Astronomy 330

This class (Lecture 26):
Interstellar Travel

Last Class:
Visitations

HW 11 is due Thursday!

Music: Space Race is Over – Billy Bragg

Last Class?

- Thursday could be the last class.
- However, CHP allows $100 for informal get togethers.
- Would we like to meet on Tuesday, watch a movie, order some pizza or something?
- Let's do a secret ballot. Yes/no, if yes, then also list your preferred movie and pizza or whatever.

Final Papers

- Final papers due at BEGINNING of class on May 4th.
  - Since we may not have class, then you may need to drop them off in my mailbox or at my office.
- You must turn final paper in with the graded rough draft.
- If you are happy with your rough draft grade as you final paper grade, then don't worry about it.

Final

- Take-home final
- Will email it out on the end of the week.
- Will consist of:
  - 2 large essays
  - 2 short essays
  - 5-8 short answers
- Due May 14th, hardcopy, by 5pm in my mailbox of office.

Online ICES

- ICES forms are available online.
- I appreciate you filling them out!
  - In addition to campus honors thingy
- 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.

Outline

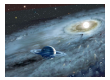
- Some examples of possible rocket ships
- What are the future options for interstellar travel?

Drake Equation

That's 190,540 advanced civs!!!

Frank Drake



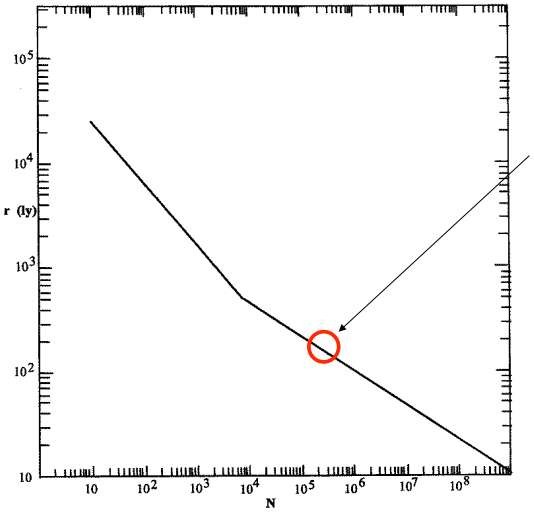





$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	10 stars/ yr	0.75 systems/ star	1.5 x 0.11 = 0.165 planets/ system	0.47 life/ planet	0.42 intel./ life	.78 comm./ intel.	1×10^6 yrs/ comm.

The Neighbors



We need to look at every star within ~200 lyrs for one detection!

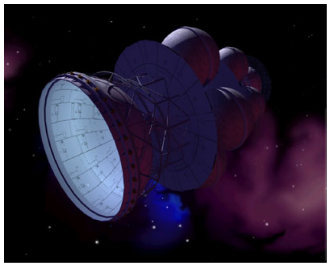
Using N=**190,540**

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

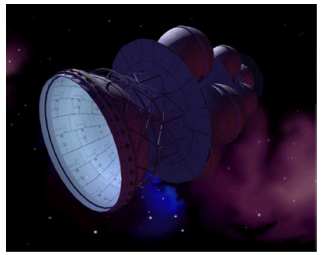
- Continuation/extension of Orion
- British Interplanetary Society project (1973-1978 planned)
- A robotic fly-by probe to Barnard's Star
  - 2nd closest star system to Earth, 6 lyr away
  - In human lifetime scale (chose 50 yrs)
  - Needs to reach 12% c.
- Idea was to also use nuclear pulsed power,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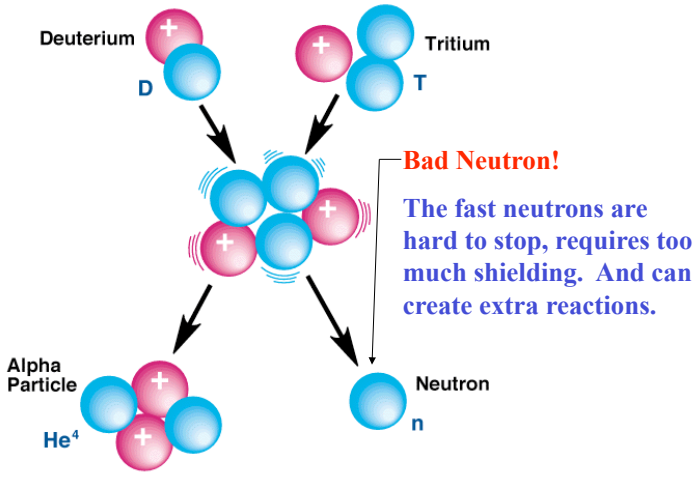
Deuterium–Tritium Fusion Reaction



