

Astronomy 330



This class (Lecture 25):

Communication

Next Class:

Interstellar Travel

HW11 due Thursday!

Music: *Rocket Man*– Elton John

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 7th, hardcopy, by 5pm in my mailbox or office.

Final Papers



- Final papers due on May 1st.
- You must turn final paper in **with the graded rough draft**.
- If you are happy with your rough draft grade as your final paper grade, then don't worry about it.

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



- How to contact ETI.
 - Problems
 - SETI experiments
- If we have to go find ET, then how to get out there?
- Interstellar travel problems

Drake Equation

Frank Drake



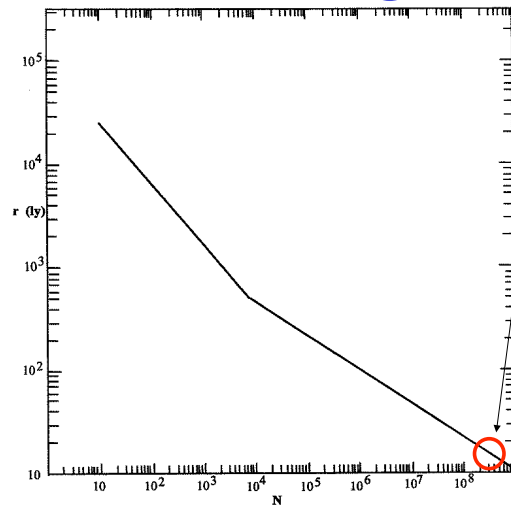
That's 500 million advanced civs!!!



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

# 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 communicate	Lifetime of advanced civilizations
	20 stars/yr	0.8 systems/star	2 x 0.11 = 0.22 planets/system	0.775 life/planet	0.505 intel./life	.7 comm./intel.	500M yrs/comm.

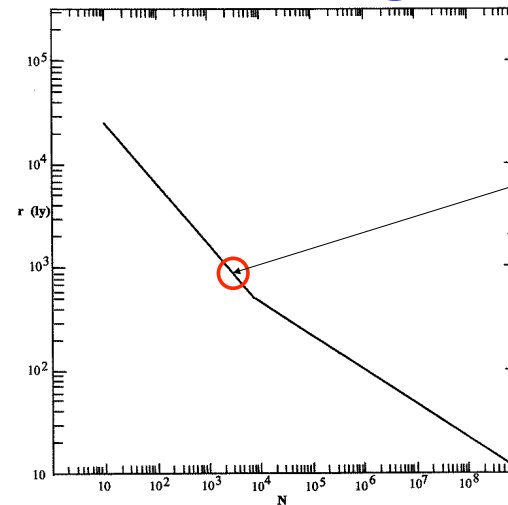
The Neighbors



We need to look at every star within ~15 lyrs for one detection!

Using N=500 million

The Neighbors



I need to look at every star within ~1000 lyrs for one detection!

Using N=2000

Interstellar Radio Messages (IRMs)



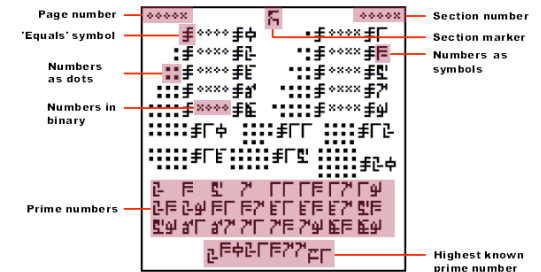
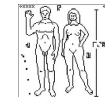
- The Morse Message (1962): Venus
- Arecibo Message (1974): M13
- Cosmic Call 1 (1999): four nearby Sun-like stars
- Teen Age Message (2001): six nearby Sun-like stars
- Cosmic Call 2 (2003): five nearby Sun-like stars
- A Message From Earth (2008): Gliese 581
- Across the Universe (2008): Polaris
- Hello From Earth (HFE, 2009): Gliese 581

http://en.wikipedia.org/wiki/Interstellar_messages

Cosmic Call



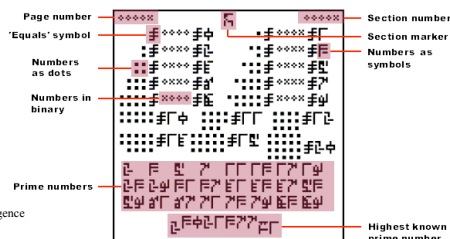
- Sent by commercial company based in Houston, Texas using the Evpatoriya Deep Space Center radio telescope in Ukraine to 5 nearby stars less than 50 lyrs.
- Drake's message had 1,679 bits of information. This has 300,000 bits, with built-in redundancy. If some bits are lost to noise en route, ET might be able to decode.
- Astronomers derived code: Dutil & Dumas
- Included names and address of 2000 donors and personal messages.



