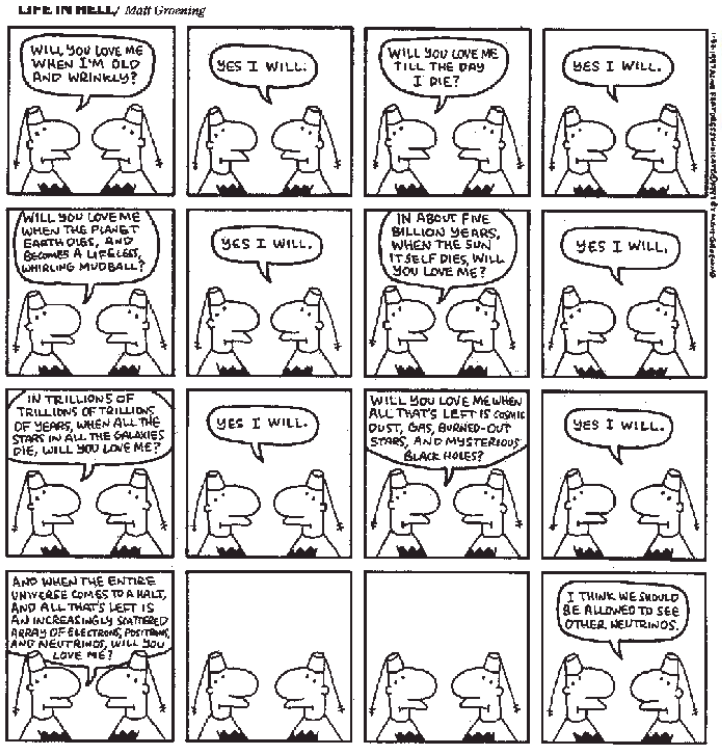


Astronomy 230

Section 1– MWF 1400-1450
106 B1 Eng Hall

This Class (Lecture 39):
Travel

Next Class:
Visitations

Extra Credit due today!

Research Papers due on Dec 6th.

FINAL EXAM is Dec 18th.

Music: *The Space Race is Over* – Billy Bragg

Outline

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

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!

$E=mc^2$

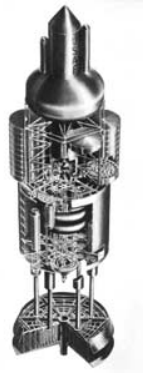
- Another consequence of special relativity is that mass has energy wrapped up in it
  - In fact, often use units of energy to quantify mass
  - A useful unit of energy in particle physics is the "***electron volt***" or "eV"
    - This is a unit of energy
    - It is used to measure mass as well since mass is really just wrapped-up energy
- A proton "weighs" about 1 billion electron volts: 1GeV
- An electron "weighs" only about 511,000 electron volts: 511keV
- Most of the mass of an atom is in its nucleus, clearly!

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

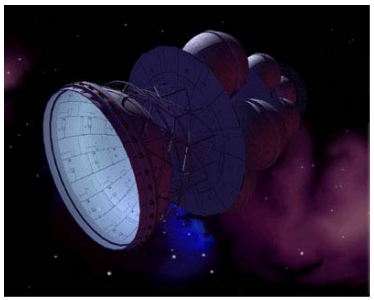
Project Orion

- 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

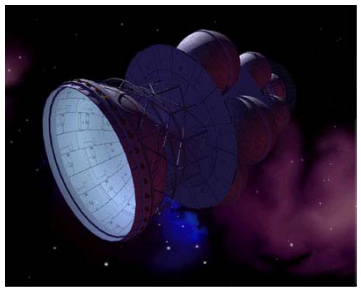
- Continuation/extension of Orion
- British Interplanetary Society project (1973-1978)
- A robotic fly-by probe to Barnard's Star
  - 2nd closest star system to Earth, 6 lyr away
  - In human lifetime scale (chose 50 yrs)
  - Needs to reach 12% c.
- Idea was to also use nuclear pulsed power, but fusion.



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.



