Astronomy 330

This class (Lecture 26):
Space Travel

Last Class:
Visitations

HW 11 is due Wednesday!

Music: Rocket Man– Elton John

Terraforming Mars: By Aliens?

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

Online ICES

- ICES forms are available online, so far 39/100 students have completed it.
- 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.

Question

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

a) Yes, I did it already.
b) Yes, sometime today
c) Yes, this weekend
d) Yes, I promise to do it before the deadline of May6th!
e) No, I am way too lazy to spend 5 mins to help you or future students out.

Final

- In this classroom, Fri, May 7th, 0800-1100.
- Will consist of
  - 15 question on Exam 1 material.
  - 15 question on Exam 2 material.
  - 30 questions from new material (Lect 20+).
  - +4 extra credit questions
- A total of 105 points, i.e. 5 points of extra credit.
- Final Exam grade is based on all three sections.
- If Section 1/2 grade is higher than Exam 1/2 grade, then it will replace your Exam 1/2 grade.

Final

- A normal-sized sheet of paper with notes on both sides is allowed.
- Exam 1and 2 and last year's final are posted on class website (not Compass).
- I will post a review sheet Friday.

Final Papers

- Final papers due at BEGINNING of discussion class on May 5th.
- 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.

Outline

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

Approaching the "c": Impact

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

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

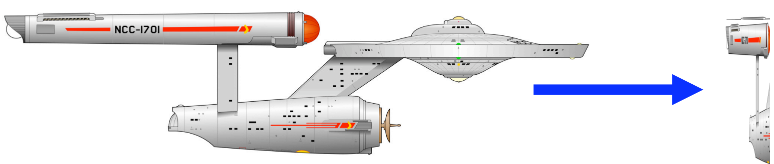
Gamma

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

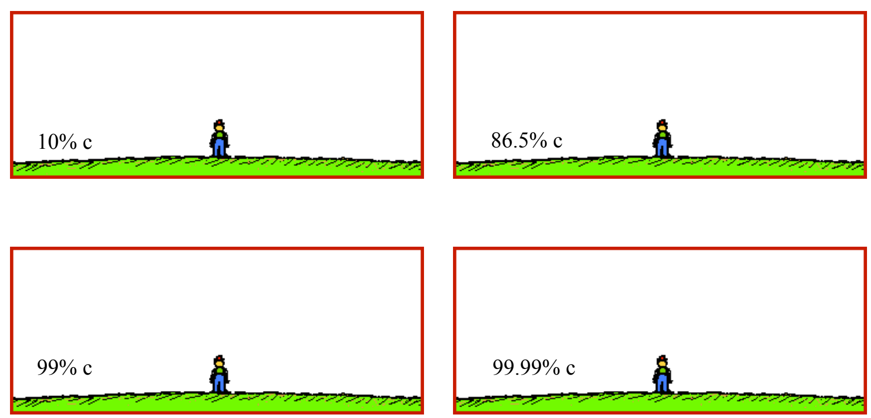
Moving objects appear shorter in the direction of relative motion



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

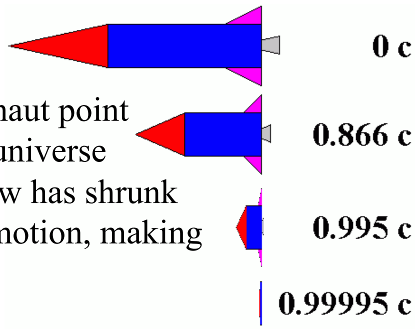
Moving objects are shorter in the direction of relative motion



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.



Question

Your best friend is going on a near light speed trip. When at rest you measure her spaceship to be 100 feet long. Now, she's in flight and you're on the Earth, and you measure her spacecraft to be

a) Exactly 100 feet long.
b) Less than a 100 feet long.
c) More than a 100 feet long.

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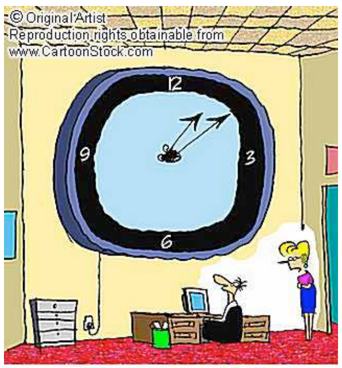
Counterintuitive Result #2