Cosmic Call



Name	Designation	HD	Constellation	Date sent	Arrival date	Message
16 Cyg A	HD 186408		Cygnus	May 24 , 1999	November 2069	Cosmic Call 1
15 Sge	HD 190406		Sagitta	June 30 , 1999	February 2057	Cosmic Call 1
	HD 178428		Sagitta	June 30 , 1999	October 2067	Cosmic Call 1
Gl 777	HD 190360		Cygnus	July 1 , 1999	April 2051	Cosmic Call 1
	Hip 4872		Cassiopeia	July 6 , 2003	April 2036	Cosmic Call 2
	HD 245409		Orion	July 6 , 2003	August 2040	Cosmic Call 2
55 Cnc	HD 75732		Cancer	July 6 , 2003	May 2044	Cosmic Call 2
	HD 10307		Andromeda	July 6 , 2003	September 2044	Cosmic Call 2
47 UMa	HD 95128		Ursa Major	July 6 , 2003	May 2049	Cosmic Call 2



http://en.wikipedia.org/wiki/Communication_with_Extraterrestrial_Intelligence

Contacting Us



- What does an advanced civilization that wants to contact us do?
- Could set-up radio beacons
 - Broadcast in all directions.
 - Broadcast at several frequencies.
 - Would require enormous energy sources.
- Would be much better if they could use directional messages.
- Existing transmitters on Arecibo are strong enough to communicate across the galaxy with similar telescopes, but with a very small beam.
- The problem is where to look or to transmit.

Does ET Love Lucy?



- One solution is to look for unintentional leakage signals.
- Leakage, as it “leaks” from the planet’s ionosphere.
- We can not currently detect this, but maybe other civilizations can.
- This is the scenario explored in the novel *Contact* by Carl Sagan and the movie based on the novel.
- What leakage do we have? TV, FM Radio, radar
- Television transmission exceeds 10^7 watts (10 MW).



<http://www.time.com/time/time100/scientist/profile/farnsworth.html>

Contact



“If humans were the only life in the Universe it would be a terrible waste of space.”

Vega (25lyr) calls us back, but how can we be sure that we’re listening?

Our leakage radiation is actually decreasing with cable, fiber optics, direct satellite, etc. Civilizations may not spend much time in that phase.

<http://www.youtube.com/watch?v=SRoj3jK37Vc>



Does ET Love Lucy?



- ET would be unable to really distinguish individual stations due to the rotation of the Earth.
- To detect early carrier signals at 50 lyrs, need 3000 acres of antenna.
- To watch the TV show, need antenna the size of Colorado. It is possible?



http://www.space.com/searchforlife/seti_shostak_alien_031023.html

Does ET Love Lucy?



- Still Earth would produce a regular 24 hour pattern for the last 60 years.
- Military radar is more promising. Highly focused and powerful.
- Only requires a 1000 foot antenna.



http://www.space.com/searchforlife/seti_shostak_alien_031023.html

Does ET Love Lucy?



- We've had leakage signals for ~60 years.
- As radio travels at speed of light, our leakage signals have reached the nearest 20,000 stars!
- Still, this is way too few for most estimates.
- It is unlikely that a civilization is within 60 lyrs. $\rightarrow N_{\text{required}} = 10^7$
- So probably ET does not love Lucy, at least yet.



Problems...Problems



- Assume that an advanced civilization is broadcasting either in all directions or toward us.
- Where and when do we listen?
- Which frequency?
- Which channel?
- Which polarization?
- What is the code?



Problems...Problems



- The problem is worse than searching for a needle in a haystack.
- We have to assume that they are constantly broadcasting, or the problem is impossible.
- Have to make the needle bigger!

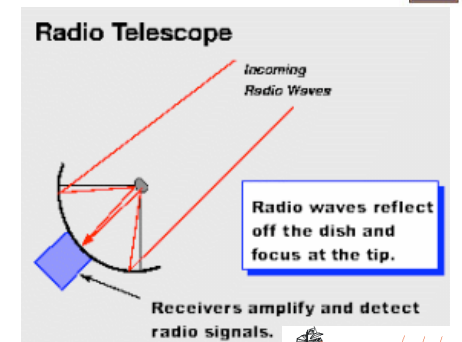


http://nl.ijs.si/et/talks/essli02/metadata_files/Haystack-FINALb.jpg

Sky Dishes

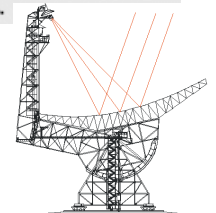


- Radio telescopes are similar to optical telescopes, just different wavelength.
- Most radio telescopes are Parabolic Cassegrains.
- Radio telescopes measure the source intensity.
- The bigger the dish, the more sensitive.
- So a big dish is best, right?



