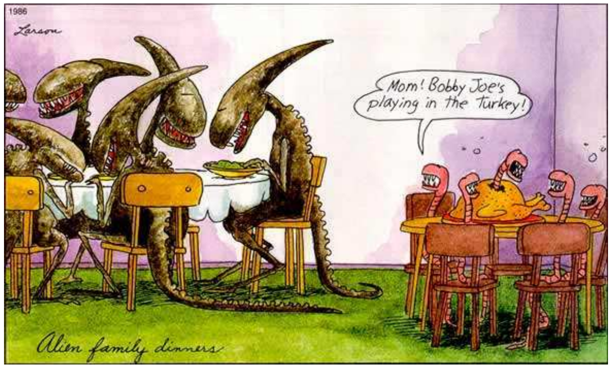
# Astronomy 230




This class (Lecture 25):
Lifetime

Next Class:
Communication

Music: What's the Frequency, Kenneth? – R.E.M.



# Final Papers

- You must turn it in with the graded rough draft.
- It must be turned in this week, if you want the grade posted (probably) before the final exam.
- Last possible acceptable date it Dec $7^{th}$.



# Outline

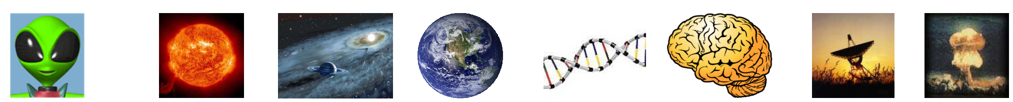
- What factors determine the lifetime of a civilization?
  - Resource Exhaustion
  - Population growth
  - Nuclear war
  - Natural catastrophe
- Arguably, the most uncertain factor in the Drake Equation.



# Drake Equation

**That's 2.1 communicating life/century**

Frank Drake

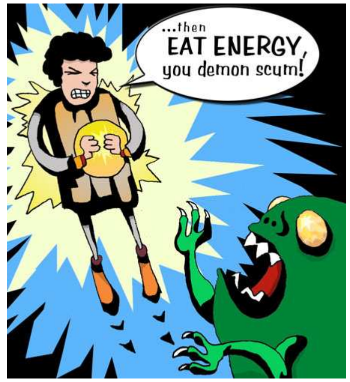


$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

| $N$ | $R_*$ | $f_p$ | $n_e$ | $f_l$ | $f_i$ | $f_c$ | $L$ |
|---|---|---|---|---|---|---|---|
| # of advanced civilizations we can contact in our Galaxy today | Star formation rate | Fraction of stars with planets | # of Earthlike planets per system | Fraction on which life arises | Fraction that evolve intelligence | Fraction that commun-icate | Lifetime of advanced civilizations |
| | 15 stars/ yr | 0.5 systems/ star | 2.7 x 0.134 = 0.36 planets/ system | 0.095 life/ planet | 0.1 intel./ life | 0.8 comm./ intel. | yrs/ comm. |

# 1. Depletion of Resources

- Modern life depends on metals and rare elements.
- Recycling can delay the depletion.
- Pollution of our water or air supply is still a problem.
- <u>But</u>, many of these issues can be solved with sufficient ***energy***.




http://www.timboucher.com/portfolio/eat-energy.jpg



# 2. Population Growth

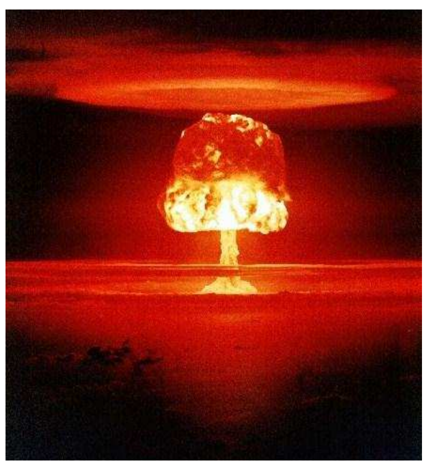
- Currently world population is around 6.6 billion ($6.6 \times 10^9$).
- Population roughly doubles every 50 years–
  - 2050: 10 billion
  - 2100: 20 billion
  - 2150: 40 billion
  - 3000: $2.6 \times 10^5$ times present population = $\boldsymbol{1.3 \times 10^{15}}$
- In the year 3000, each person will have 4 square feet (2' by 2') of space (including the oceans!).
- A final absurdity, in 2550 years (the year 4554), the weight of humans would outweigh the Earth.
- Obviously something will have to be done!

http://w3.whosea.org/aboutsearo/88-97-7.htm



# 3. Nuclear War


- May be the only human activity that can catastrophically end our technological civilization.
- Effect may be seen days or years afterwards.
- Makes lots of radioactive elements with various half-lifes.
- Most destructive global nuclear war could cause a nuclear winter.