Clocks on Moving objects slow down

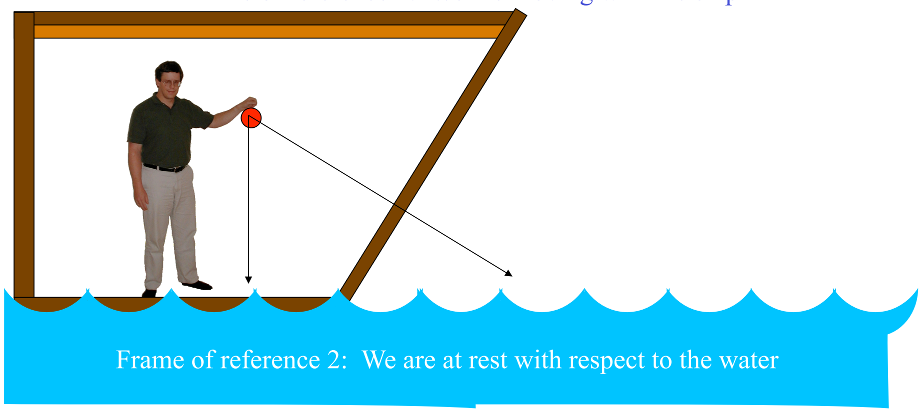


"Try not to watch the clock. It only makes the day go slower."

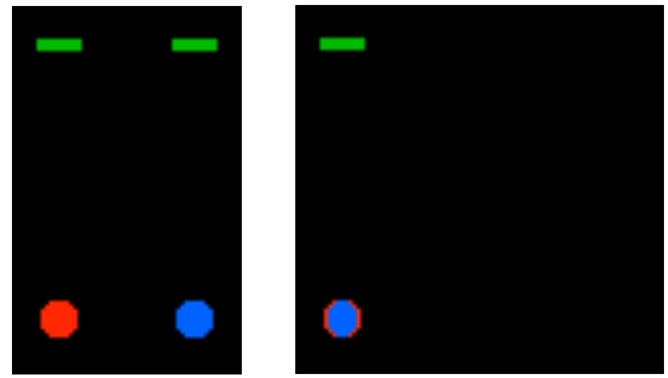
Galileo's ship thought experiment

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



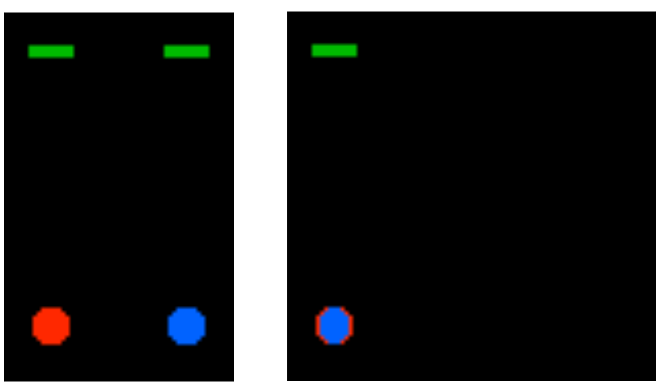
If the Ball is light?



A. Hamilton (Colorado)

Counterintuitive Result #2

Time appears to advance more slowly for moving objects (time dilation)

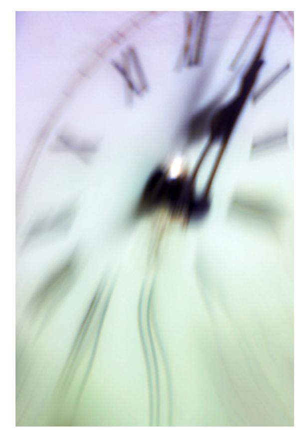


Red & blue at rest   Blue moving to right

http://www.youtube.com/watch?v=KHjpBjgIMVk   A. Hamilton (Colorado)

Time Dilation

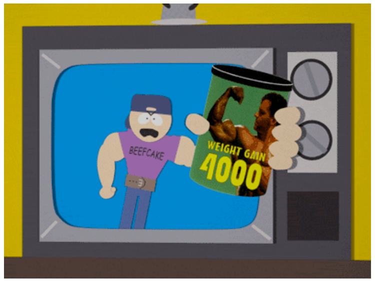
- The effects of time dilation are curious but not prohibitive for space travel
  - Astronauts will age less than the Earth-bound folks waiting for the return. Can spoil the homecoming celebrations.
  - The faster you go, the bigger difference between astronaut time and Earth time



- 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!

