Astronomy 330

This class (Lecture 25):
Rockets

Next Class:
Space Travel

Music: Rocket Man – Elton John

Final Papers

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

Final

- Take home exam (will try to bring it on the 24th).
- Must be dropped off no later than May 2nd (noon) in my mailbox in astro building.
- You are allowed 4 hours– must be typed.
- Will probably consist of 40 multiple choice/ true-false questions (2 points each), 3 small essay questions (17 points each), and 2 large essay question (40 points each).
- 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.
- Multiple-choice is heavily weighted toward the last half of the course.
- Might want a calculator for easy math.

Outline

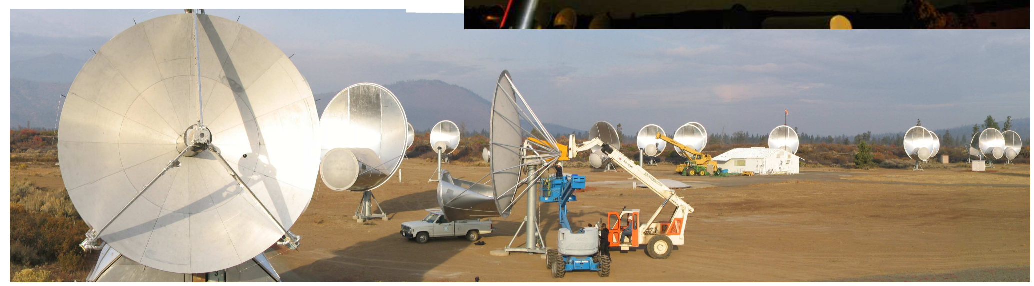
- Interstellar Travel
- The speed limit
  - What's up with time and distance when you travel fast?

Allen Telescope Array

- At the BIMA site, UC Berkeley and the SETI Institute, with majority of funding from Paul Allen, are building the ATA.
- 350 antennas that are 6.1 m in diameter, planned.
- Area comparison: Arecibo (70,650 m^2) & ATA (10,200 m^2) but still > 100 m single dish.

Allen Telescope Array

- And small dishes– larger field of view.
- But LOTS of them.. planned
- With advanced electronics it will cover 1-10 GHz with many channels.
- Can image a few stars per field.



Allen Telescope Array

- 100% SETI (with science on for the ride)
- Will increase search to 100,000 or 1 Million stars.
- Current status is 42 dishes.
- Is now observing!
- http://www.seti.org/ata/

Allen Telescope Array

See the telescope in action:

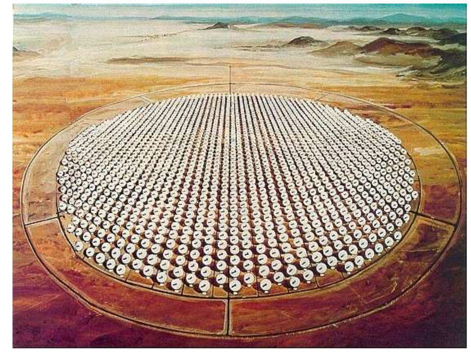
http://atacam.seti.org/maincam-index.html

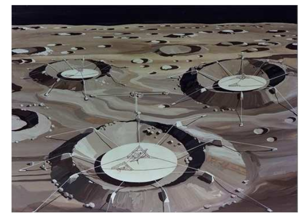
End All

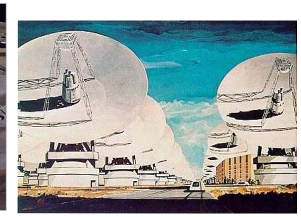
- The modern SETI searches are really expanding the frequency range in which we search, but we are still sensitivity limited.
- In any SETI experiment, what does a null result mean?

The Future?

- Cyclops – 1000 telescopes each 100 m in diameter.
- Resembles a giant eye.
- Could detect leakage transmission at 100 ly.
- Could detect a 1000 MW transmission at 1000 lyrs.
- Bucco Bucks– $50B and 10-20 yrs to build.



