Astronomy 330

This class (Lecture 25):
Interstellar Travel

Next Class:
Interstellar Travel

HW10 is due tonight!
4 lectures remaining.

Music: *Rocket Man*– Elton John

Classes

- CHP allows $100 for informal get togethers.
- Would we like to meet next Thursday, watch a movie, order some pizza or try to end early and likely skip the last day of class.
- Let's do a secret ballot.   Yes/no, if yes, then also list your preferred ~1 hour long thing and pizza or whatever.

Final Papers

- Final papers due on May 3rd.
  - 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 last class.
- Will consist of:
  - 2 large essays
  - 2 short essays
  - 5-8 short answers
- Due May 11th, hardcopy, by 5pm in my mailbox or office.

Online ICES

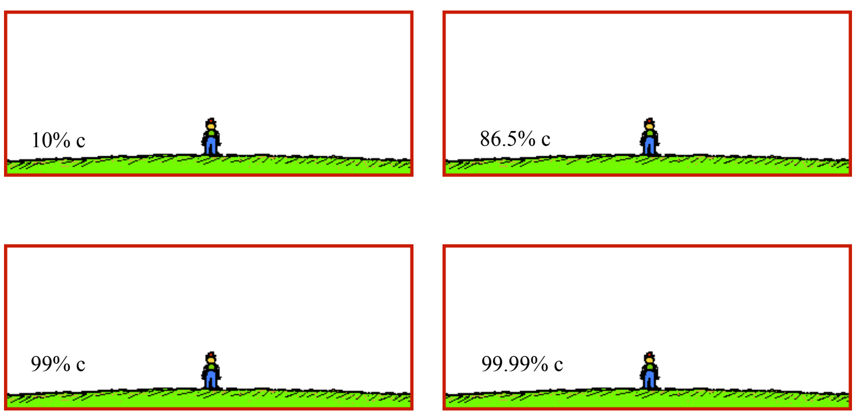
- ICES forms are available online.
- I appreciate you filling them out!
  - In addition to campus honors thingy
- Please make sure to leave written comments. I find these comments the most useful, and typically that's where I make the most changes to the course.

Outline

- If we have to go find ET, then how to get out there?
- Interstellar travel problems

Counterintuitive Result #1

Moving objects are shorter in the direction of relative motion



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

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

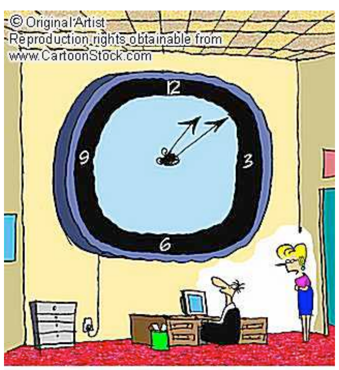
Question

Your best friend is going on a near light speed trip. When at rest she measures the Earth's diameter to be 6,870 km. Now, she's in flight and you're on the Earth, and she measures the Earth's diameter to be

a) Exactly 6,780 km long.
b) Less than a 6,780 km long.
c) More than a 6,780 km long.