<http://www.nrao.edu/whatsra/radiotel.shtml>

Unblocked Aperture



Haystack: Sensitivity



- Sensitivity of a radio telescope:
- We have to detect a weak signal in the presence of noise.
- So, ideally look in a fixed direction for a long time— better sensitivity to weak signals.
- But it may be the wrong direction.
- And a big dish is best, right?

Channel size

time

$$S \propto D^2 \sqrt{\Delta \nu \times t}$$

Dish diameter

Question



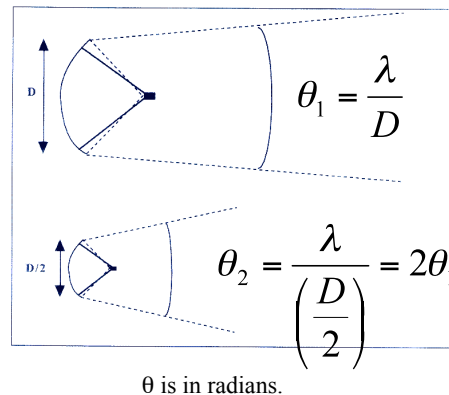
What makes a telescope more sensitive?

- Double the size
- Double the channel width
- Double the observing time
- Double the voltage
- Double the trouble

Haystack: Direction



- We can not *a priori* know which direction to look, so we must look in many directions.
- Tradeoff: The most sensitive radio telescope has the largest diameter but the smallest field of view.
- Beam size decreases as the diameter increases.
- The number of times you have to point to cover a certain area of the sky increases as diameter squared.



Dish Decision



- If ET signals are a few strong signals, we can use a small telescope and listen for a short time in any direction. The small diameter dish covers more area.
- If ET signals are many weak signals, we can use a bigger telescope and observe in a single direction for a long time. A weak signal requires a **big** dish.



<http://www.noao.edu/staff/mighell/sacpeak/jpina/VLA%20in%20dish%204.jpg>

Question



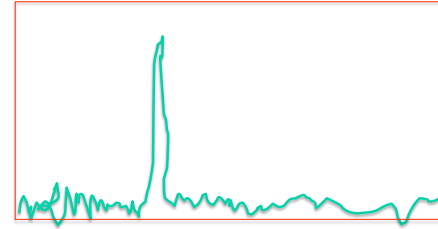
In any SETI experiment, it is best

- a) To use the biggest radio telescope available.
- b) To use a big radio telescope and sit on one star for a long time.
- c) To use a combination of small and large telescopes.
- d) To look for UFOs directly.

Haystack: Frequency



- Would the signal be concentrated in a small range of freqs?
- What size should a channel be?

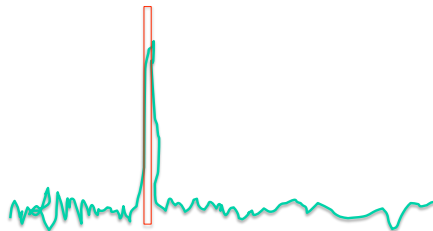


Large channel, averaging mostly noise, so signal is weaker

Haystack: Frequency



- Would the signal be concentrated in a small range of freqs?
- What size should a channel be?

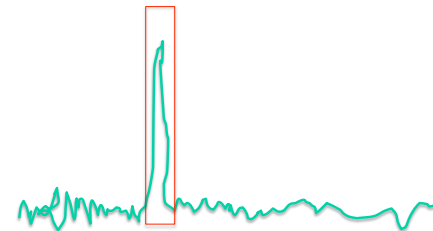


Too small, you only detect a portion of the signal– less signal to noise

Haystack: Frequency



- Would the signal be concentrated in a small range of freqs?
- What size should a channel be?



Perfectly matched channel, best signal to noise, best detection.

Haystack: Frequency



- Maybe best choice is around 1 Hz?
- Then in the 1-10 GHz band there are 9×10^9 channels!
- With modern electronics we can survey large numbers of channels, but not that many.
- What's the history of SETI?

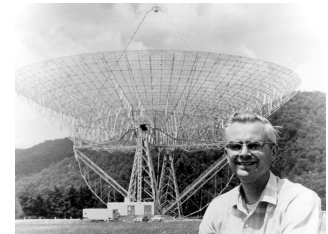
Project Ozma



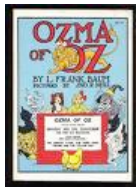
- The first look for ET radio signals by Frank Drake in 1960.
- Used a 26 meter telescope in W.V. using the H atom frequency band of 1.42 GHz.
- Targeted search of 2 nearby stars (11 lyrs) that are the same age as our Sun
- 200 hours over 3 months.
- A single 100 Hz channel scanned 400 kHz.
- 1 false alarm due to a secret military experiment.
- Nothing else detected