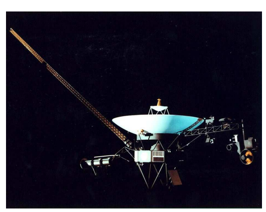




http://www.astrosurf.com/lombry/ovni-bioastronomie-et.htm

Interstellar Travel

- The distances are freaky huge!
- Nearest star is 4.3 ly away or around 4×10^{13} km!
- **40,000,000,000,000 km! 40 TRILLION km!!!**
  - **Voyager (our fastest spacecraft to date) would take** 100,000 years



Interstellar Travel

- But, what if all communication with ET fails?
  - Wrong frequencies.
  - Everyone is listening and no one is broadcasting.
  - We fail to recognize the signal.
- We can go visit them or the microbes. “To boldly go…”
- Human colonization of the Galaxy has to start somewhere. Our own backyard!

Humans Spreading Out

If we assume that no life is found in our solar system, we have multiple options.

- Seed other planets with genetically engineered life or terraform the planet for terrestrial life.
- Colonize the planets or asteroids.
- Send robots to exploit solar system resources.

GELFs

- Genetic engineering techniques might allow us to develop organisms suitable for life on Mars, in the clouds of Venus, or the upper atmosphere of Jupiter.
- But the most likely organism would be those that are part of a larger plan to transform an environment into one suitable for human colonization.
- Terraforming– forming a planet or moon into something like the Earth conditions.

Spider genes being injected into a goat egg. Goat produces spider silk protein in milk– Biosteel.

http://science.howstuffworks.com/designer-children3.htm

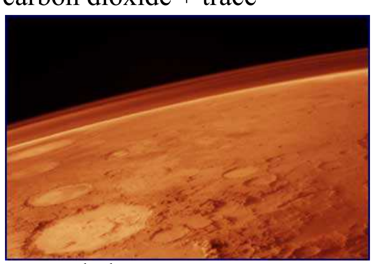
http://www.nexiabiotech.com

Terraforming Mars

- Mostly envision Mars for terraforming.
- Comparison:

Mars:		Earth:	
– 95.3%	carbon dioxide	– 78.1%	nitrogen
– 2.7%	nitrogen	– 20.9%	oxygen
– 1.6%	argon	– 0.1%	carbon dioxide + trace
– 0.2%	oxygen		

- Why terraform?
  - In 1-2 x 10^9 yrs, Earth will get hot.
  - Other economical possibilities.
- What are the essential ingredients?
  - Water, Oxygen, and Ozone.
- The bacteria that can build up oxygen need the water.



Or Aliens?

http://www.youtube.com/watch?v=cZN5_zyX4oU

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

http://www.geocities.com/mattcash777/gallery4frames.html

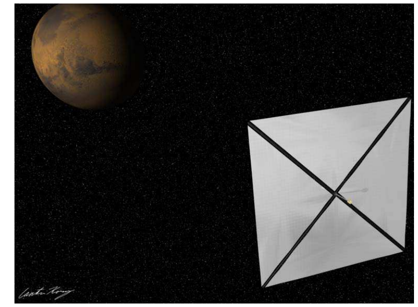
Wet Mars

- There is clearly water on Mars frozen in the permanent ice caps or in icy deposits below the surface.
- Probably 10^{14} tons of ice in the caps, but how to melt it?
- Spread a layer of dark soil, which will sublimate the water to water vapor.
- Water vapor is a greenhouse gas, so eventually pressure and temperature goes up and liquid water can exist.
- Would take about 10,000 yrs to melt.

http://www.ucl.ac.uk/GeolSci/MITC/marsinfo/icecap.jpg

Solar Mirror?

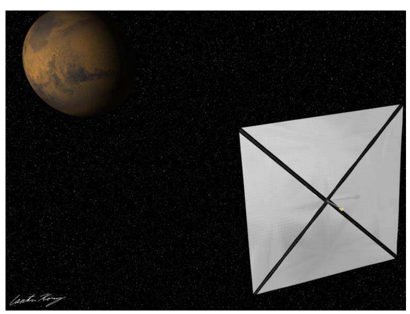
- Could build huge solar mirrors in space to add light to mars– size of Texas for 2% increase.
- Power needed to melt the icecap (remember only first step) is equivalent to 2500 yrs of the US energy output!



http://www.futurespace.de/gallery/pictures/sail-mars1.jpg

Solar Mirror?