Counterintuitive Result #2

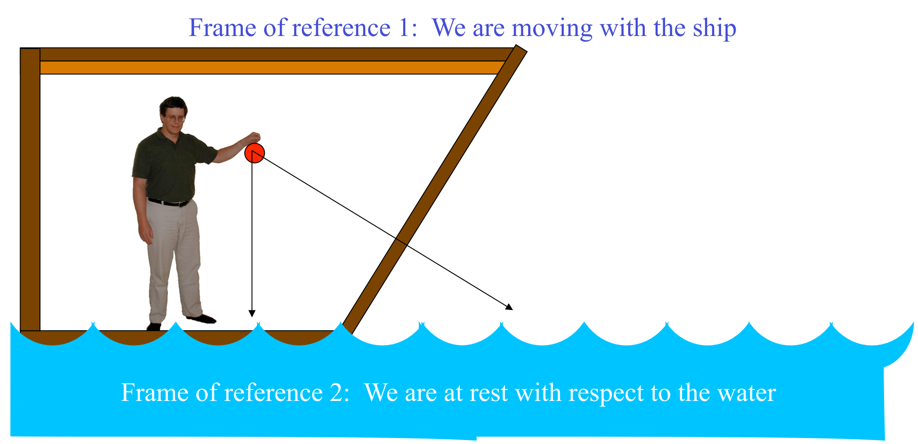
Clocks on Moving objects slow down



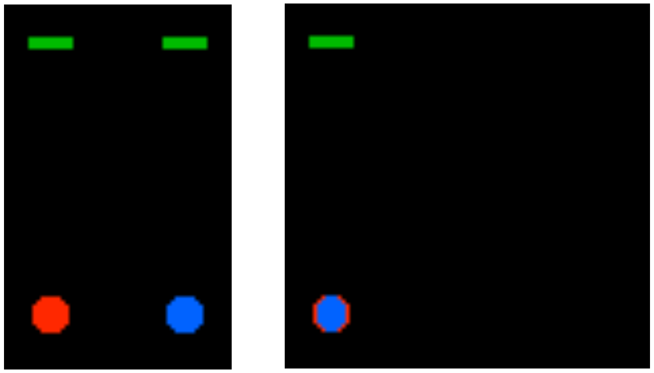
"Try not to watch the clock. It only makes the day go slower."

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.



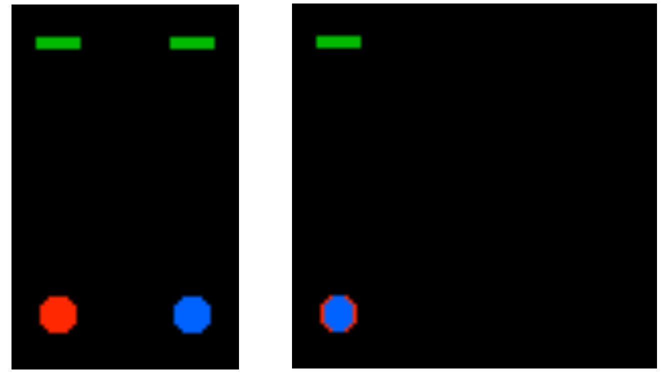
If the Ball is light?



A. Hamilton (Colorado)

Counterintuitive Result #2

Time appears to advance more slowly for moving objects (<u>time dilation</u>)



Red & blue at rest — Blue moving to right

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

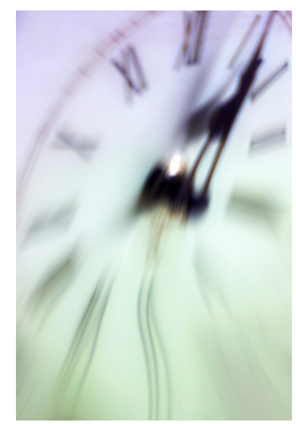
Question

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.

Time Dilation

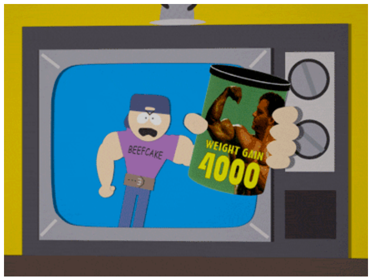
- The effects of time dilation are curious but not prohibitive for space travel
  - Astronauts will age less than the Earth-bound folks waiting for the return. Can spoil the homecoming celebrations.
  - The faster you go, the bigger difference between astronaut time and Earth time



- 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!

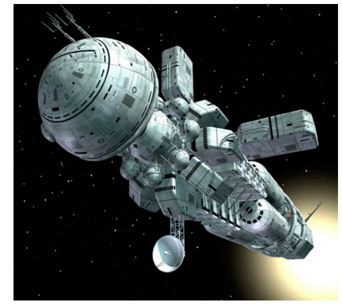
Counterintuitive Result #3

Mass increases for moving objects



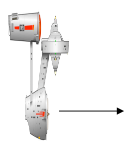
Mass Increase

- 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.