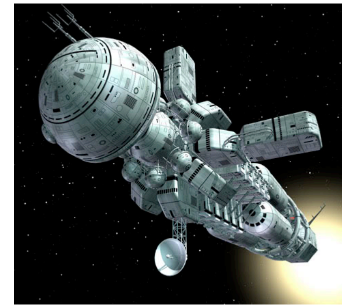
Counterintuitive Result #3

Mass increases for moving objects

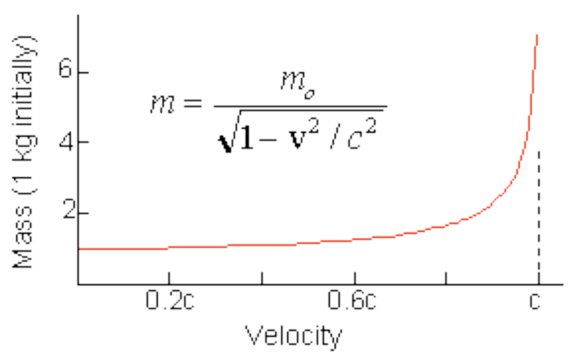


Mass Increase

- 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 appear as larger mass.
  - For 99% speed of light travel, 5.5 meters of shield would erode every year.



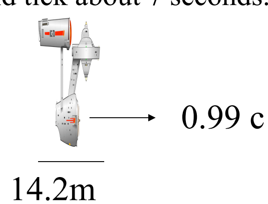
The gamma factor and mass:



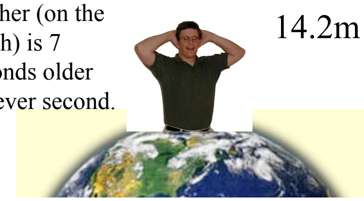
Infinite Mass!!!!

So, what does that mean?

- If you're on a 100m spaceship going near the speed of light (.99 c), the spaceship measures 100m 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.



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

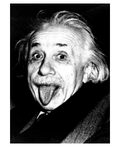


And Paul's measured mass increased by a factor of 7.

Question

You are traveling near light speed. You see the Earth slide past your window. You notice that you left a clock (readable from space), and for every second that pasts on the spacecraft

a) Exactly 1 second pasts on Earth.
b) Less than a second pasts on Earth.
c) More than a second pasts on Earth.



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.

Mass of the moving object appears to rapidly increase as an objects moves close to the speed of light.

Question

Okay, so length and time can change, then what exactly is a constant?

a) The speed of light.
b) The length of an iron pipe.
c) The time it takes for a photon to cross the Universe.
d) The speed of sound.
e) The speed of a class.. it is always too slow.

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

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

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.

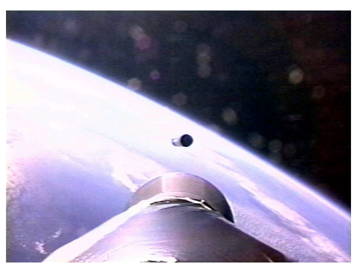
How's it work?

- 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

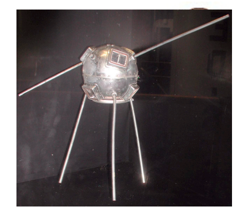
What you talking 'bout Willis?

- 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.

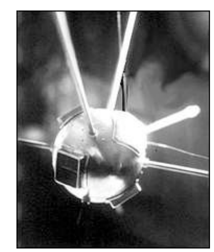


http://www.utahredrocks.com/stardust/launch6.jpg

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.

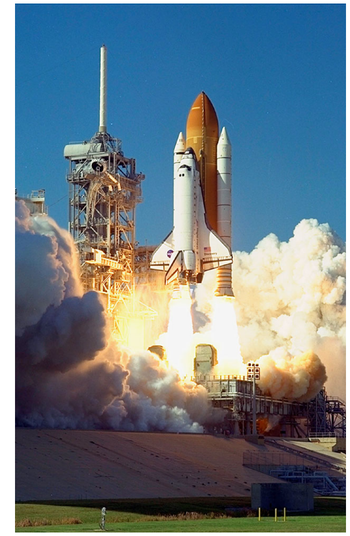
http://www.bafsat.com/h3.html

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 = 2.95×10^4 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

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

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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 Launch

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.