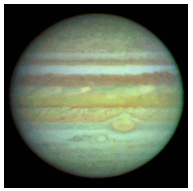
PPPL#91X0410

Project Daedalus

- Instead Daedalus would use:

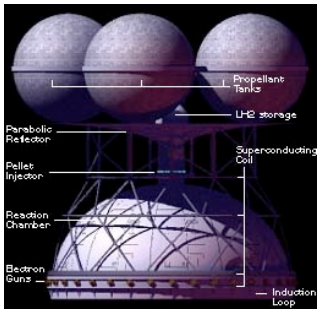
$$d + {}^3He \rightarrow {}^4He + p$$

- 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

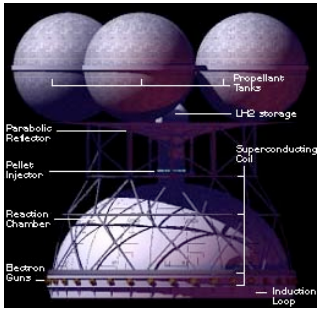
- Daedalus would accelerate for 4 years, then coast for 50 years to reach Barnard's star.
- At blastoff the mass would be 54,000 tons, of which 50,000 would be fuel.
  - Built in space though.
- That's an $R_M = 12$.
- The fuel would be in pellets that enter the reaction chamber 250/sec.
- Sophisticated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



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

Project Daedalus

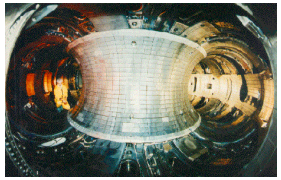
- For dust erosion at 0.12c, requires a beryllium erosion shield 7mm thick and 55 meters in diameter.
- Once it reached Barnard's star, it would disperse science payload that would study the system.
- Would transmit back to Earth for 6-9 years.
- So does not require a return trip.

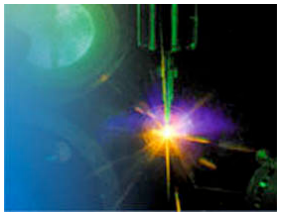


http://www.daviddarling.info/encyclopedia/D/Daedalus.html

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"



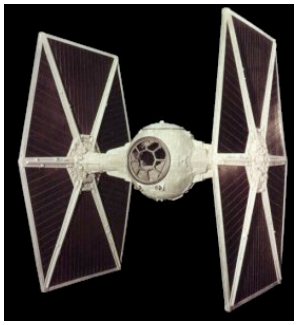


Fusion Rockets

- 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

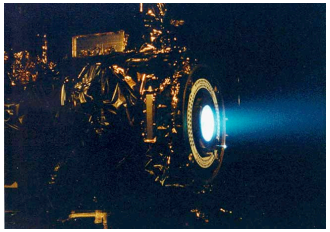
Ion Drives

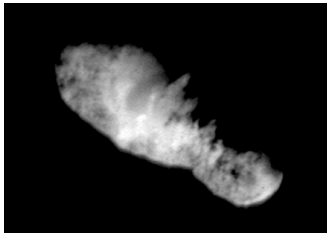
- These are not science fiction.
- A propellant system: "stuff" is thrown backwards propelling the ship forwards.
- They eject a beam of charged atoms out the back, pushing the rocket forward
  - Kind of like sitting on a bike and propelling yourself by pointing a hairdryer backwards



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.