So, what does that mean?

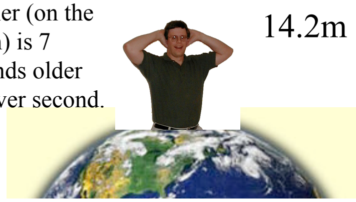
- If you're on a 100m spaceship going near the speed of light (.99 c), the spaceship measures 100m long, but someone on the Earth would measure the spaceship to only be 14m long.
- As you speed by the Earth your clock would tick 1 second, and an observer would tick about 7 seconds.



0.99 c

14.2m

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

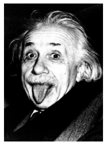


And Paul's measured mass increased by a factor of 7.

Question

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.



Special Relativity Summary

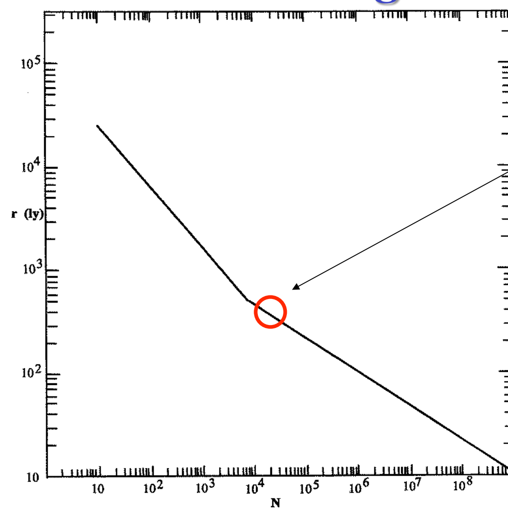
All motion is relative, except for that of light. Light travels at the same speed in all frames of reference.

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.

The Neighbors



We need to look at every star within ~300 lyrs for one detection!

With no radio detection, then we have to go to them!

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

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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.

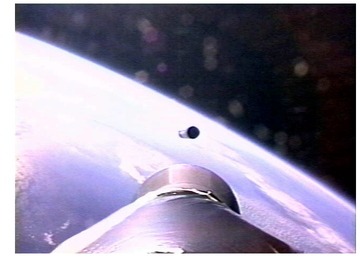
How's it work?

- 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

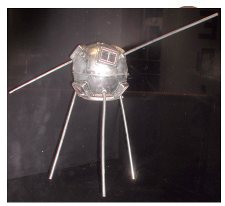
What you talking 'bout Willis?

- 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.

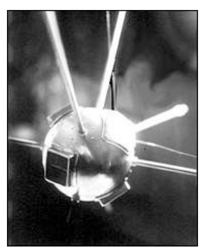


http://www.utahredrocks.com/stardust/launch6.jpg

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
- $R_M = \dfrac{2 \times 10^6 + 2.95 \times 10^4}{2.95 \times 10^4} = 67.8$

Kiss and Make Better

- Shuttle thrust is 29 x 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 and is 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

Petroleum rocket fuel in action

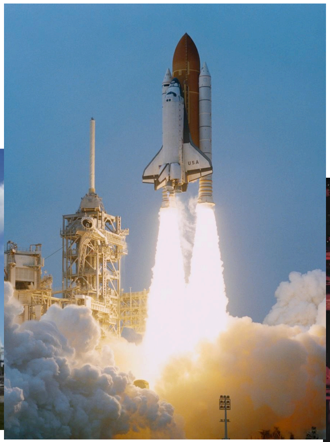
The mighty Saturn V 1st stage (launched Apollo 11).