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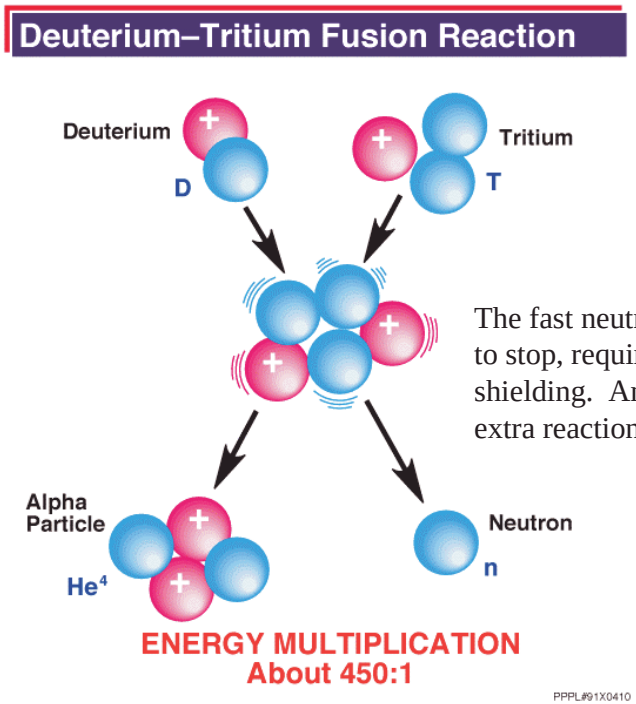


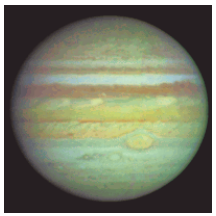
The fast neutrons are hard to stop, requires too much shielding. And can create extra reactions.

Project Daedalus

- Instead Daedalus would use:

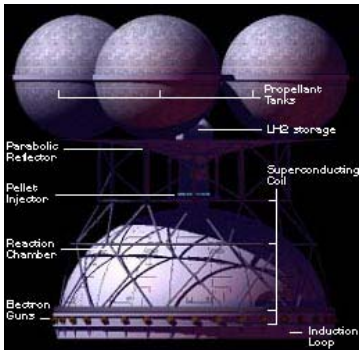
$$d + {}^{3}He \rightarrow {}^{4}He + p$$

- 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, converting 4 x 10^{-3} mass into energy.
- 1 MINOR problem. ^{3}He is very rare on Earth.
- But, it could be collected from Jupiter's atmosphere.



Project Daedalus

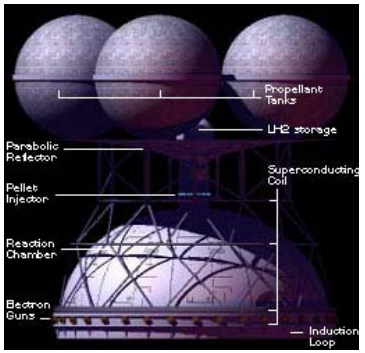
- Daedalus would accelerate for 4 years, then coast for 50 years to reach Barnard's star.
- At blastoff the mass would be 54,000 tons, of which 50,000 would be fuel.
- That's an $R_M = 12$.
- The fuel would be in pellets that enter the reaction chamber 250/sec.
- Sophisticated robots needed for repair.



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

Project Daedalus

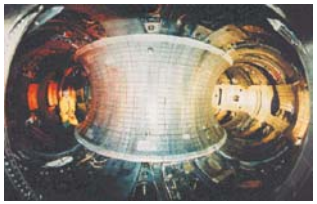
- For dust erosion at 0.12c, requires a beryllium erosion shield 7mm thick and 55 meters in diameter.
- Once it reached Barnard's star, it would disperse science payload that would study the system.
- Would transmit back to Earth for 6-9 years.
- So does not require a return trip.