<http://www.angelfire.com/pa/maryanne/images/ozma.jpg>



<http://216.120.234.103/setiprime/setiprime/images/images-2003.html>



Ozma II



- Ben Zuckerman and Pat Palmer used the 91m telescope in W.V. to survey the 670 nearest “suitable” stars.
- Targeted Search of stars with low mass and binaries that allowed stable planet orbits.
- Also observed at 1.42 GHz with 192 channels of 4 kHz and 192 channels of 52 kHz.
- Could have detected a 40 MW transmitter on a 100m telescope.
- Observed for 500 hours.
- No detection at a sensitivity 10 times better than Ozma

Ohio State Survey



- In 1973 by F. Dixon and D. Cole.
- Used Ohio State radio telescope for a continuous survey of sky.
- Not steerable— sort of like Arecibo, so cuts a swath through the sky: A Sky Survey
- Searched overhead for signals.



<http://www.bigear.org>

Ohio State



- 1.42 GHz with 50 channels of 10 kHz.
- Modest sensitivity— 100 times worse than Ozma II
- But not just looking at stars.
- Could only detect extremely strong transmissions.
- Land was sold to a golf course development.

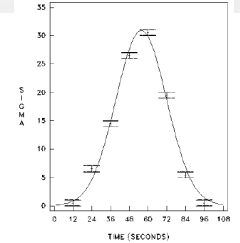
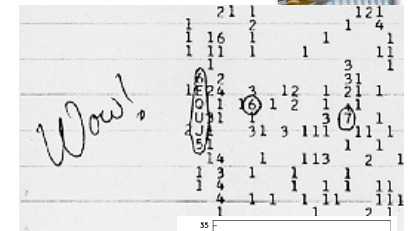


<http://www.bigear.org>

The Wow Signal



- Aug. 15, 1977, Jerry Ehman was looking through the data when he recorded the Wow! signal.
- A major signal in the telescope— 30σ detection!
- Stayed around for >72 seconds.
- Unlikely to be noise, but never seen again.
- "Even if it were intelligent beings sending a signal, they'd do it far more than once."



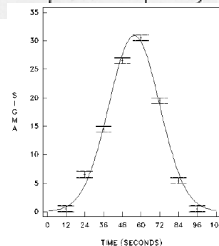
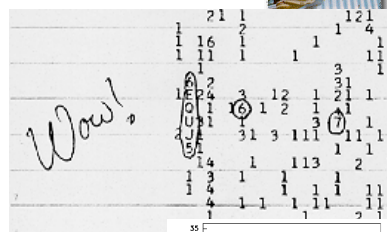
<http://www.bigear.org/wow.htm>
Gray & Marvel 2001, ApJ 546, 1171



The Wow Signal: Facts



- Narrowband signal: < 10 kHz wide (one channel only)
- Signal observed in only one (of two) horns (Separated by 3 mins on the sky)
- Signal observed only once ("Big Ear" or other observatories)



<http://www.bigear.org/wow.htm>
Gray & Marvel 2001, ApJ 546, 1171

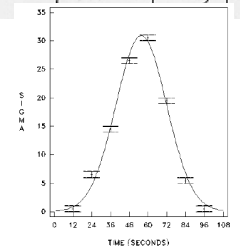
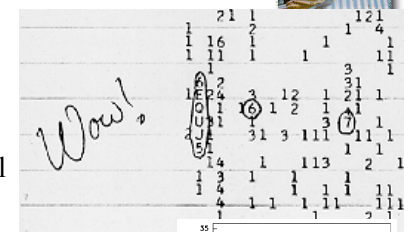
<http://www.bigear.org/Wow30th/wow30th.htm#otheranal>



The Wow Signal: Facts



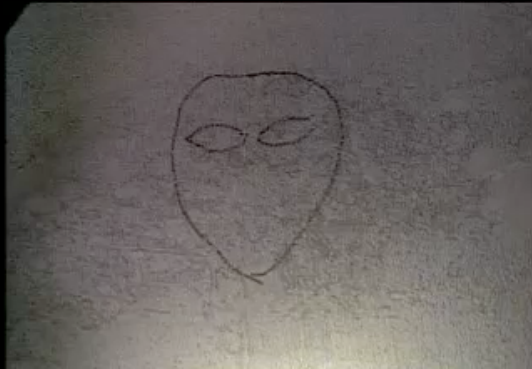
- Within each 10-second observing interval, the average signal strength remained constant.
- For the entire observing interval of 6 data points lasting 72 seconds, the average signal strength remained constant (because the 6 data values follow the antenna pattern to better than a 99% accuracy).
- Modulation (signal strength variation) on a time scale less than 10 seconds could not be measured.



<http://www.bigear.org/wow.htm>
Gray & Marvel 2001, ApJ 546, 1171

<http://www.bigear.org/Wow30th/wow30th.htm#otheranal>

Wow!