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

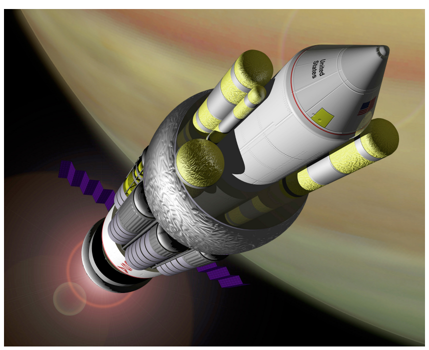
- To really think about interstellar travel or even going to Mars, we need the most bounce for the ounce:
  - Need to carry (probably MUCH) fuel
  - Must be very thrifty about efficiency
  - In other words, if we are going to carry fuel mass on a ship, we had better get as much energy from it as possible!

Fuel Efficiency: $E=mc^2$

- Chemical fuel (like burning wood or rocket fuel) one only gets about 1 billionth of the total mass .
- Nuclear fission about 1 thousandth of the mass.
- Nuclear fusion about 1 hundredth of the mass

Project Orion

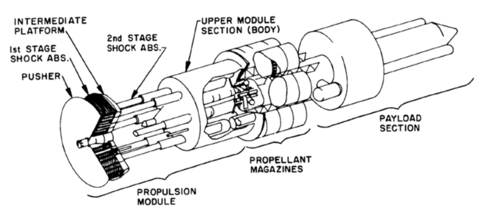
- A spacecraft powered by nuclear bombs– nuclear fission.
- Idea was sponsored by USAF in 1958
- Physicist Freeman Dyson took a year off from Princeton to work on idea
- Sounds crazy now… but a real project



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

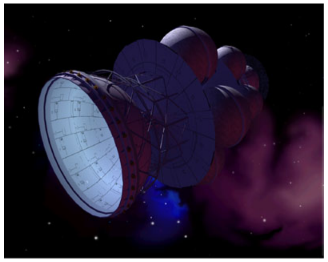
Project Orion

- 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

Project Daedalus

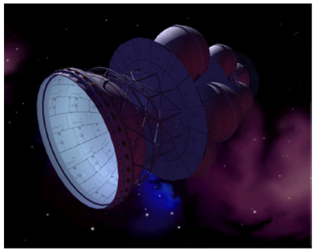
- Continuation/extension of Orion
- British Interplanetary Society project (1973-1978 planned)
- A robotic fly-by probe to Barnard’s Star
  - 2nd closest star system to Earth, 6 lyr away
  - In human lifetime scale (chose 50 yrs)
  - Needs to reach 12% c.
- Idea was to also use nuclear pulsed power,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



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

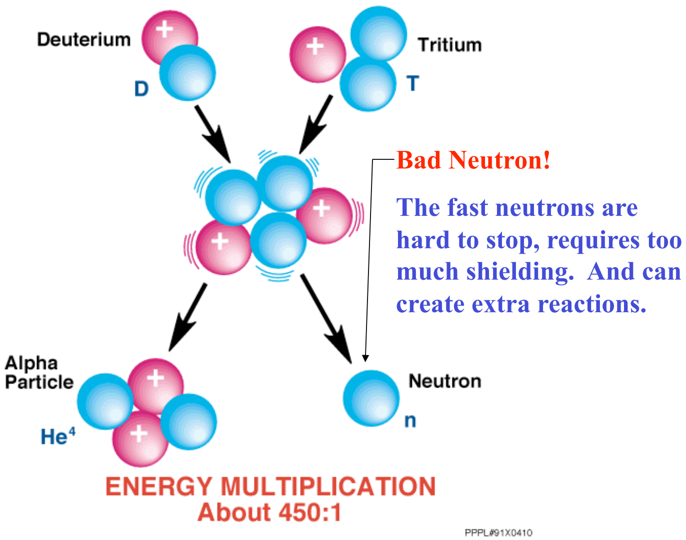
Project Daedalus

- Good example of interstellar travel with foreseeable technology.
- Use fusion, like the stars.
- But, we have to use the more energy efficient part of hydrogen → helium.
- But there’s a problem.



