

## Carl Sagan Says



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

Warning, not really Carl Sagan quote.

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## Astronomy 330



This class (Lecture 26):  
Space Travel

Next Class:  
Visitations  
ICES eval

**HW 11 is due!**

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

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## Final Papers



- You must turn final paper in with the graded rough draft.
- Unless you are happy with your rough draft grade as your final paper grade, then email me to keep the grade.
- Final paper is due on last day of class.

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## Final



- Take home exam (will try to bring it on the 24<sup>th</sup>).
- Must be dropped off no later than May 2<sup>nd</sup> (noon) in my mailbox in astro building.
- You are allowed 4 hours– must be typed.
- Will consist of
  - 7 short answer questions (5-10 points each, 1 short paragraph)
  - 2 short essays (15 points each, 2-3 paragraphs)
  - 2 large essay question (50 points each, 1-2 pages).
- A total of 210 points graded out of 200 points.
- A normal-sized sheet of paper with notes on both sides is allowed, but otherwise closed-book/lecture notes.

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## Outline



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

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## 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.

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## 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.

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## Fuels



- Look at the “octane” of various fuels available today.
- $\text{H}_2 + \text{O}_2 \rightarrow \text{s.i.} = 455 \text{ sec}$
- $\text{O}_2 + \text{hydrazine (N}_2\text{H}_4) \rightarrow \text{s.i.} = 368 \text{ sec}$
- $\text{H}_2 + \text{fluorine (F)} \rightarrow \text{s.i.} = 475 \text{ sec}$ 
  - But exhaust gas is hydrofluoric acid
- **Note: No chemical fuel can achieve s.i. > 500 sec.**

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# 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>

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# Petroleum rocket fuel in action



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



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

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Astronomy 330 Spring 2008 <http://www.hq.nasa.gov/office/pao/History/alsj/a16/ap16-KSC-72PC-184.jpg>

# Cryo fuel in action



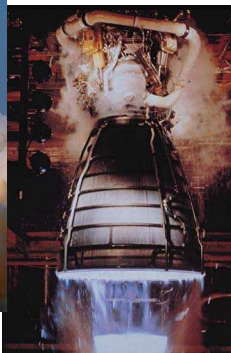
The Shuttle's main engines!



[http://www.slivka.com/Trips/ShuttleLaunch/pics/LOX\\_tank\\_750,000\\_gallons\\_at\\_launch\\_complex\\_39\\_A\\_T.jpg](http://www.slivka.com/Trips/ShuttleLaunch/pics/LOX_tank_750,000_gallons_at_launch_complex_39_A_T.jpg)



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



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

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# 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>

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# Hypergolic



Space shuttle orbital maneuvering system uses hypergolic fuel



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# 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 (oxidizer)
- Aluminum (fuel)
- Iron Oxide (catalyst)
- Polymer (binder)



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# 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!

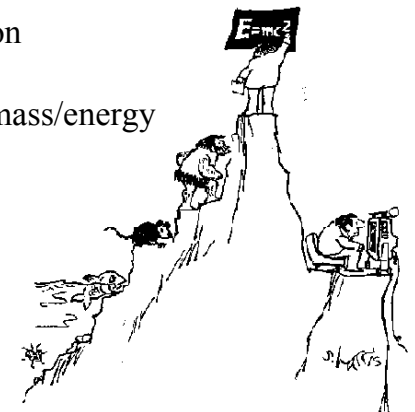
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# $E=mc^2$



- 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



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<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!