Paul Horowitz Searches 1.42 GHz



- Paul Horowitz moved from a small number of channels to many many many channels.
- 1983 Sentinel: 128,000 channels covering 6 kHz each
- 1985 META: 8 million channels with 400 kHz bandwidth.
- 1993: Horowitz and Sagan reported 8 unexplained signals that did not repeat.
- 1995 BETA: Nearly a billion channels (2.5×10^8) covering 2 GHz, 10 kHz channels. Windstorm blew the telescope over in late 1990s.
- Overall, Paul has found 37 signals that did not repeat, and did not have any other known source.

The NASA Search



The most ambitious search was planned by NASA on the 500th anniversary of the *Discovery* of America— Oct 12, 1992.



Christopher Columbus
(1451 – 1506)



<http://www.teslasociety.com/exposition2.jpg>
<http://www.sailtexas.com/columbusships.html>

The NASA Plan



- 2 prong approach using both Targeted Search and Sky Survey
- Sky Survey:
 - NASA's 34 m tracking telescopes in CA and Australia.
 - 6 year plan covering 1-40 GHz with 16 million channels of 20 Hz each and 30 different settings.
 - Would only detect very strong signals.
- Targeted Search:
 - Cover 800 suitable stars within 75 lyrs.
 - 16 million channels with 1 Hz bandwidth
 - 1-3 GHz range and very good sensitivity!



The NASA Search



- “In 1993, Nevada Senator Richard Bryan successfully introduced an amendment that eliminated all funding for the NASA SETI program.
- The cost of the program was less than 0.1% of NASA's annual budget, amounting to about a nickel per taxpayer per year. The Senator cited budget pressures as his reason for ending NASA's involvement with SETI.”



The NASA Search



- “The Great Martian Chase may finally come to an end. As of today millions have been spent and we have yet to bag a single little green fellow. Not a single Martian has said take me to your leader, and not a single flying saucer has applied for FAA approval.”



<http://www.planetary.org/html/UPDATES/seti/history/History12.htm>
http://www.seti.org/about_us/faq.html



<http://www.planetary.org/html/UPDATES/seti/history/History12.htm>
http://www.seti.org/about_us/faq.html

The SETI Institute



- An independent institute that was working with NASA on their SETI project.
- Once NASA cut funding, they went ahead with a more modest version of the Targeted Search—Project Phoenix.
- Now funded by private donors.
- Initially a search of 200 stars within 150 ly younger than 3×10^9 yrs using an Australian 63 m telescope for 5 minutes on each target.
- Scanned 28 million channels each 1 Hz wide, used multiple settings to scan 1.2 to 13.0 GHz

http://www.seti.org/seti/our_projects/project_phoenix/overview/overview.html

Project Phoenix



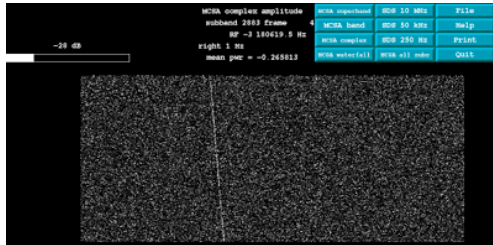
- Just finished up in 2004.
(<http://www.seti.org/seti/projects/project-phoenix/faq.php>).
- About 2-3 weeks a year of telescope time to scan a total of 800 stars (out to 240 lyrs) for a total of 11,000 hours.
- Best survey to date, but no ET signals.



Project Phoenix



- Proof of concept was shown by tracking the Pioneer 10 spacecraft (launched in 1973) that is 6 billion miles away and broadcasting with a few Watts of power.
- The signal was detected.
- As the Earth and object are moving, there is a small Doppler shift in the frequency of the light received over time.



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 m²) & ATA (10,200 m²) 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

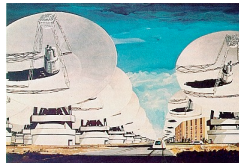
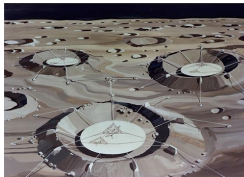
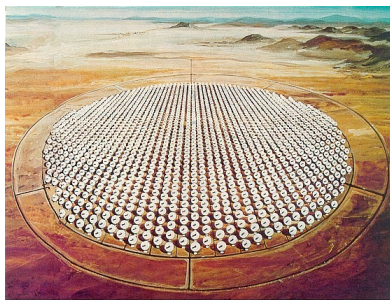


- The modern SETI searches are really expanding the frequency range in which we search, but we are still sensitivity limited.
- In any SETI experiment, what does a null result mean?

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



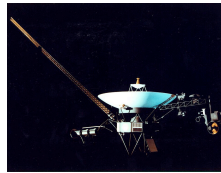
- But, what if all communication with ET fails?
 - Wrong frequencies.
 - Everyone is listening and no one is broadcasting.
 - We fail to recognize the signal.
- We can go visit them or the microbes. “To boldly go...”
- Human colonization of the Galaxy has to start somewhere. Our own backyard!