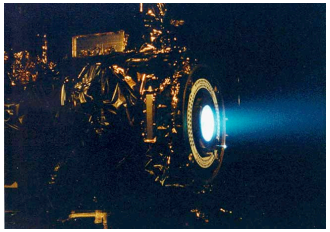


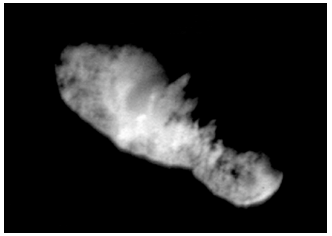


http://antwrp.gsfc.nasa.gov/apod/ap030720.html

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.

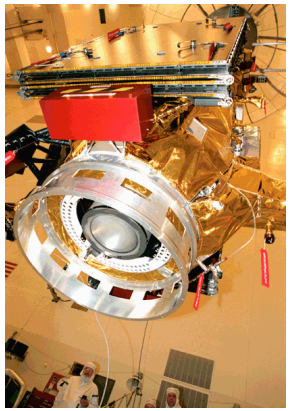




http://antwrp.gsfc.nasa.gov/apod/ap030720.html

DS1

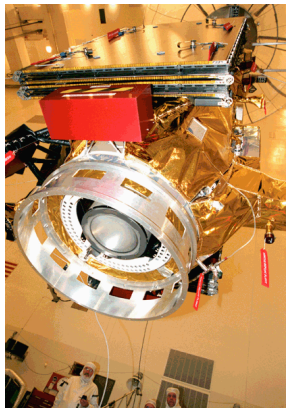
- DS1 only used 81.5 kg of xenon.
- Thrust of engine is only about as strong as the weight of a piece of paper in your hand!
  - If you keep pushing lightly, you will keep accelerating, so after time you can build up speed
  - DS1 eventually reached velocity of 4.5 km/s (10,000 mph!)
  - Remember fastest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



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

DS1

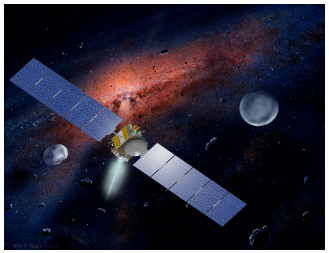
- Not useful for missions that need quick acceleration
- But, more efficient than chemical
  - Can achieve 10 times greater velocity than chemical!



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

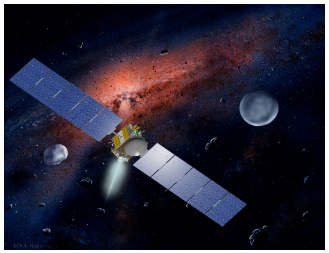
The New Dawn

- 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



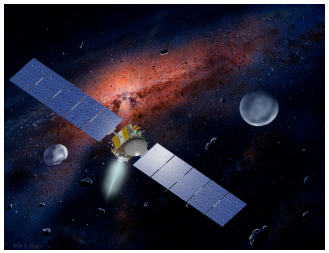
The New Dawn

- 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

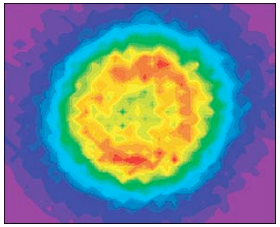
- For interstellar travel with any propellant, you must carry with you the stuff that you eventually shoot out the back
  - Fine for Saturn V rocket and "short" lunar missions
  - Bad for interstellar travel
    - Maybe even prohibitive
- But, it is unlikely that the methods discussed up to now will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

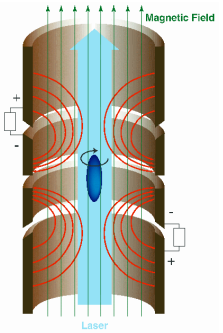
Anti-(Anti-matter)