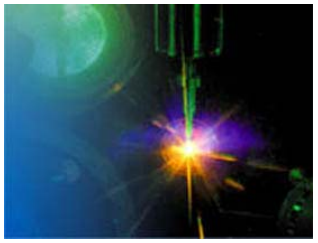


http://www.daviddarling.info/encyclopedia/D/Daedalus.html

Project Daedalus

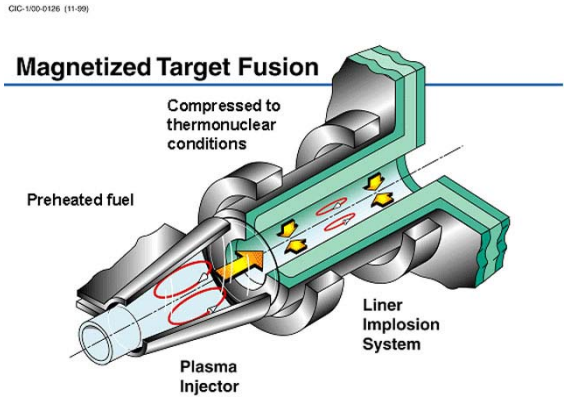
- Still requires more technology.
- How to get the deuterium and ^{3}He close enough to fuse in the first place.
- This requires a hot, compressed collection of nuclei that must be confined for long enough to get energy out
  - It's like "herding cats"
- As we have discussed, nuclear fusion reactors on the ground are trying to use magnetic (heavy containers) confinement [MCF] or inertial (high powered lasers) confinement [ICF].
- Daedalus would have to use a hybrid of the two.





MTF: Magnetic Target Fusion

- You make a small, magnetically confined plasma (like MCF) then compress it to thermonuclear conditions with a magnetically driven imploding liner (sort of like ICF).
- Being studied at numerous research centers for possible ground use too.



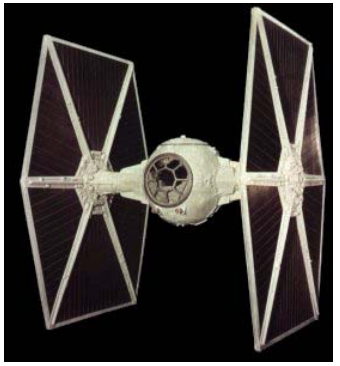
http://wsx.lanl.gov/mtf.html

Fusion Rockets

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

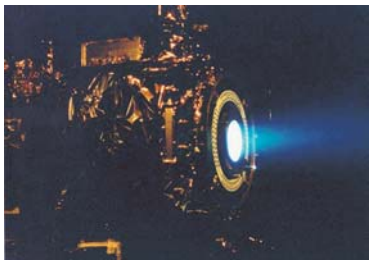
Ion Drives

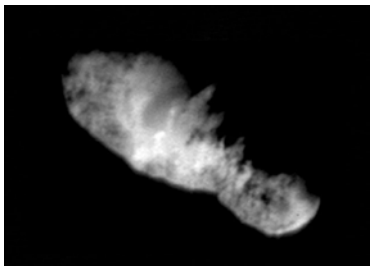
- These are not science fiction.
- A propellant system: "stuff" is thrown backwards propelling the ship forwards.
- They eject a beam of charged atoms out the back, pushing the rocket forward
  - Kind of like sitting on a bike and propelling yourself by pointing a hairdryer backwards



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.

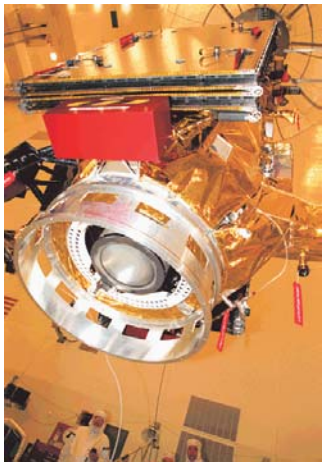




http://antwrp.gsfc.nasa.gov/apod/ap020720.html

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/pwg/98pc1191.gif

Our Problem

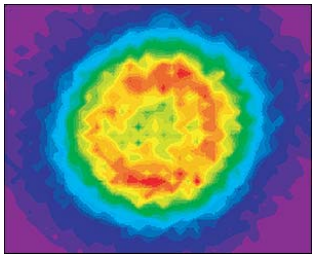
- For interstellar travel with any propellant, you must carry with you the stuff that you eventually shoot out the back
  - Fine for Saturn V rocket and "short" lunar missions
  - Bad for interstellar travel
    - Maybe even prohibitive
- But, it is unlikely that the methods discussed up to now will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

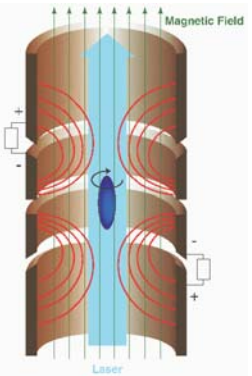


Anti-Hydrogen from CERN.