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**



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:

- 95.3% carbon dioxide
- 2.7% nitrogen
- 1.6% argon
- 0.2% oxygen

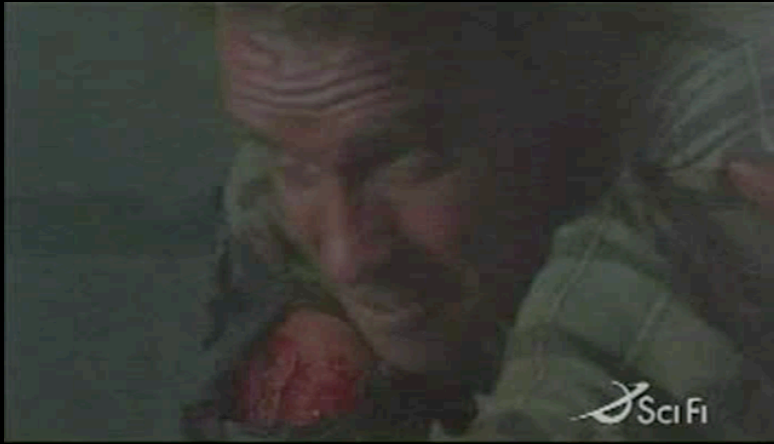
Earth:

- 78.1% nitrogen
- 20.9% oxygen
- 0.1% carbon dioxide + trace

- Why terraform?
 - In $1-2 \times 10^9$ 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.



Terraforming Mars: By Aliens?

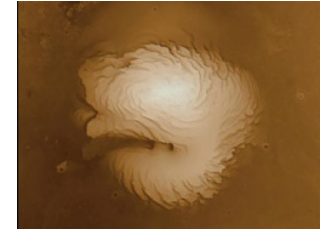


- Sometime movies are full of errors.
- But what can you do?

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.

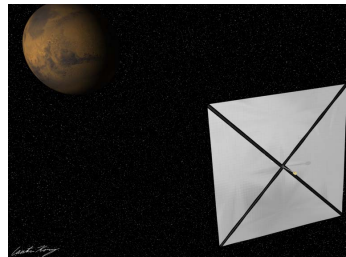


<http://www.ucl.ac.uk/GeolSci/MITC/marsinfo/icecap.jpg>

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!

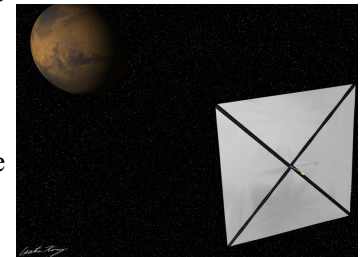


<http://www.futurespace.de/gallery/pictures/sail-mars1.jpg>

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.

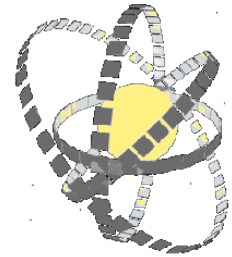


<http://static.howstuffworks.com/gif/space-station-space-settlement.gif>

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.

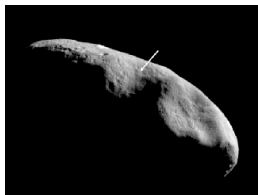


http://www.homoexcelsior.com/omega.db/datum/megascale_engineering/dyson_sphere/ 237

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 laying on the Moon, it would not be cost effective to go get it.

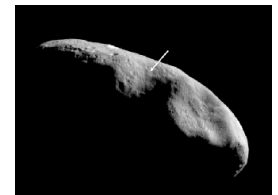


http://apollo-society.org/images/near_arrow_sm.jpg

Asteroid Living and...



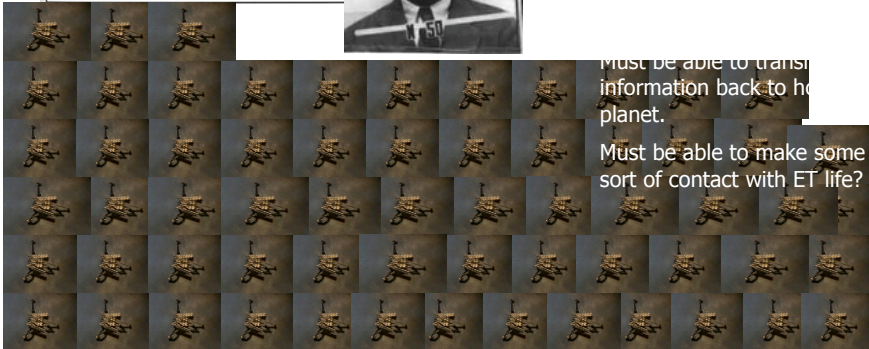
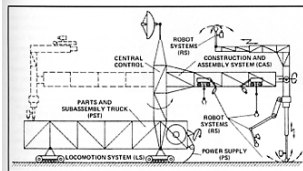
- But, remember to date human space travel has cost 10 times as much as remote “robot” travel.
- Probably devise ways to mine remotely.
- Efficient mining requires more and more intelligent robots.
- What if they get too smart?
- Still self-replicating space probes could be result of such advances.