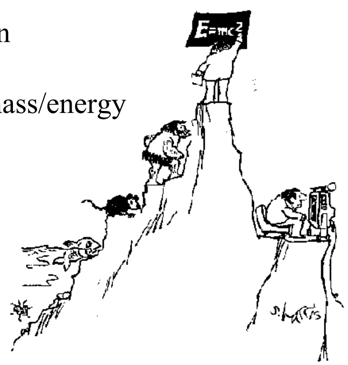
- Ammonium perchlorate (oxider)
- Aluminum (fuel)
- Iron Oxide (catalyst)
- Polymer (binder)

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



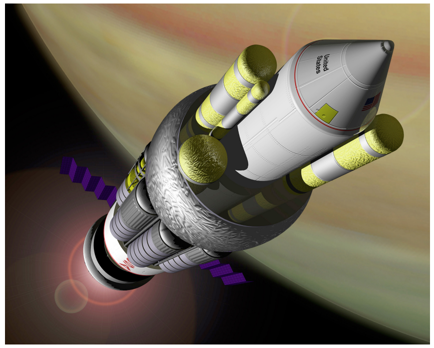
http://www.owlnet.rice.edu/~spac205/E=mc2.gif

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

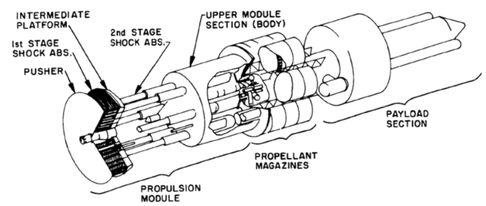
- A spacecraft powered by nuclear bombs– nuclear fission.
- Idea was sponsored by USAF in 1958
- Physicist Freeman Dyson took a year off from Princeton to work on idea
- Sounds crazy now… but a real project



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 0.10c.
- 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.

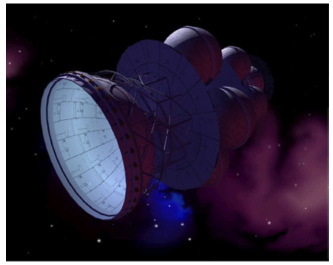
http://www.daviddarling.info/encyclopedia/O/OrionProj.html

Getting Off the Earth

- Interstellar trips will have to be in spacecraft that are built in orbit.
- Launching off the Earth is too prohibitive
- Need in orbit or on Moon construction facilities
- Possible solutions:
  - Space elevator
  - Space gun

Project Daedalus

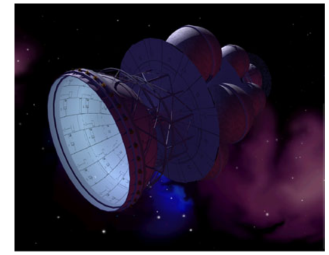
- Continuation/extension of Orion
- British Interplanetary Society project (1973-1978 planned)
- A robotic fly-by probe to Barnard's Star
  - 2^{nd} closest star system to Earth, 6 lyr away
  - In human lifetime scale (chose 50 yrs)
  - Needs to reach 12% c.
- Idea was to also use nuclear pulsed power,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



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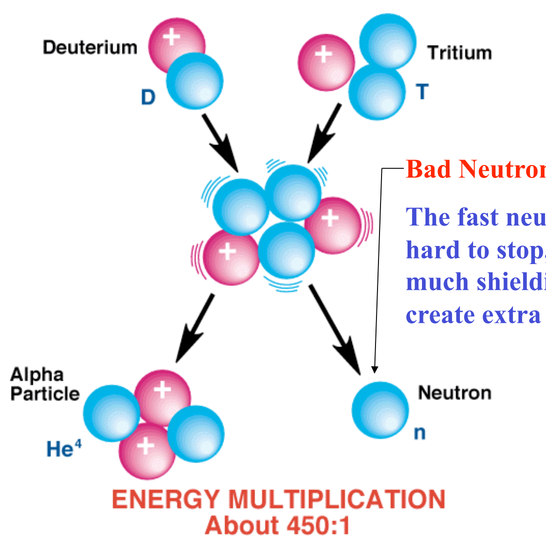
Deuterium–Tritium Fusion Reaction



Bad Neutron!

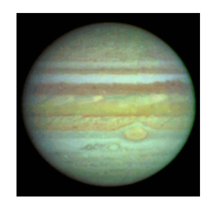
The fast neutrons are hard to stop, requires too much shielding. And can create extra reactions.