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

Storage Issues

- Antimatter can be like 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" which confines particles with electric and magnetic force fields
  - "Penning trap"



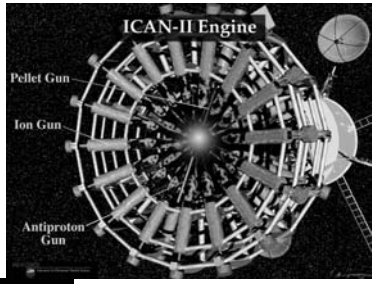
http://www.engr.psu.edu/antimatter/

Nonetheless

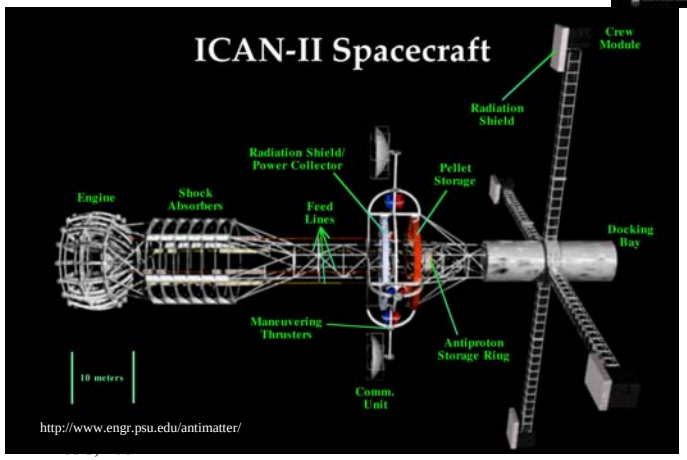
Propulsion	Specific Impulse [sec]
Chemical	200 - 450
Electromagnetic	600 - 3000
Nuclear Fission	500 - 3000
Nuclear Fusion	5000 - 10000
Antimatter	1000 - 100000

- 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/

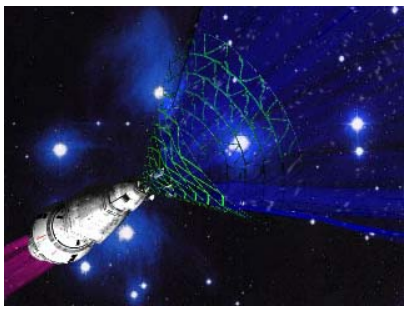
Interstellar Problem

- 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 and back.

http://lsda.jsc.nasa.gov/images/libertybell.jpg
http://www.craftygal.com/archives/septembertable0900.htm

Lose the Fuel, Fool

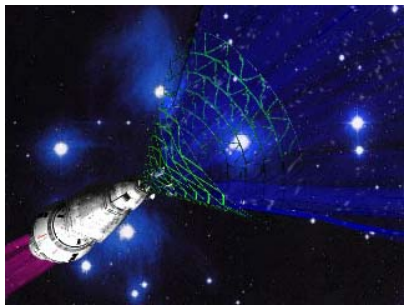
- What if we didn't have to carry all the fuel?
- One option is the Bussard ramjet.
- The spacecraft collects its own fuel as it moves forward.
- But, in interstellar space there is only 1 atom/cm3.



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

Lose the Fuel, Fool

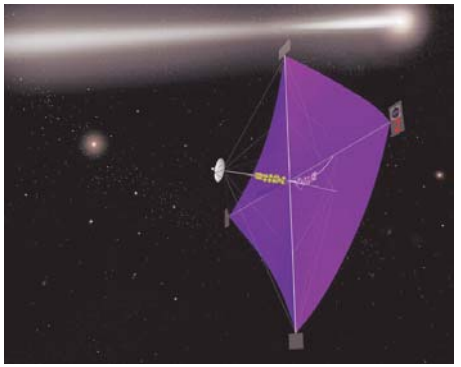
- The scoop would have to be 4000 km in diameter (size of US).
- Or magnetic fields to collect the material.
- But would mostly be low-grade hydrogen fuel, so it is a technological step ahead of what we already discussed.
- Could reach speeds close to 0.99c.



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

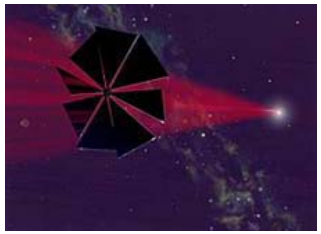
Light Sails

- 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.