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

Deuterium–Tritium Fusion Reaction

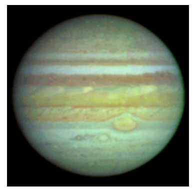


Project Daedalus

- Instead Daedalus would use:

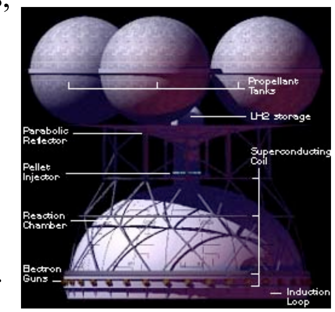
$$d + {}^{3}He \rightarrow {}^{4}He + p$$

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



Project Daedalus

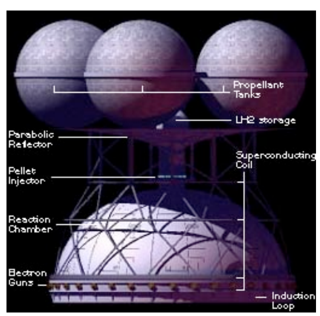
- Daedalus would accelerate for 4 years, then coast for 50 years to reach Barnard's star.
- At blastoff the mass would be 54,000 tons, of which 50,000 would be fuel.
  - Built in space though.
- That's an $R_M = 12$.
- The fuel would be in pellets that enter the reaction chamber 250/sec.
- Sophisticated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



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

Project Daedalus

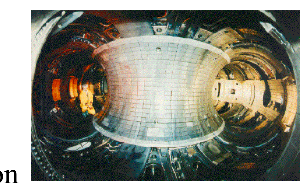
- For dust erosion at 0.12c, requires a beryllium erosion shield 7mm thick and 55 meters in diameter.
- Once it reached Barnard's star, it would disperse science payload that would study the system.
- Would transmit back to Earth for 6-9 years.
- So does not require a return trip.



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"

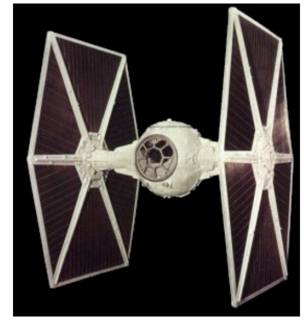


Fusion Rockets

- 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

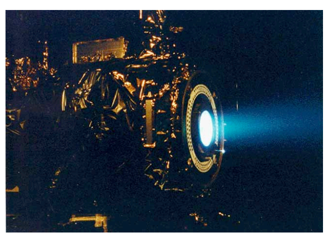
Ion Drives

- 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

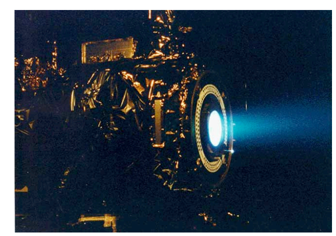
- First successful used in Deep Space 1, which took the closest images of a comet nucleus (Comet Borrelly).
- The engine worked by ionizing xenon atoms, then expelling them out the back with strong electric fields.