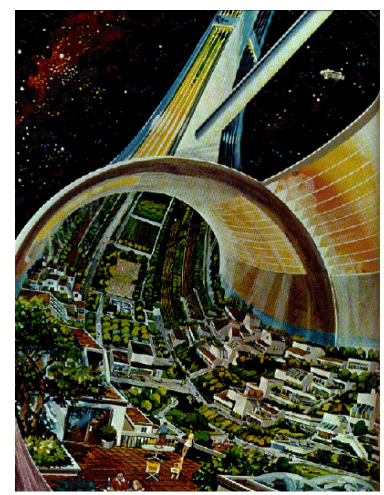
- A solar sail satellite (diameter of 125 km) above the pole should melt the icecap in 10 yrs.
- Other options: genetically engineered bacteria to add greenhouse gases, nanobots, etc.
- Bottom line, at this time it would be very costly and time consuming to terraform Mars.



http://www.futurespace.de/gallery/pictures/sail-mars1.jpg

Space Colonies?

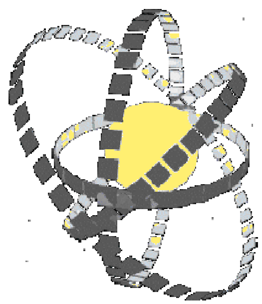
- Super-duper version of the Space Station.
- Collect materials from Moon, and make a large space structure.
- Artificial gravity from rotation– life could exist.
- But why?
- Hard to justify the expense.
- Maybe solar power collector– beaming microwaves back to Earth.



http://static.howstuffworks.com/gif/space-station-space-settlement.gif

Dyson Spheres– Recap

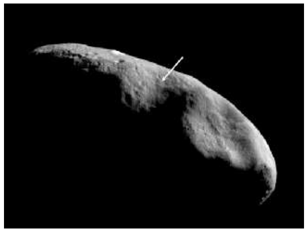
- Again, one could imagine a Dyson Sphere around the Sun to collect the sunlight.
- If other advanced civilizations built one, could we detect it?
- If at 1AU, the sphere would be about 300 K and emit in the IR.
- But if we detected it, we would think it was a star surrounded by dust-- a circumstellar disk of a young star or a blown out shell of dust from an old star.



http://www.homoexcelsior.com/omega.db/datum/megascale_engineering/dyson_sphere/237

Asteroid Living and…

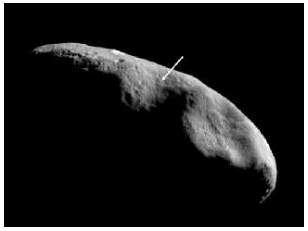
- Mining the Apollo (near Earth) asteroids for metals is a possible economical driver for life in space.
- But all of this requires moving machines, humans, or material around the solar system.
- Today, if there were piles of gold lying on the Moon, it would not be cost effective to go get it.



http://apollo-society.org/images/near_arrow_sm.jpg

Asteroid Living and…

- But, remember to date human space travel has cost 10 times as much as remote “robot” travel.
- Probably devise ways to mine remotely.
- Efficient mining requires more and more intelligent robots.
- What if they get too smart?
- Still self-replicating space probes could be result of such advances.



http://apollo-society.org/images/near_arrow_sm.jpg

Space Probed

- A single probe is constructed and dispatched to a nearby star system
- It surveys the system in an intelligent and exhaustive manner
- After which, the probe uses the energy and available raw materials of the system to reproduce itself .

Space Probed

- Dispatches its "children" onwards to repeat its mission in other star systems
- The parent probe is then able to choose whether it wants to stay in the system or not, depending on what it found
- Still need a way to get to other worlds.

http://www.biochem.wisc.edu/wickens/meetings.html

Energy into Propulsion

- For any type of space travel, we need an energy source to propel the vehicle.
- The basic idea is to convert some stored energy into *energy of motion* for the spacecraft
- Two ways basically:
  1. Process some sort of fuel
     - Carried onboard
     - Collected from space and processed
  2. Other, non-fuel-like energy source:
     - Solar (if near a star)
     - Gravity (using an astronomical body's gravity field to propel a ship)

We got a speed limit!