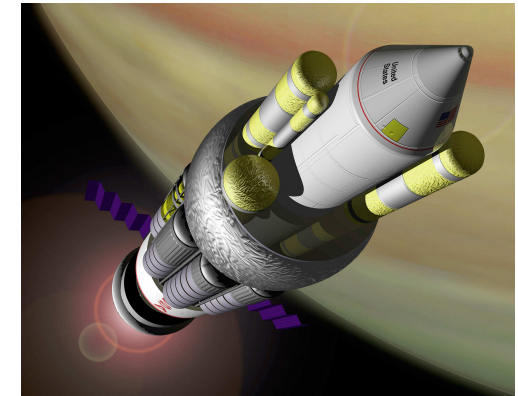
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# Project Orion



- 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>

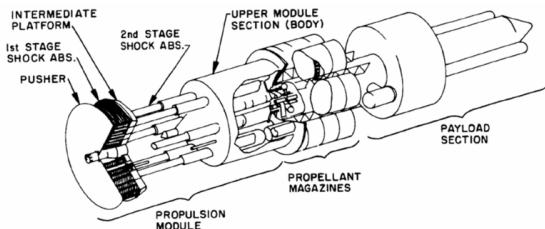
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# Project Orion



- 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](http://en.wikipedia.org/wiki/Project_Orion_%28nuclear_propulsion%29)



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# 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>

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# Project Daedalus



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

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# 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.

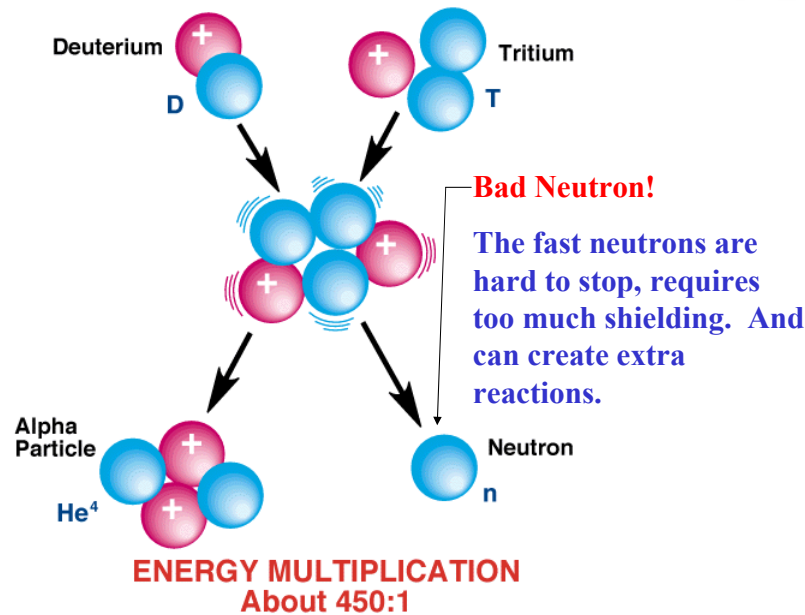


<http://www.daviddarling.info/encyclopedia/D/Daedalus.html>

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## Deuterium-Tritium Fusion Reaction



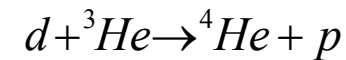
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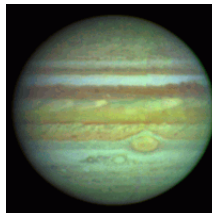
# Project Daedalus



- Instead Daedalus would use:



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



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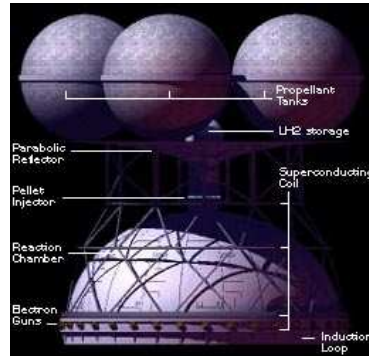
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## Project Daedalus



- 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>

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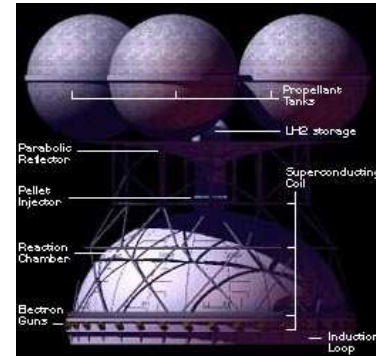
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## Project Daedalus



- 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>

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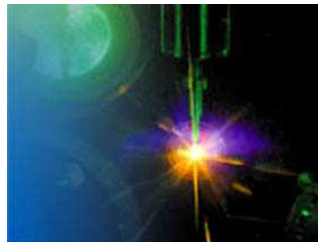
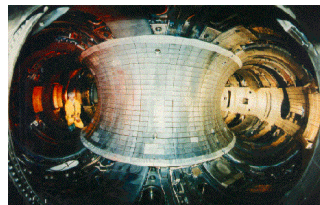
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## Project Daedalus



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



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## 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.

