The spacecraft collects its own fuel as it moves forward.
- But, in interstellar space there is only 1 atom/cm3.



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

# Lose the Fuel, Fool

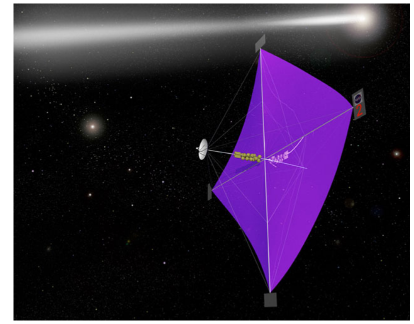
- The scoop would have to be 4000 km in diameter (size of US).
- Or magnetic fields to collect the material.
- But would mostly be low-grade hydrogen fuel, so it is a technological step ahead of what we already discussed.
- Could reach speeds close to 0.99c.



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.

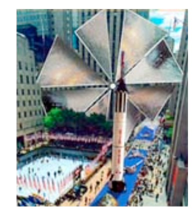


# COSMOS 1

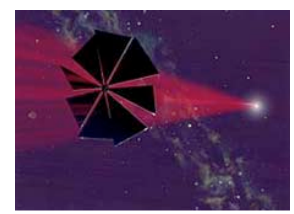
- First solar sail spacecraft (and private!) launched from a Russian nuclear submarine on June 21, 2005!
- Unfortunately, the first stage of the Volna never completed its scheduled burn, and the spacecraft did not enter orbit.
- Built in Russia at Babakin Space Center
- Had 8, 15m sails
  - 100kg payload (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

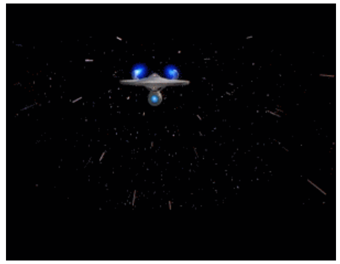


- It would take about 1,000 years for a solar sail to reach one-tenth the speed of light, even with light shining on it continuously.
- It will take advanced sails plus a laser power source in space that can operate over interstellar distances to reach one-tenth the speed of light in less than 100 years.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



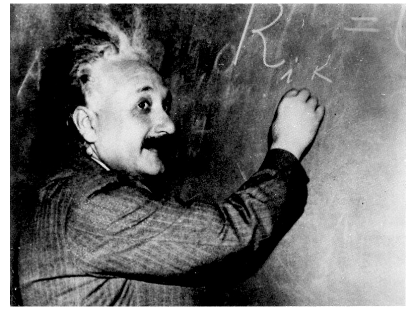
# Warp Drives

- 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

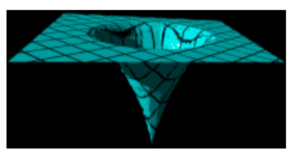
# Einstein Is Warping My Mind!

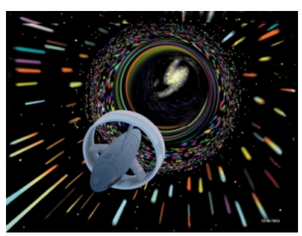


- Einstein's General Relativity around 1918
- Space and time were re-interpreted
- No longer were they seen as immutable, constant properties
- Space itself can be "warped" by mass.

# General relativity

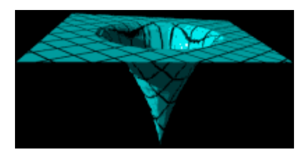
- Gravitational fields can also change space and time
  - A clock runs more slowly on Earth than it does in outer space away from any mass, e.g. planets.
- Einstein revealed that gravity is really 'warped' space-time.
- A black hole is an extreme example.

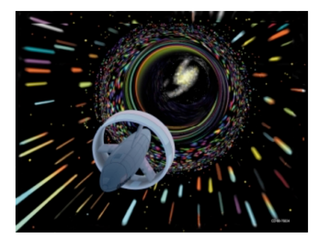




# General relativity

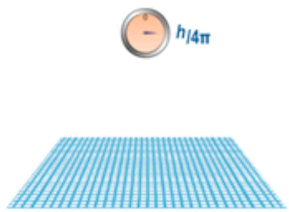
- Rotating black holes may form wormholes to "elsewhen" but they are thought to be short-lived.
- Researchers are considering stabilizing them with exotic matter.
- What if it were possible to create a localized region in which space-time was severely warped?
  - A car has a speed limit on a road, but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





# Quantum field theory

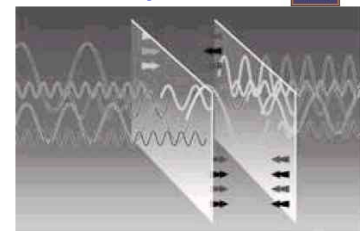
- The subatomic world is not a world of billiard ball-like particles
- “Empty space” is full of waves/ particles popping in and out of existence
  - Like a choppy sea, “virtual particles” are born and interact for an allowed window of time
- This sea of “virtual particles” that inhabits space-time can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

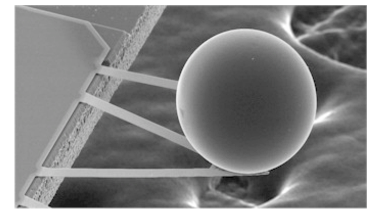



http://zebu.uoregon.edu/~js/glossary/virtual_particles.html

# Quantum field theory

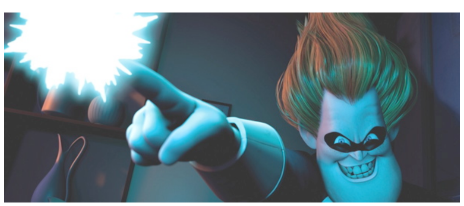
- In 1948, Hendrik Casimir predicted a weak attraction between two flat plates due to the effect of the sea of virtual particles.
- Two 1 meter plates placed a micron apart, would have 1.3mN of force. This is like a weight of 130 mg.
- It is force from nothing!





# Zero Point Energy

- Harnessing this power for propulsion has been an idea since at least the 90’s.
- Science fiction has even caught on.. idea of harnessing this “free” energy.
- For example, the zero point module (ZPM) from Stargate.
- Or Syndrome from The Incredibles



http://www.todayscacher.com/2005/feb/img/zero_point_module.jpg

# Making Propulsion?

- Need to create repulsive effects in the quantum vacuum, which should be possible.
- This work is underway, sponsored by NASA and others.

# 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!

# 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

http://www.jedisaber.com/SW/wallpaper/light%20speed.jpg