- No matter what we do, we can not go faster than the speed of light!
- That naturally occurs when one demands that the speed of light ***must*** be the same regardless of who measures it.
- This is completely counter-intuitive!
- Basis of Einstein's Theory of Special Relativity.

http://www.rpi.edu/dept/phys/Dept2/APPhys1/optics/optics/node4.html

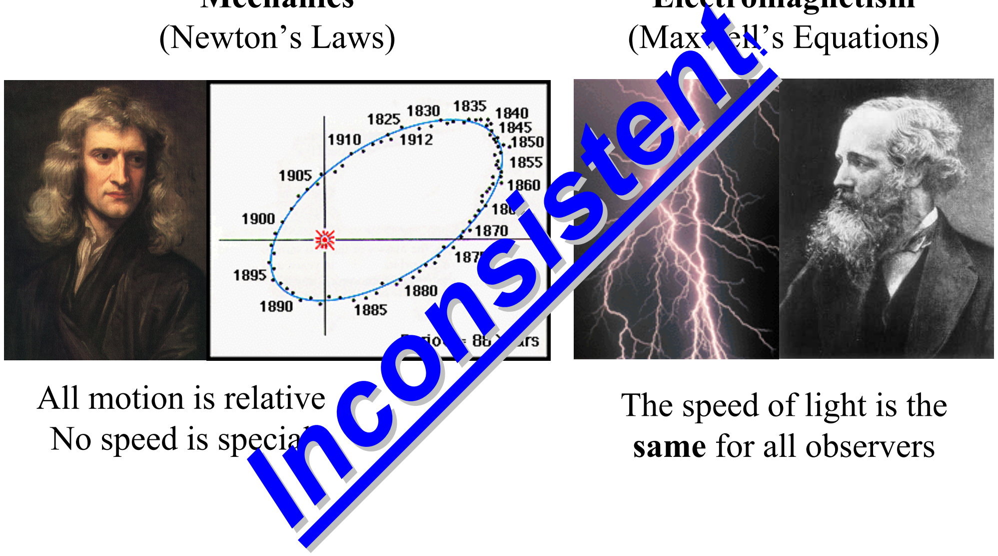
How Fast is Light?

- The speed of light is $c = 3\times10^{8}$ m/s (186,000 miles per second)!
- How fast is that?
  - Around the Earth over 7 times in a second
  - From Earth to the Moon in under 2 seconds (it took the astronauts 2 weeks)
  - From the Sun to the Earth in a little over 8 minutes
  - From the Sun to Pluto in about 5½ hours
  - From the nearest star to Earth, about 4 years

Two Threads of Thought in Physics up to 1900

Mechanics
(Newton's Laws)

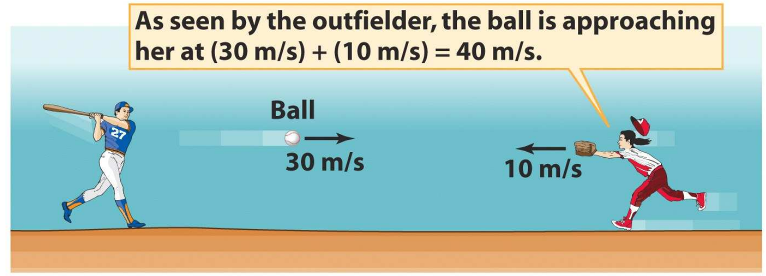
Electromagnetism
(Maxwell's Equations)



All motion is relative
No speed is special

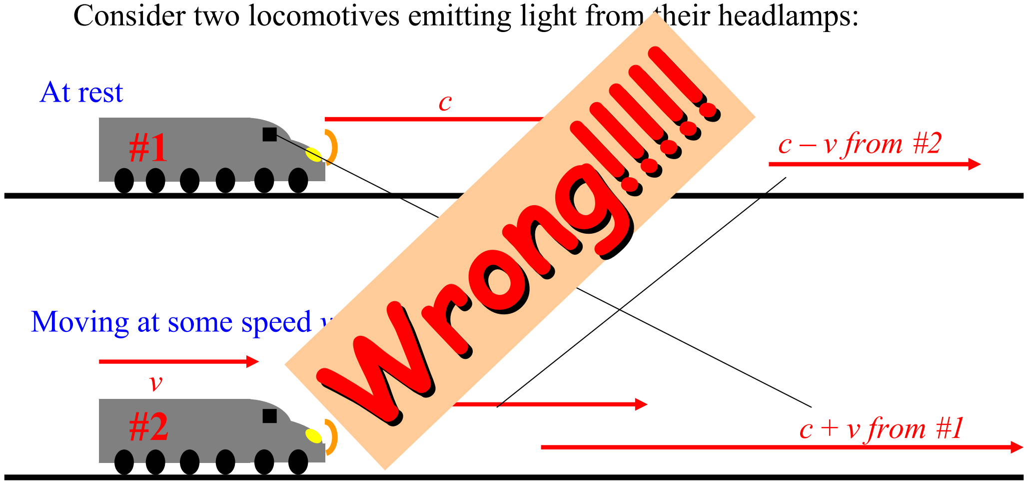
The speed of light is the **same** for all observers