Project Daedalus

- Instead Daedalus would use:

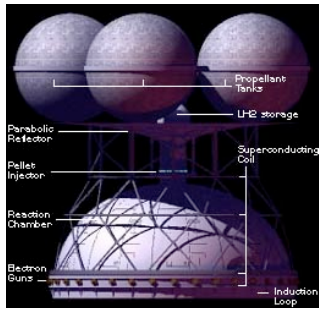
$$d + {}^3He \rightarrow {}^4He + p$$

- 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

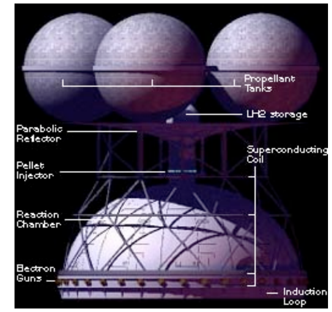
- Daedalus would accelerate for 4 years, then coast for 50 years to reach Barnard's star.
- At blastoff the mass would be 54,000 tons, of which 50,000 would be fuel.
  - Built in space though.
- That's an $R_M = 12$.
- The fuel would be in pellets that enter the reaction chamber 250/sec.
- Sophisticated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



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

Project Daedalus

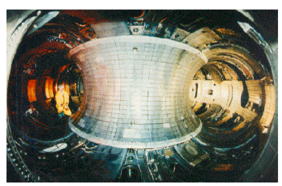
- For dust erosion at 0.12c, requires a beryllium erosion shield 7mm thick and 55 meters in diameter.
- Once it reached Barnard's star, it would disperse science payload that would study the system.
- Would transmit back to Earth for 6-9 years.
- So does not require a return trip.



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"

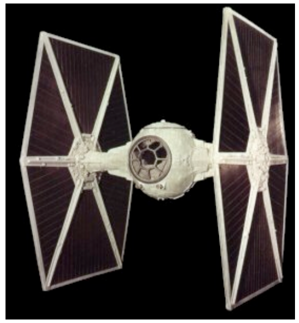


Fusion Rockets

- 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 many decades before the technology is feasible.
- We need energy gain factor of 15-22 for commercial use, today, best is 1.25.
  - New experiments ITER and HiPER are encouraging

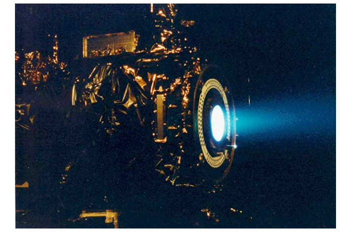
Ion Drives

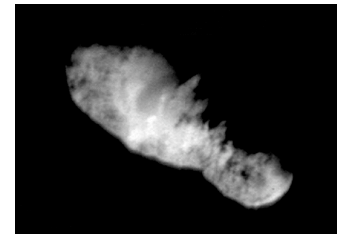
- These are not science fiction.
- A propellant system: “stuff” is thrown backwards propelling the ship forwards.
- They eject a beam of charged atoms out the back, pushing the rocket forward
  - Kind of like sitting on a bike and propelling yourself by pointing a hairdryer backwards



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.

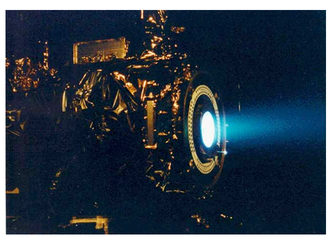




http://antwrp.gsfc.nasa.gov/apod/ap030720.html

Ion Drive

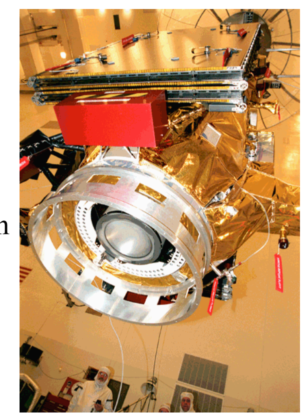
- The only waste is the propellant itself, which can be a harmless gas like xenon.
- But, requires energy input to power electric field which pushes the ions out the back
  - Solar cells usually provide power
  - But could imagine fusion powered version.



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

DS1

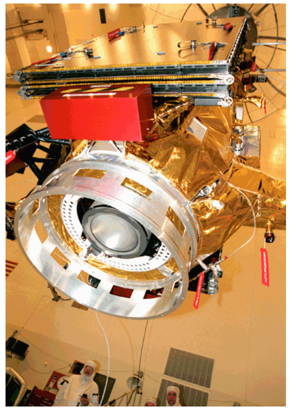
- DS1 only used 81.5 kg of xenon.
- Thrust of engine is only about as strong as the weight of a piece of paper in your hand!
  - If you keep pushing lightly, you will keep accelerating, so after time you can build up speed
  - DS1 eventually reached velocity of 4.5 km/s (10,000 mph!)
  - Remember fastest space vehicle is Pioneer, which is still going about 12km/s



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

DS1

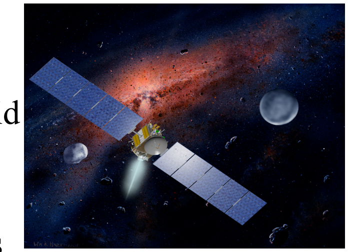
- Not useful for missions that need quick acceleration
- But, more efficient than chemical
  - Can achieve 10 times greater velocity than chemical!