- 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/

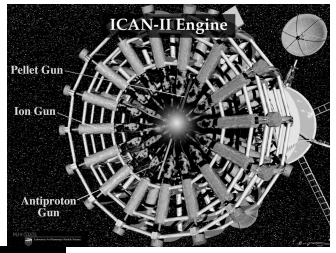
Nonetheless

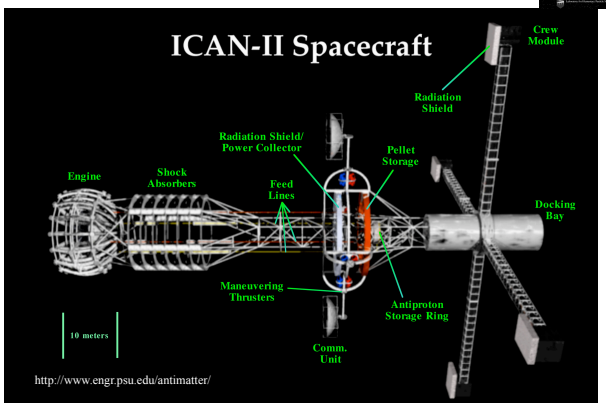
Propulsion	**Specific Impulse** [sec]
Chemical	200 - 450
Electromagnetic	600 - 3000
Nuclear Fission	500 - 3000
Nuclear Fusion	5000 - 10000
Antimatter	1000 - 100000

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

ICAN

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





Interstellar Problem

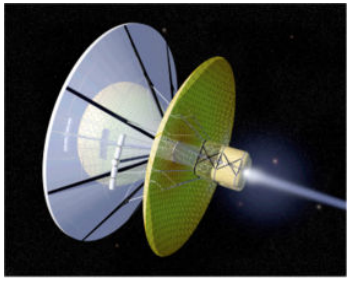
- Still for interstellar trips, we got a problem with carrying around the fuel.
- Edward Purcell thought about antimatter interstellar travel and found even that to be lacking!
- The lightest mass U.S. manned spacecraft was the Mercury capsule– the "Liberty Bell". It weighed only 2836 pounds (about 1300kg)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

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

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

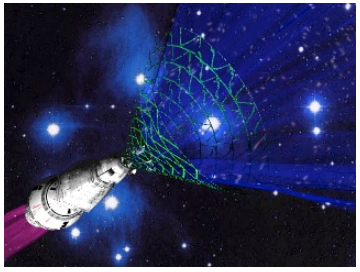
Lose the Fuel, Fool

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



Lose the Fuel, Fool

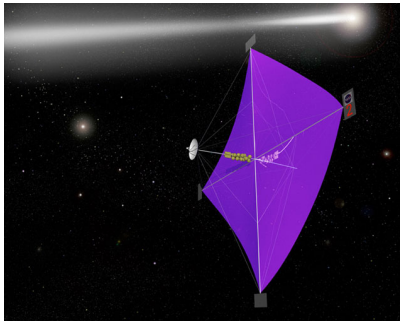
- The scoop would have to be 4000 km in diameter (size of US).
- Or magnetic fields to collect the material.
- But would mostly be low-grade hydrogen fuel, so it is a technological step ahead of what we already discussed.
- Could reach speeds close to 0.99c.



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

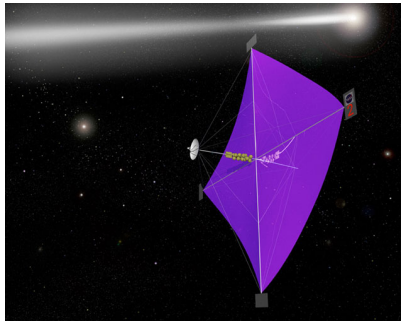
Light Sails

- 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.



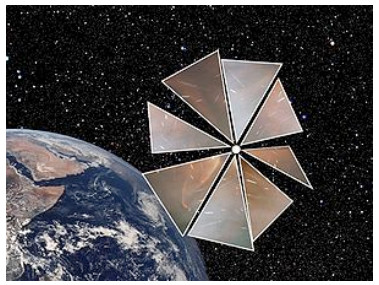
Light Sails

- 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.