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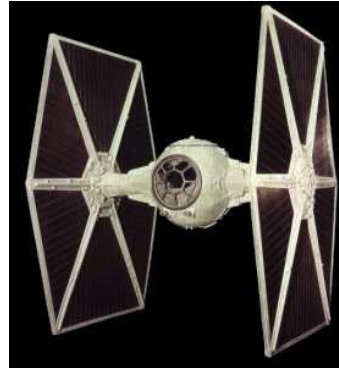
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## Ion Drives



- 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



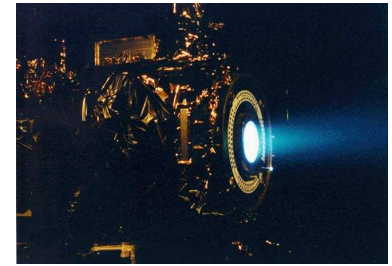
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## Ion Drive



- 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://antwarp.gsfc.nasa.gov/apod/ap030720.html>

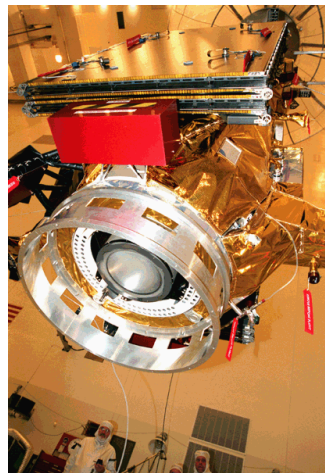
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## DS1



- 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>

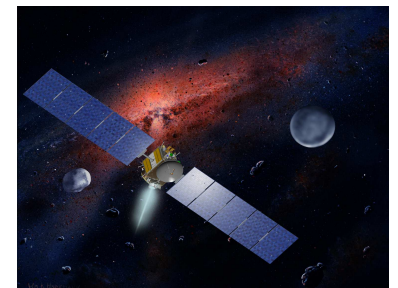
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## The New Dawn



- 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)



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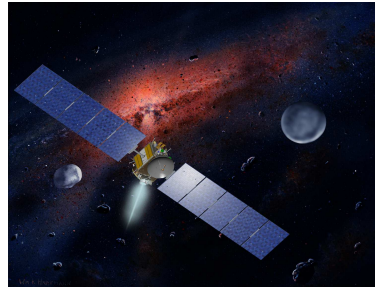
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# The New Dawn



- 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



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# 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.

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# 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.
- $V_{ex} = c$



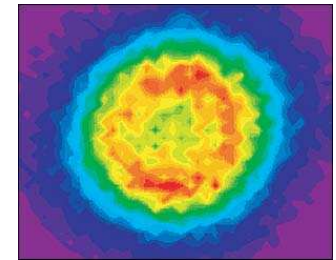
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# Anti-(Anti-matter)



- 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>

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# 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>

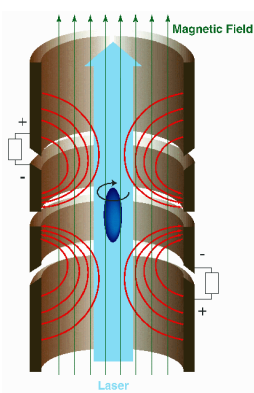
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# Storage Issues