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

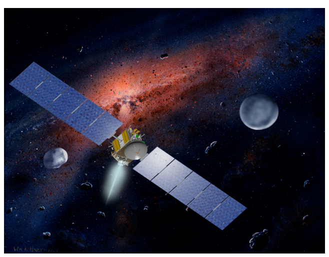
The New Dawn

- Launched Sept 2007.
- Will explore two most massive members of asteroid belt – Ceres and Vesta
- Propelled by three DS1 heritage xenon ion thrusters (firing only one at a time).
- s.i. = 3100 s



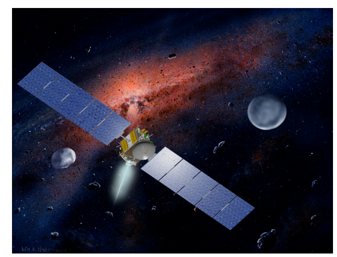
The New Dawn

- Thrust of 90 mN (weight of a sheet of paper on Earth)
- 0-60 mph 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

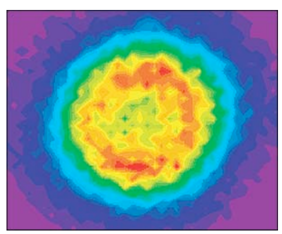
- For interstellar travel with any propellant, you must carry with you the stuff that you eventually shoot out the back
  - Fine for Saturn V rocket and “short” lunar missions
  - Bad for interstellar travel
    - Maybe even prohibitive
- But, it is unlikely that the methods discussed up to now will 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.
  - $62.5 trillion per gram for anti-hydrogen!
- 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

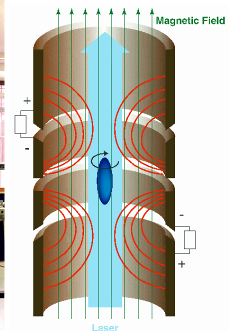
Anti-(Anti-matter)

- 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"



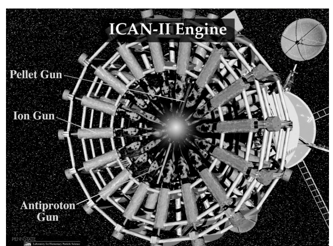
http://www.engr.psu.edu/antimatter/

Nonetheless

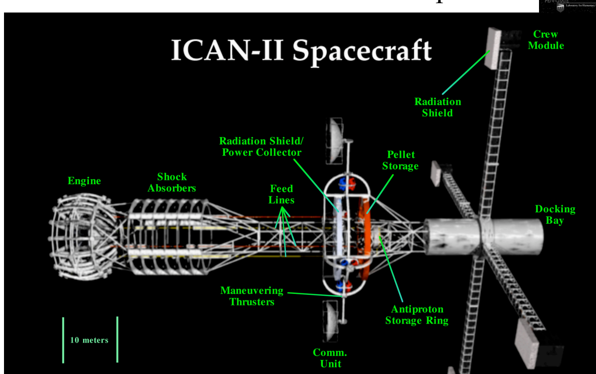
Propulsion	Specific Impulse [sec]
Chemical	200 - 450
Electromagnetic	600 - 3000
Nuclear Fission	500 - 3000
Nuclear Fusion	1000 - 10000
Antimatter	1000 - 100000

- 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

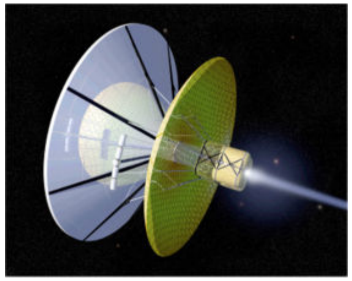
- Still for interstellar trips, we got a problem with carrying around the fuel.
- Edward Purcell thought about antimatter interstellar travel and found even that to be lacking!
- The lightest mass U.S. manned spacecraft was the Mercury capsule– the "Liberty Bell". It weighed only 2836 pounds (about 1300kg) 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

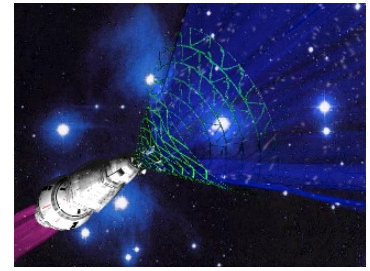
Lose the Fuel, Fool

- 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.