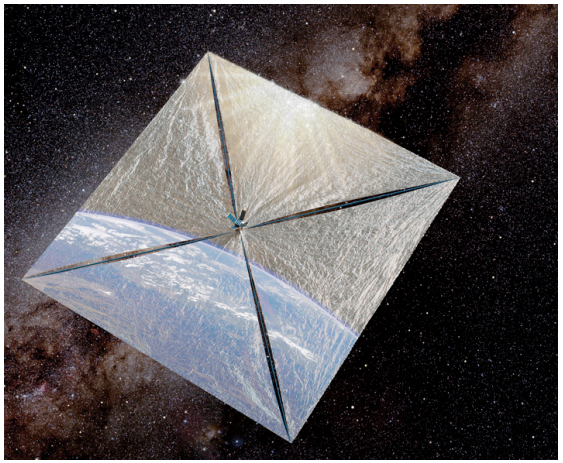
COSMOS 1

- 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.



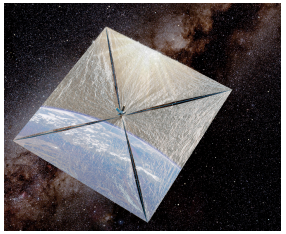
COSMOS 1

- 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



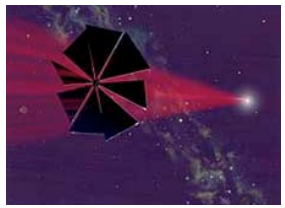
LightSail 1

- *"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



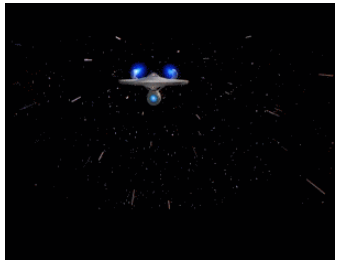
Light Sails

- 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.



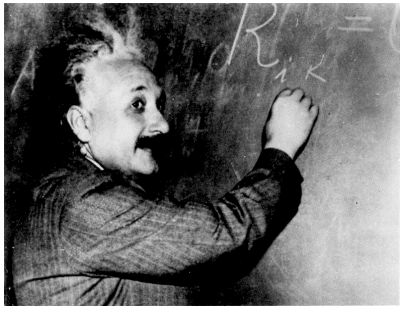
Warp Drives

- 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

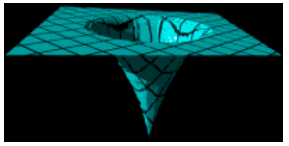
Einstein Is Warping My Mind!



- 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.

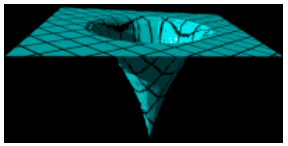
General relativity

- 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.



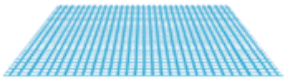
General relativity

- 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

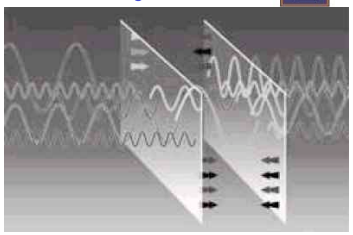
- The subatomic world is not a world of billiard ball-like particles
- "Empty space" is full of waves/ particles popping in and out of existence
  - Like a choppy sea, "virtual particles" are born and interact for an allowed window of time
- This sea of "virtual particles" that inhabits space-time can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

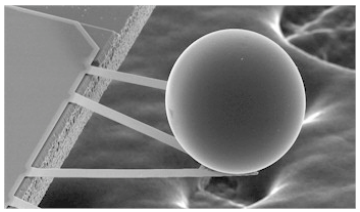


http://zebu.uoregon.edu/~js/glossary/virtual_particles.html

Quantum field theory

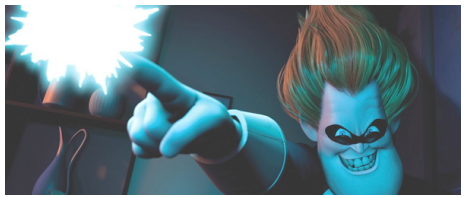
- In 1948, Hendrik Casimir predicted a weak attraction between two flat plates due to the effect of the sea of virtual particles.
- Two 1 meter plates placed a micron apart, would have 1.3mN of force. This is like a weight of 130 mg.
- It is force from nothing!