Why Newton and Maxwell Can't Both Be Right

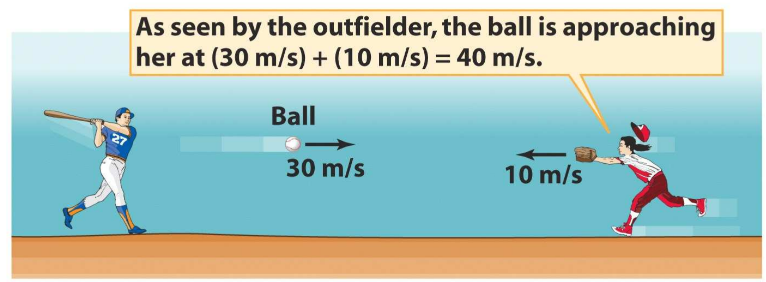


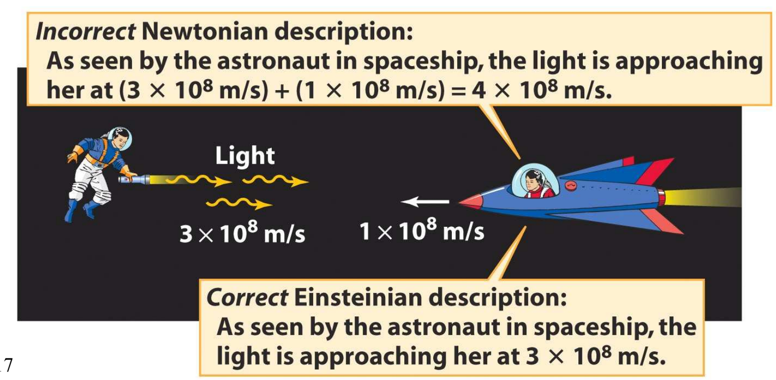
Why Newton and Maxwell Can't Both Be Right

Consider two locomotives emitting light from their headlamps:



Why Newton and Maxwell Can't Both Be Right





Why Galileo and Maxwell Can't Both Be Right

So the speed of light can't be the same for everyone if Galileo – and our intuition – are right. But Maxwell says it is constant!

Something must happen. And what must happen for Galileo and Maxwell to be both right, is that there is a modification of time and distance. Remember

$$speed = \frac{dist}{time}$$

Distance and time become relative to the observer.

Approaching the "c"

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

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

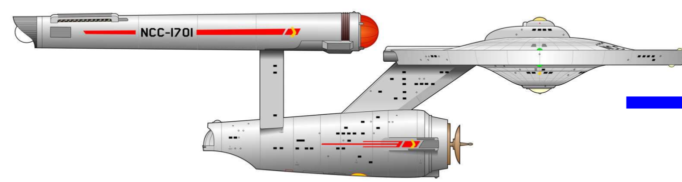
Gamma

The factor by which all of these changes occur is called "gamma"

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

Counterintuitive Result #1

Moving objects appear shorter in the direction of relative motion (Lorentz contraction)



Fraction of the speed of light	% of original length
0.00	100%
0.001	99.99995%
0.01	99.995%
0.1	99.5%
0.5	86.6%
0.9	43.6%
0.99	14.1%