Lose the Fuel, Fool

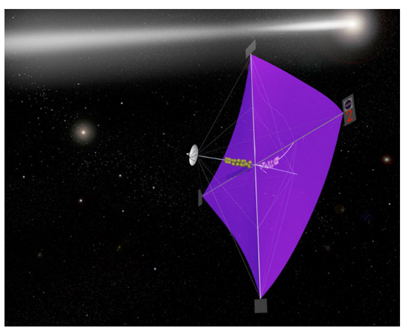
- The scoop would have to be 4000 km in diameter (size of US).
- Or magnetic fields to collect the material.
- But would mostly be low-grade hydrogen fuel, so it is a technological step ahead of what we already discussed.
- Could reach speeds close to 0.99c.



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

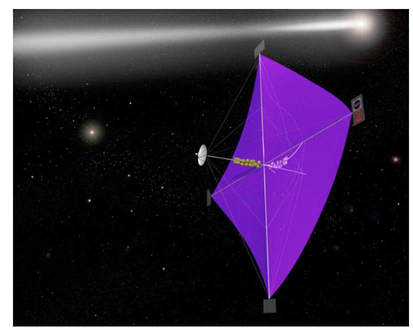
Light Sails

- 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.



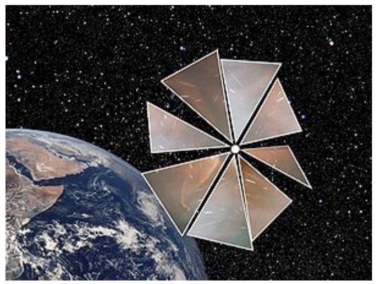
Light Sails

- But, photons 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.

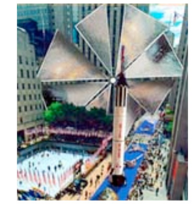


COSMOS 1

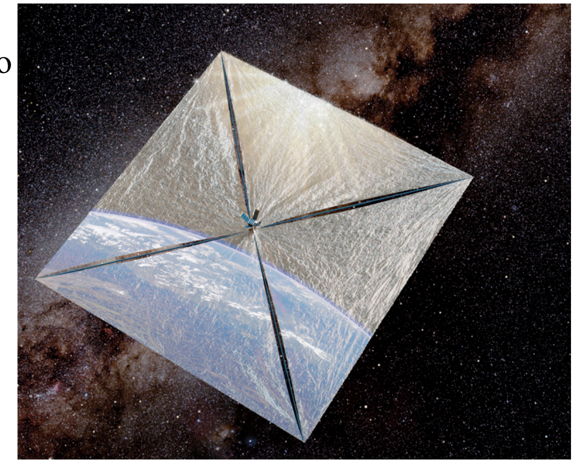
- First solar sail spacecraft (and private!) launched from a Russian nuclear submarine on June 21, 2005!
- Planetary society raised $4M
- Unfortunately, the first stage of the Volna never completed its scheduled burn, and the spacecraft did not enter orbit.



COSMOS 1

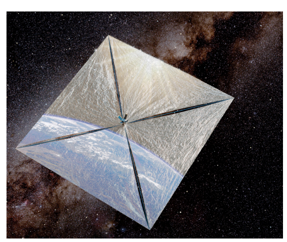


- Had 8, 15m sails designed
  - 100kg payload (small, but first step!)
- The planetary society is going to try again, if they can raise the money.
- LightSail-1

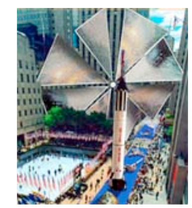


LightSail 1

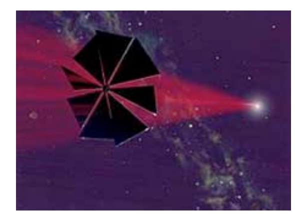
- *"Lightsail-1 fits into a volume of just three liters before the sails unfurl to fly on light. It's elegant,"- Bill Nye the Science Guy, Planetary Society Vice President.*
- 32 m^2 of mylar
  Launch in 2010?
- Mission: higher Earth orbit using sail
- Part of three prong mission
  - LightSail-2 and LightSail-3