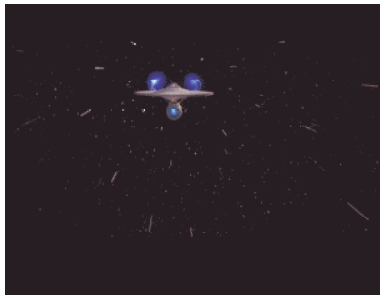
COSMOS 1

- Expected to be launched in March 1, 2005!
- First solar sail spacecraft (and private!)
- Built in Russia at Babakin Space Center
- Will be launched from a Russian nuclear sub.
- Will have 8, 15m sails
  - 100kg payload (small, but first step!)
- 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.
- http://www.planetary.org/solarsail/animation.html



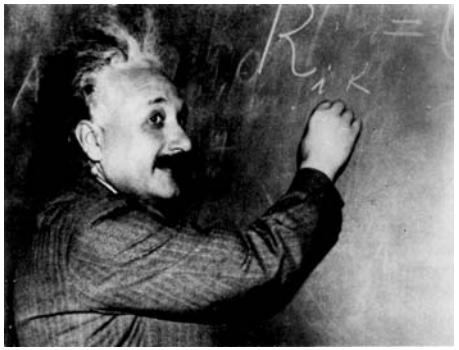
Warp Drives

- 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

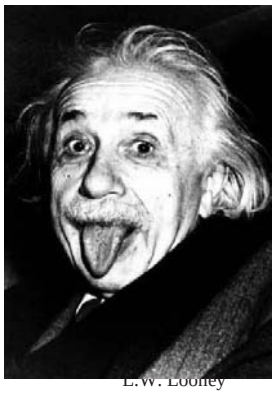
Einstein Is Warping My Mind!



- 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.

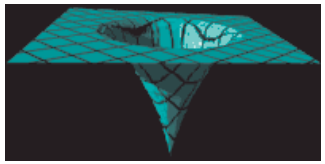
Special Relativity Summary

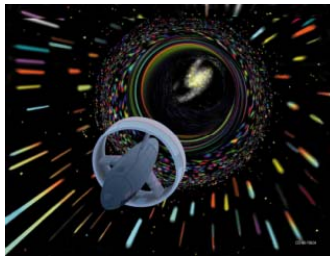
- **Length of space depends on observer's speed.**
- **Length of time depends on observer's speed.**
- **Mass depends on observer's speed.**



General relativity

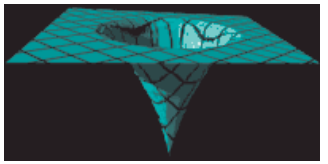
- Gravitational fields can also change space and time
  - A clock runs more slowly on Earth than it does in outer space away from any mass, e.g. planets.
- Einstein revealed that gravity is really 'warped' space-time.
- A black hole is an extreme example.

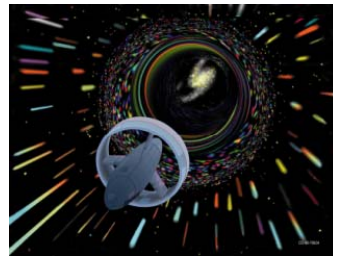




General relativity

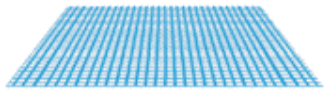
- Rotating black holes may form wormholes to "elsewhen" but they are thought to be short-lived.
- Researchers are considering stabilizing them with exotic matter.
- What if it were possible to create a localized region in which space-time was severely warped?
  - A car has a speed limit on a road, but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





Quantum field theory

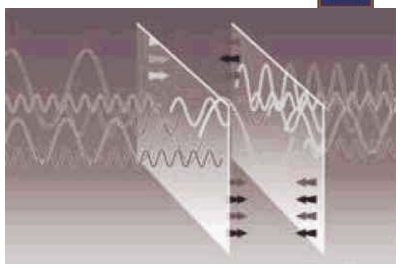
- The subatomic world is not a world of billiard ball-like particles
- "Empty space" is full of waves/particles popping in and out of existence
  - Like a choppy sea, "virtual particles" are born and interact for an allowed window of time
- This sea of "virtual particles" that inhabits space-time can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

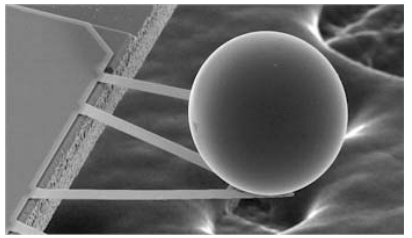


http://zebu.uoregon.edu/~js/glossary/virtual_particles.html

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?