Counterintuitive Result #1

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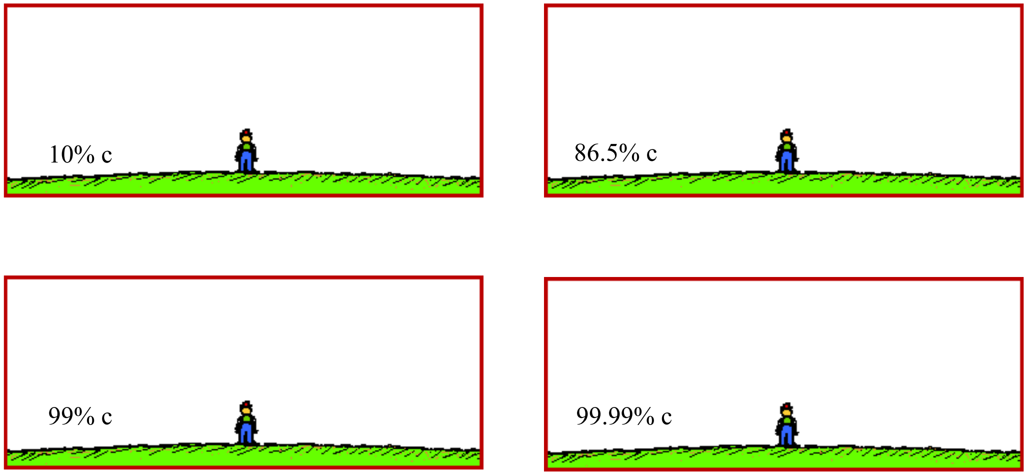


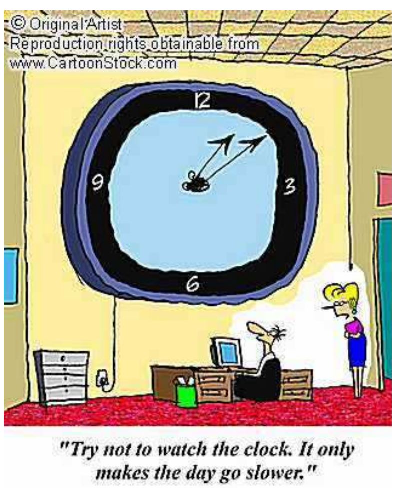
http://www.physicsclassroom.com/mmedia/specrel/lc.html

Length Contraction

- This effect has some benefits:
  - Outside observers will see that the length of the spaceship has shrunk.
    - This doesn't really help or harm us
  - But, from the astronaut point of view, the entire universe outside their window has shrunk in the direction of motion, making the trip shorter!
- It's all relative.

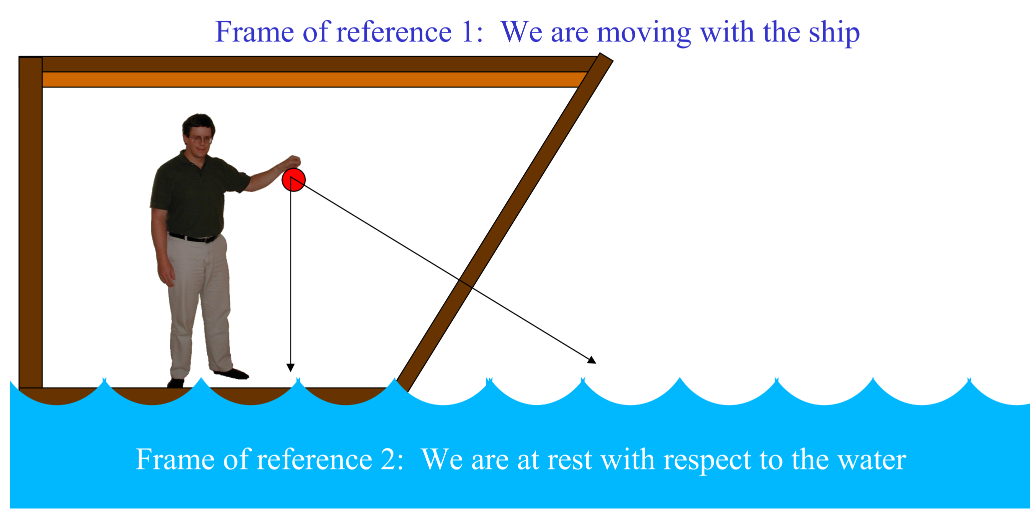
Counterintuitive Result #2

Clocks on Moving objects slow down

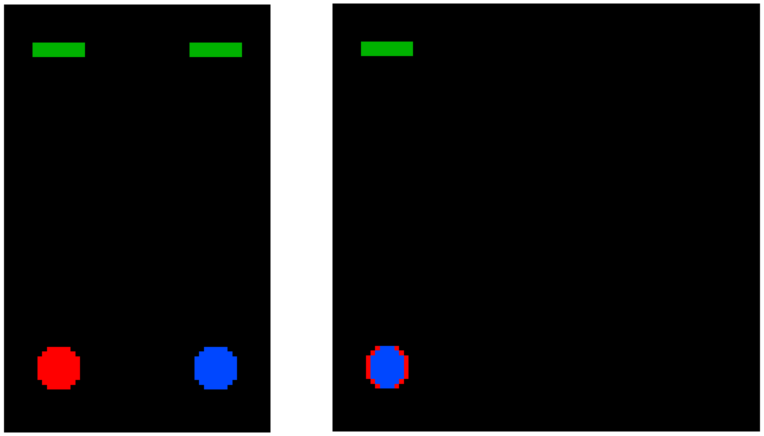


Galileo's ship thought experiment

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.