- 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/>

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# Nonetheless



## Propulsion

Chemical  
Electromagnetic  
Nuclear Fission  
Nuclear Fusion  
Antimatter

## Specific Impulse [sec]

200 - 450  
600 - 3000  
500 - 3000  
5000 - 10000  
1000 - 100000

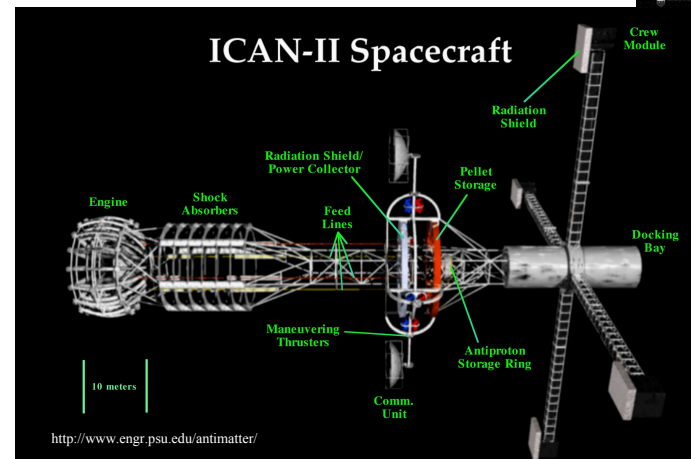
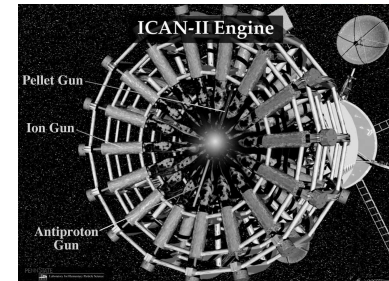
- Antimatter has potential to be about 1000 times more powerful than chemical combustion propulsion
- Antimatter propulsion has potential to be about 10 times more powerful than fusion

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# ICAN

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



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

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# 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>

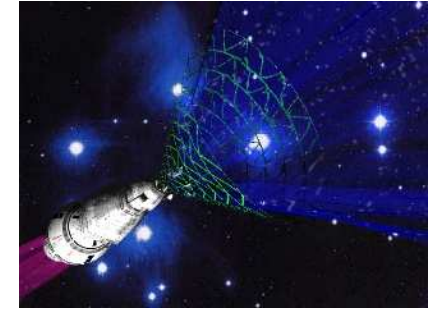
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# Lose the Fuel, Fool



- 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/cm<sup>3</sup>.



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

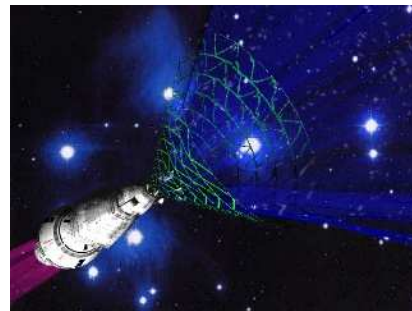
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# Lose the Fuel, Fool



- 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>

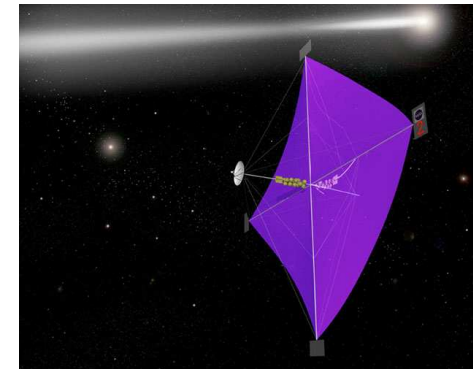
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# Light Sails



- 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.



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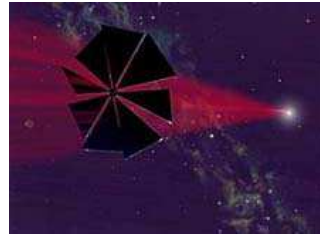
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# COSMOS 1



- 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>

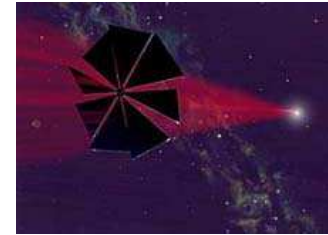
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# COSMOS 1



- 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.