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

What?

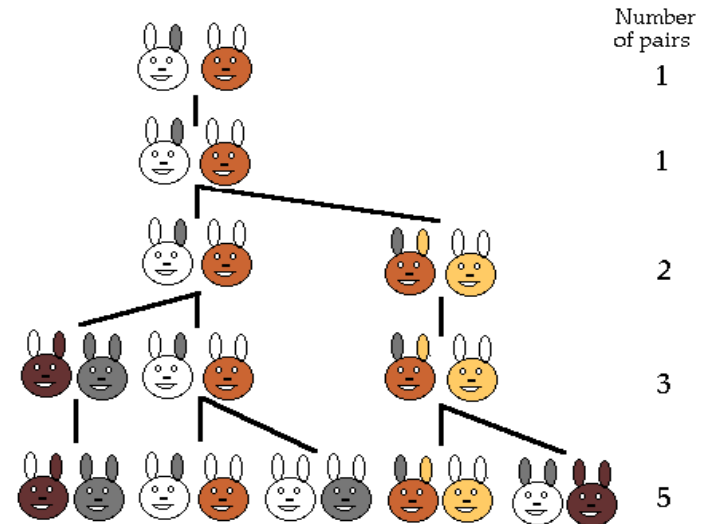
"it is in principle possible to set up a machine shop which can make a copy of any machine, given enough time and raw materials." Von Neumann



Must be able to transmit information back to home planet.

Must be able to make some sort of contact with ET life?

Propagation Run Away



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.



Neumann 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>



BERSERKERS!!!!!!



- Self-Replicating Devices
- Openly hostile to life forms
- Out of control
- Probe ecosystem?
- Programmed to evolve?

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?



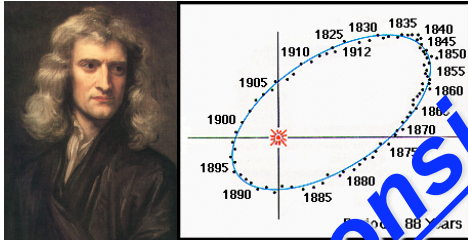
- The speed of light is $c = 3 \times 10^8$ m/s (186,000 miles per second)!
- How fast is that?
 - Around the Earth over 7 times in a second
 - From Earth to the Moon in under 2 seconds (it took the astronauts 2 weeks)
 - From the Sun to the Earth in a little over 8 minutes
 - From the Sun to Pluto in 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)



All motion is relative
No speed is special

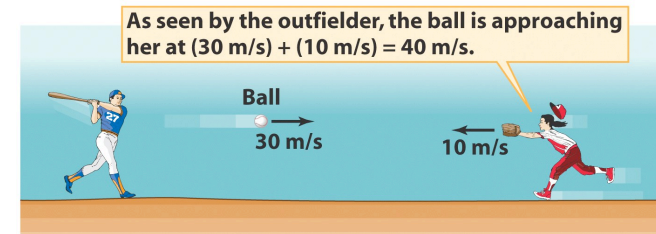
Electromagnetism (Maxwell's Equations)



The speed of light is the
same for all observers

Inconsistent

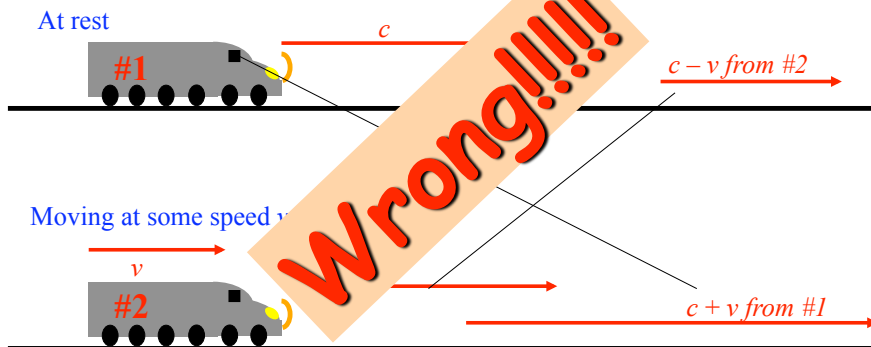
Why Newton and Maxwell Can't Both Be Right