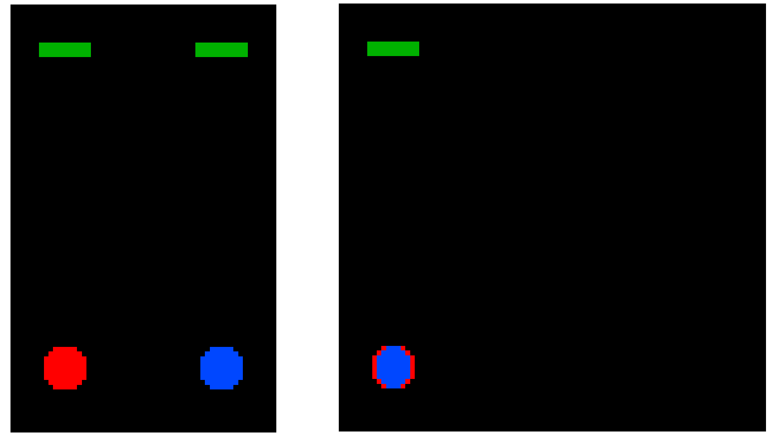
If the Ball is light?



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

A. Hamilton (Colorado)

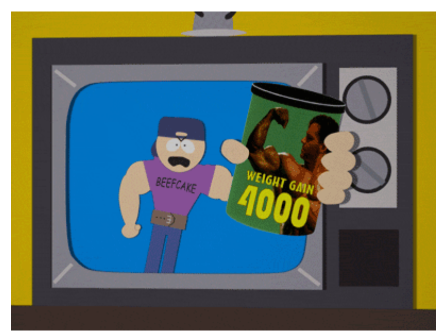
Time Dilation

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

- Example: Trip to the center of the Galaxy and back. Accelerate at 1g for the first half and decelerate for second half and you can go 30,000 ly in 20 years! But more than 30,000 years has elapsed on Earth!

Counterintuitive Result #3

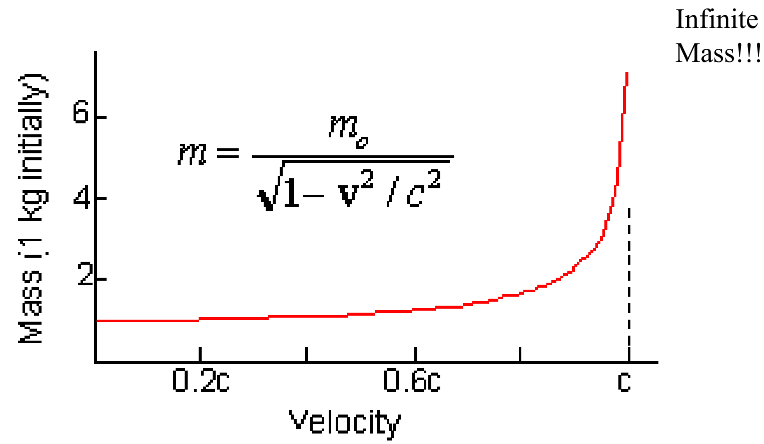
Mass appears to increase for moving objects



Mass Increase

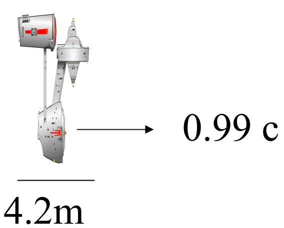
- The increase of effective mass (and kinetic energy) with velocity makes acceleration and deceleration more difficult if you intend to travel close to "c"
  - This translates to very costly starflight in terms of required energy.
  - And now the interstellar dust that you strike at relativistic speeds appears as larger mass.
  - For 99% speed of light travel, 5.5 meters of shield would erode every year.