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

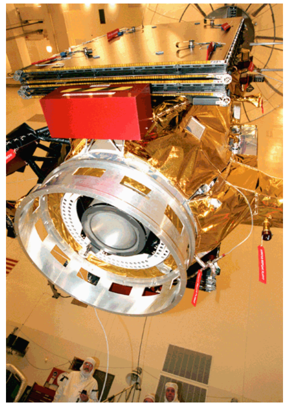
Ion Drive

- 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

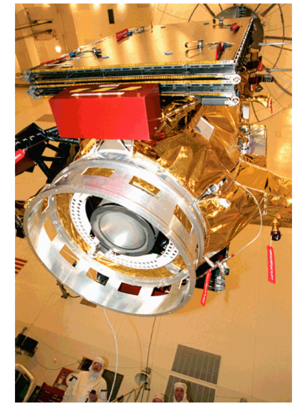
DS1



- 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

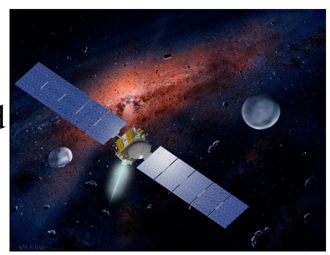
DS1



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

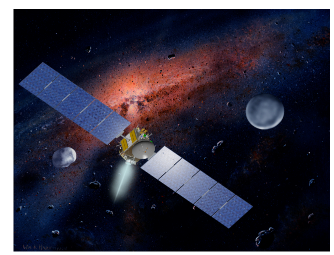
http://nmp.jpl.nasa.gov/ds1/img/98pc1191.gif

The New Dawn



- Launched Sept 2007.
- Will explore two most massive members of asteroid belt – Vesta (July 2011) and Ceres (Feb 2015)
- Propelled by three DS1 heritage xenon ion thrusters (firing only one at a time).
- s.i. = 3100 s
- Dawn spent 270 days using less than 72 kg of fuel to change its velocity by 1.81 km/s (4050 mph)!

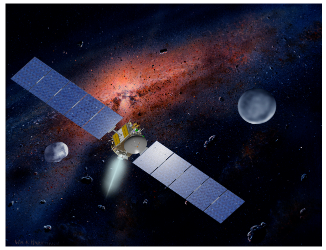
The New Dawn



- 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

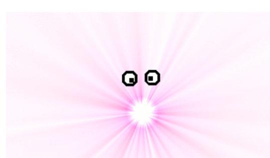


Our Problem

- 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.

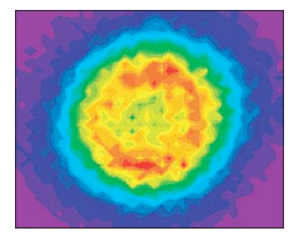
Antimatter

- 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

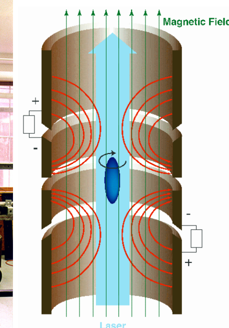
Anti-(Anti-matter)

- 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/

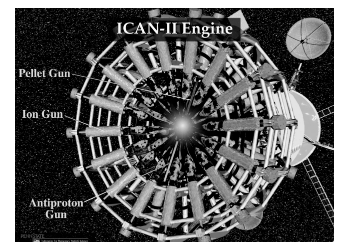
Nonetheless

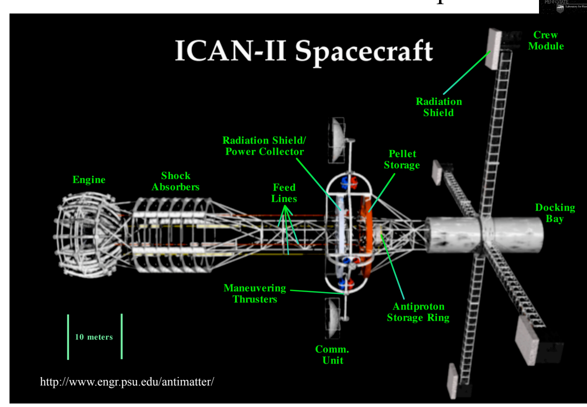
Propulsion	**Specific Impulse [sec]**
Chemical	200 - 450
Electromagnetic	600 - 3000
Nuclear Fission	500 - 3000
Nuclear Fusion	5000 - 10000
Antimatter	1000 - 100000

- 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.