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## 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.

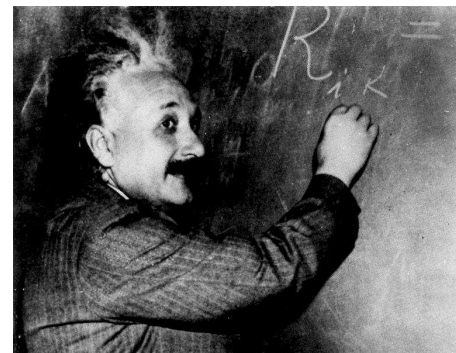


<http://www.filmjerk.com/images/warp.gif>

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## 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.

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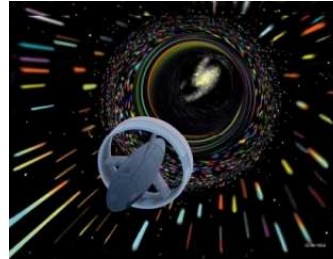
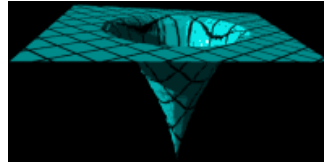
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# General relativity



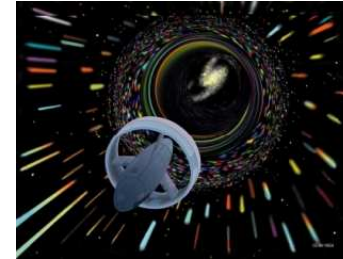
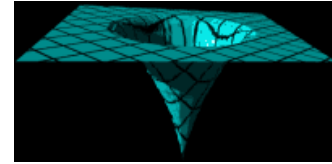
- Gravitational fields can also change space and time
  - A clock runs more slowly on Earth than it does in outer space away from any mass, e.g. planets.
- Einstein revealed that gravity is really ‘warped’ space-time.
- A black hole is an extreme example.



# General relativity



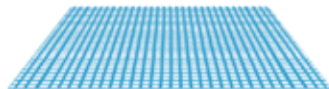
- Rotating black holes may form wormholes to “elsewhen” but they are thought to be short-lived.
- Researchers are considering stabilizing them with exotic matter.
- What if it were possible to create a localized region in which space-time was severely warped?
  - A car has a speed limit on a road, but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

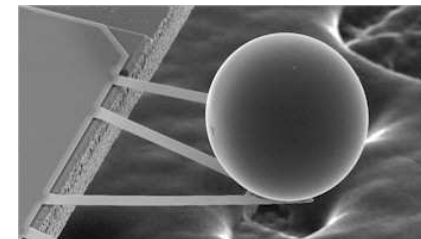
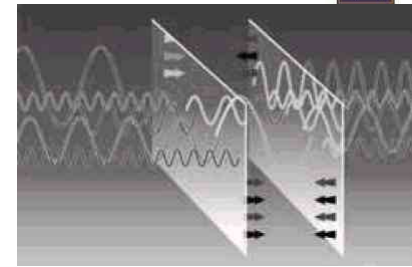


[http://zebu.uoregon.edu/~js/glossary/virtual\\_particles.html](http://zebu.uoregon.edu/~js/glossary/virtual_particles.html)

# 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!



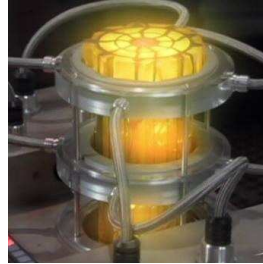
# Zero Point Energy



- 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.todayschacher.com/2005/feb/img/zero\\_point\\_module.jpg](http://www.todayschacher.com/2005/feb/img/zero_point_module.jpg)



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# Making Propulsion?



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

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# 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!

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# 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>

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