The gamma factor and mass:



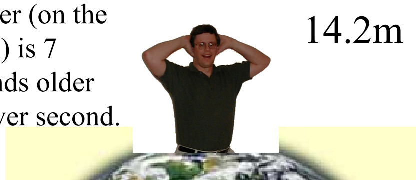
So, what does that mean?

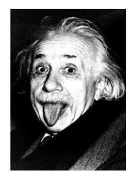
- If you're on a 100m spaceship going near the speed of light (.99 c), the spaceship would look 100m long, but someone on the Earth would observe the spaceship to only be 14m long.
- As you speed by the Earth your clock would tick 1 second, and an observer would tick about 7 seconds– $\gamma = 7$.



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

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





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.

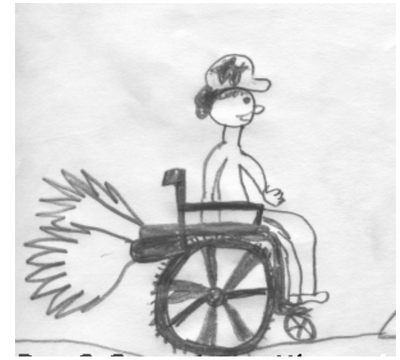
Time appears to advance more slowly for objects moving close to the speed of light.

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

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:

$$s.i. = \frac{thrust}{Fuel\ Rate} = \frac{\frac{mass}{s} \times V_e}{\frac{mass}{s}}$$

Rocket Man: 4 Quantities

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$$s.i. = \frac{thrust}{Fuel\ Rate} = \frac{\frac{mass}{s} \times V_e}{\frac{mass}{s}}$$

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

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

Rocket Man: 4 Quantities

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

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

The units have traditionally been in seconds. But it is a little confusing, and has nothing to do with time.

It is a property of the fuel and engine design. Sort of like octane rating in gasoline–
a large s.i. is a good thing.

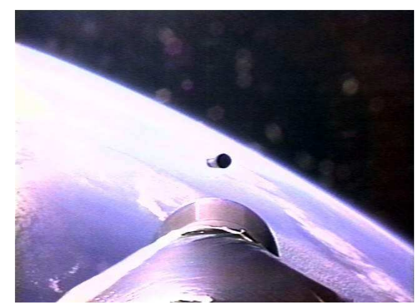
How's it work?

- For rocket to take-off, its thrust must be greater than its weight (force up > force down).
- In addition, the rocket needs to escape the Earth's pull.
- That means that the rocket velocity must exceed the Earth's escape velocity
(11.2 km/s or 7 miles/s).
- Humans have never built a rocket that can do this!!!

http://www.eos.ucar.edu/mopitt/instr/rocket.jpg

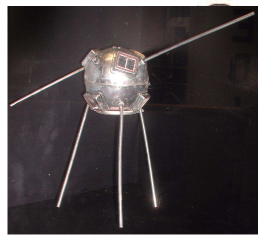
What you talking 'bout Willis?

- Humans have never built a rocket that can escape the pull of Earth?
- No, that's why we have to use multistage rockets.
- Once the fuel from the first stage is spent, it's dropped.
- Then, the next stage is higher up, so the escape speed is less than from ground level.
- To escape the Earth's gravity many stages are necessary.

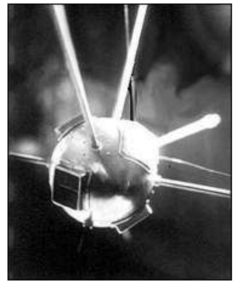


http://www.utahredrocks.com/stardust/launch6.jpg

Not Good



- Multistage rockets are wasteful.
- The Mass Ratio can be huge!
- The first US satellite was the Vanguard launched on March 17, 1958. (Still in orbit!)
- 6.4 inch diameter with 2 radio transmitters.
- Weighed 3 lbs = 1.4 kg.
- Rocket mass was 36,000 kg.
- $R_M = \frac{36000+1.4}{1.4} = 25{,}715 >> 1$
- 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
- $R_M = \frac{2\times10^6 + 2.95\times10^4}{2.95\times10^4} = 67.8$

Kiss and Make Better

- Shuttle thrust is 29×10^6 N with 80% from solid rocket boosters– they fall off at 40km.
- s.i. = 455 seconds
- Good, but not good enough to leave Earth's orbit (shuttle orbits @185 km)