Light Sails

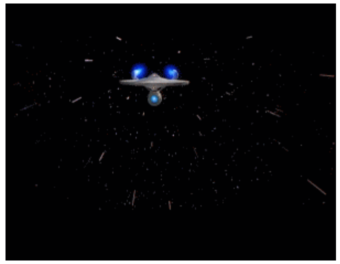


- It would take about 1,000 years for a solar sail to reach one-tenth the speed of light, even with light shining on it continuously.
- It will take advanced sails plus a laser power source in space that can operate over interstellar distances to reach one-tenth the speed of light in less than 100 years.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



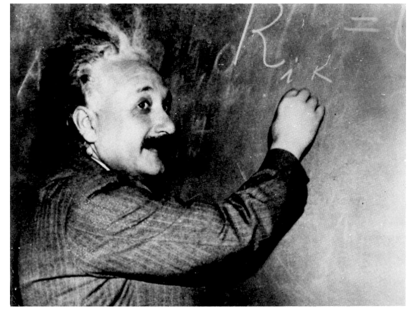
Warp Drives

- 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

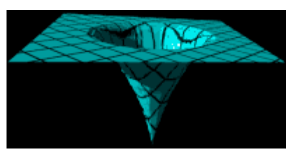
Einstein Is Warping My Mind!

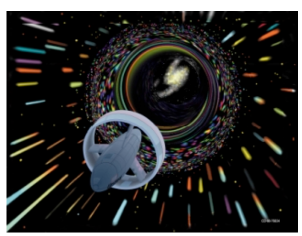


- Einstein's General Relativity around 1918
- Space and time were re-interpreted
- No longer were they seen as immutable, constant properties
- Space itself can be "warped" by mass.

General relativity

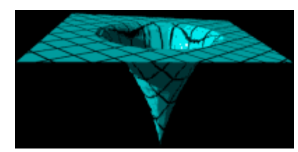
- Gravitational fields can also change space and time
  - A clock runs more slowly on Earth than it does in outer space away from any mass, e.g. planets.
- Einstein revealed that gravity is really 'warped' space-time.
- A black hole is an extreme example.

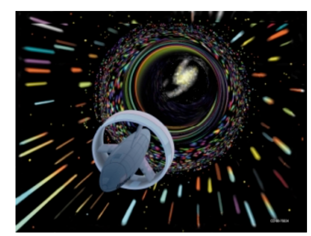




General relativity

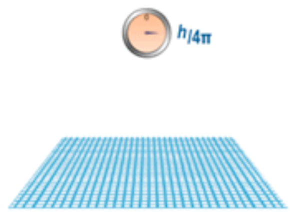
- Rotating black holes may form wormholes to "elsewhen" but they are thought to be short-lived.
- Researchers are considering stabilizing them with exotic matter.
- What if it were possible to create a localized region in which space-time was severely warped?
  - A car has a speed limit on a road, but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





Quantum field theory

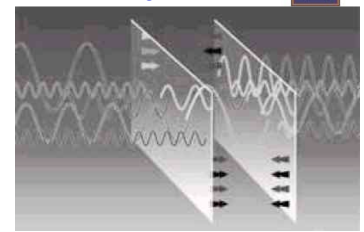
- The subatomic world is not a world of billiard ball-like particles
- "Empty space" is full of waves/ particles popping in and out of existence
  - Like a choppy sea, "virtual particles" are born and interact for an allowed window of time
- This sea of "virtual particles" that inhabits space-time can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

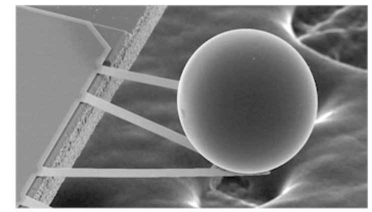


http://zebu.uoregon.edu/~js/glossary/virtual_particles.html

Quantum field theory

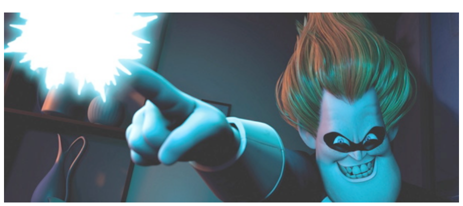
- In 1948, Hendrik Casimir predicted a weak attraction between two flat plates due to the effect of the sea of virtual particles.
- Two 1 meter plates placed a micron apart, would have 1.3mN of force. This is like a weight of 130 mg.
- It is force from nothing!





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

Issues and Incentives

- Assume there is intelligent life out there.
- Will they try to travel to us?
  - Is it worth it?
  - Exploration?
- If a civilization has been around for 1 million more years than ours…
- But interstellar travel is HARD!!!!
- Back to thinking about autonomous probes..

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 the stars first
  - Lighter payload!
- Self-replicating probes?