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

Interstellar Problem

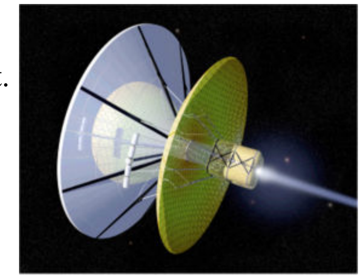
- Still for interstellar trips, we got a problem with carrying around the fuel.
- Edward Purcell thought about antimatter interstellar travel and found even that to be lacking!
- The lightest mass U.S. manned spacecraft was the Mercury capsule– the "Liberty Bell". It weighed only 2836 pounds (about 1300kg)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

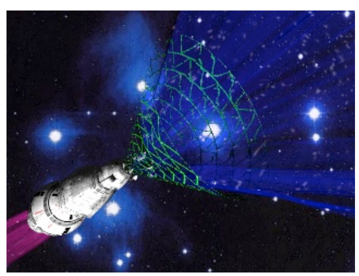
Lose the Fuel, Fool

- 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

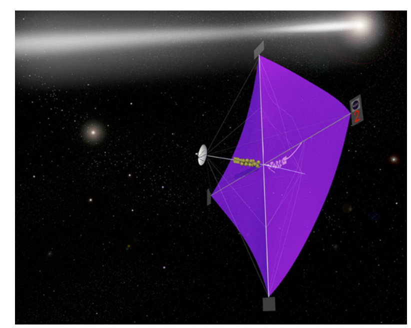
- The scoop would have to be 4000 km in diameter (size of US).
- Or magnetic fields to collect the material.
- But would mostly be low-grade hydrogen fuel, so it is a technological step ahead of what we already discussed.
- Could reach speeds close to 0.99c.



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

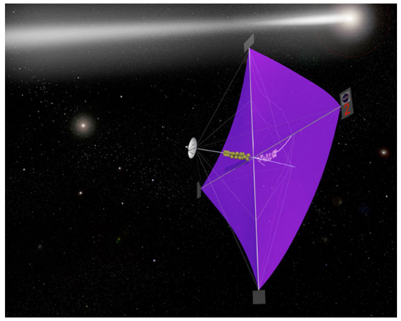
Light Sails

- 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.

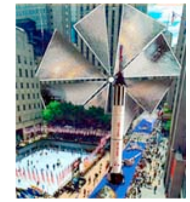


Light Sails

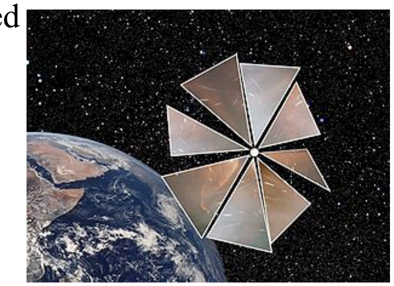
- But, photons do carry momentum!
  - It is related to the energy such that $p = E / c$
- So, such a craft is not propelled by solar winds!
- But by light bouncing off, like a mirror.



COSMOS 1



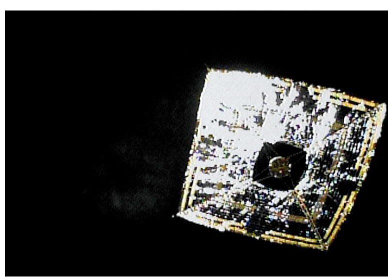
- First solar sail spacecraft (and private!) launched from a Russian nuclear submarine on June 21, 2005!
- Planetary society raised $4M
- Unfortunately, the first stage of the Volna never completed its scheduled burn, and the spacecraft did not enter orbit.



IKAROS

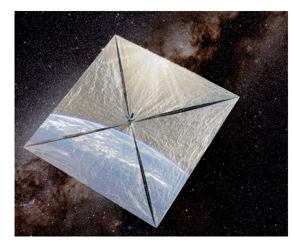
- IKAROS (Interplanetary Kite-craft Accelerated by Radiation Of the Sun) was first successful solar sail propulsion spacecraft (20 m diag.).

- Japan Aerospace Exploration Agency and The Planetary Society project.
- Planned full space craft for Jupiter mission in the next decade.



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 2011?
- 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.