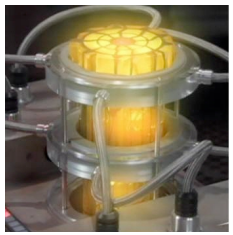




Zero Point Energy

- 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?

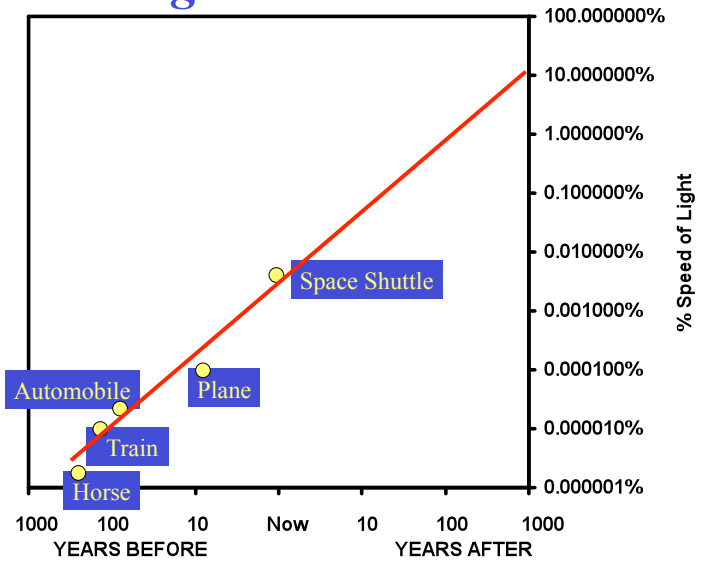
- We really don't know yet how to get to the stars realistically, so we don't know what advanced civilizations might use.
- But it is
  - Smarter
  - Cheaper
  - Still very informative and
  - Realistic

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

Problems to Overcome?

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

Going Interstellar!



Nikolai Kardashev: Civilization Types

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

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

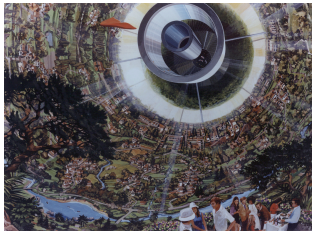
Type II: Harnesses entire output of their host star.
Dyson Sphere–can provide a trillion times more energy than we use on the Earth now. Antimatter drives?

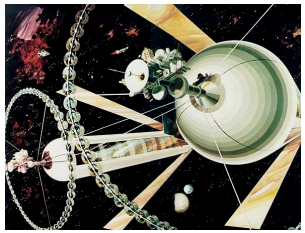
Type III: Colonizes and harnesses output of an entire galaxy
Use a trillion times the energy of Type II civilizations
Use a trillion trillion times the energy of Type I civilizations

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

1000 Years?

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





Getting Out of Here

- Even the Voyager spacecraft (one of the fastest ever flown) travels at only 20 km/s through space - not even 1% of the speed of light. They would take 60,000 years to reach even the nearest star.
- In our discussions, we argue that with foreseeable technology 10% the speed of light is possible.
- Is that enough to expect to see aliens on Earth?

Getting Out of Here

- Distances between stars are much greater than we can imagine– freaky big distances, plus difficult environment and time consuming makes interstellar travel hard to conceive.
- SciFi books and movies have dramatized space travel to make it seem possible
  - But, interstellar travel may never happen