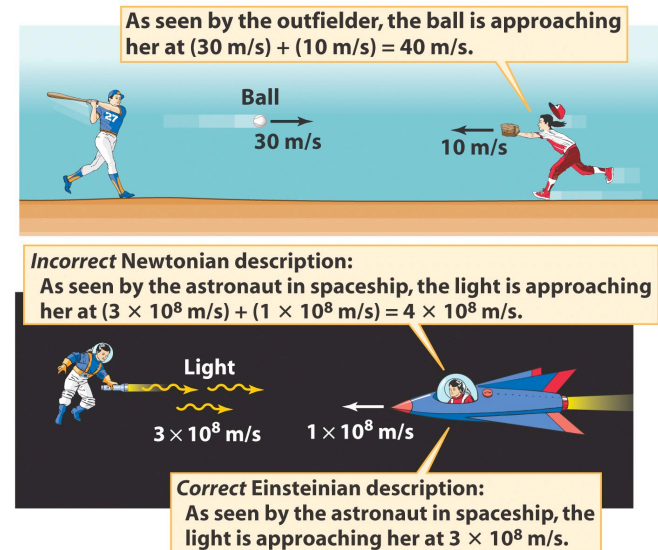
Why Newton and Maxwell Can't Both Be Right



Consider two locomotives emitting light from their headlamps:



Why Newton and Maxwell Can't Both Be Right



Why Newton and Maxwell Can't Both Be Right



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

Something must happen. And what must happen for Newton 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”



- Time dilation – Moving clocks run slow.
- Length contraction – Moving objects contract along direction of motion.
- Mass increase – moving clocks get more massive



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

Question



You are at the back of a jet traveling at 400 mph. You shine a laser toward your friend in first class. What speed does your friend measure for the laser light?

- a) $c+400$ mph
- b) $c-400$ mph
- c) c
- d) $c/400$ mph
- e) $c/(c^2-400^2)$ mph

Where c is the speed of light.

Approaching the “c”: Impact



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

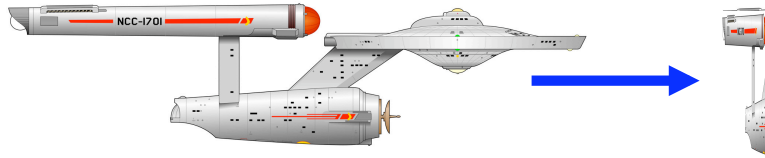


<http://www.richard-seaman.com/Travel/Japan/Hiroshima/AtomicBombMuseum/IndividualArtifacts/>

Counterintuitive Result #1



Moving objects appear shorter in the direction of relative motion



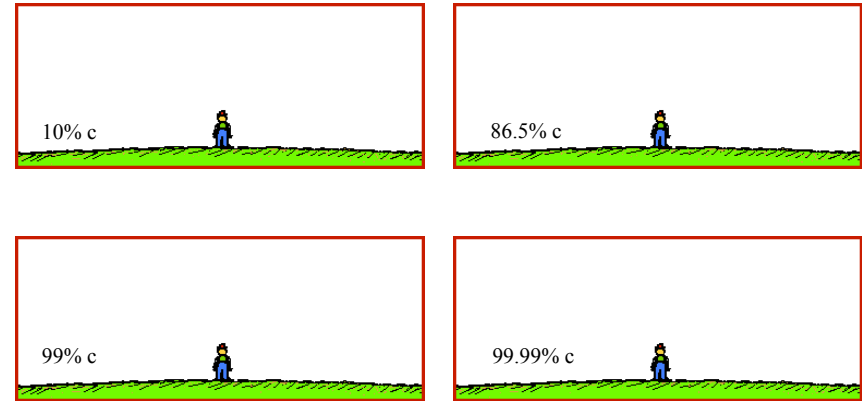
Fraction of the speed of light	% of original length
0.00	100%
0.001	99.99995%
0.01	99.995%
0.1	99.5%
0.5	86.6%
0.9	43.6%
0.99	14.1%



Counterintuitive Result #1



Moving objects are shorter in the direction of relative motion

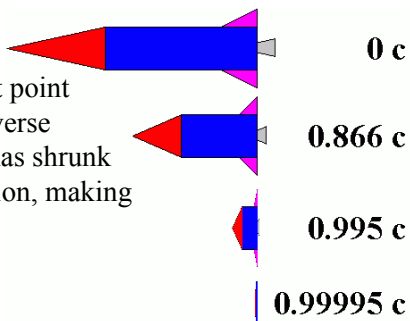


<http://www.physicsclassroom.com/mmedia/specrel/lc.html>

Length Contraction



- This effect has some benefits:
 - Outside observers will measure 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.



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

- Exactly 100 feet long.
- Less than a 100 feet long.
- More than a 100 feet long.

Question



Your best friend is going on a near light speed trip. When at rest she measures her spaceship to be 100 feet long. Now, she's in flight and you're on the Earth, and she measures her spacecraft to be

- 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.