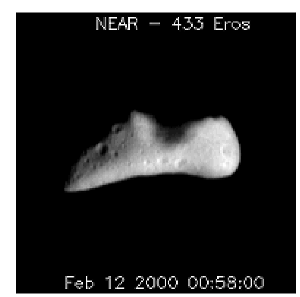


http://www.dalitstan.org/journal/recthist/nuclear/nuclear.html
http://cosmo.pasadena.ca.us/adventures/atomic/cold-war.html



# 4. Natural Catastrophes

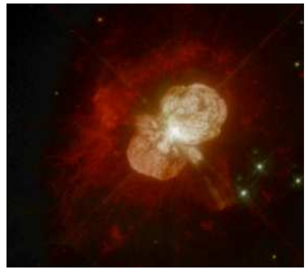
1. Volcanoes
2. Comets or asteroids
3. Stellar evolution (Sun becomes Red Giant)




http://www.vulkaner.no/v/volcan/indo/krakatau.html
http://charm.hendrix.edu/astro/krakatoa.jpg

# 4. Natural Catastrophes

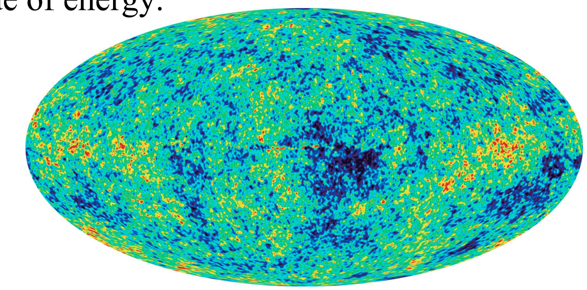
4. Killer Supernovae!
   - Death of a nearby massive star would be bad news.
   - Explosion within 30 ly would destroy ozone layer.
   - Right now, no candidates.
   - Unlikely to happen in time scales of less than 2 billion years.
   - A supernova event ~2 Myrs ago may account for a mass extinction event.





# 4. Natural Catastrophes

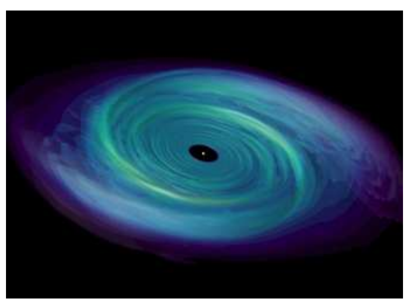
5. Ultimate limit to L!
   - Fate of the Universe.
   - A Big Crunch: $10^{12}$ years (a trillion years)
   - But, WMAP results from the cosmic microwave background suggest that we are in a flat universe.
   - Then it is an issue of energy.





# 4. Natural Catastrophes

5. Ultimate limit to L!
   - Eventually all of the stars will burn out ($10^{12}$ years).
   - Only energy source left is orbital energy.
     - Possibly extracting energy from rotating Black Holes.
   - Eventually, black holes evaporate ($10^{100}$ yrs). Remember the Universe is 13.7 x $10^{9}$ or around $10^{10}$ years!
   - But half of all protons might decay by $10^{33}$ yrs.
   - Bottom line is that the maximum age is speculative.



http://homepages.wmich.edu/~korista/web-images/accretion_ncstate.jpg



# What is L?

- How long on **average** can an advanced civilization exist?
- Again, we only have a sample of 1 from which to discuss. What is our civilization's lifetime?
  - Short Term (100-1000 yrs)
    - Give up on communication due to budgets.
    - Depletion of resources.
    - Population.
    - War.
  - Long Term ($10^{5}$ to 5 x $10^{9}$ yrs– age of galaxy is $10^{10}$ yrs and we took half of that to evolve)
    - Stellar Evolution.
  - Don't forget the random volcano, asteroid, or supernova.
  - Still in many cases an advanced civilization may be prepared for many of the issues!

## Drake Equation For Optimist

= 2.5 x $10^{11}$

Communicating Civilizations

62.5% of all stars in our Galaxy.

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

| N | $R_*$ | $f_p$ | $n_e$ | $f_l$ | $f_i$ | $f_c$ | L |
|---|---|---|---|---|---|---|---|
| # of advanced civilizations we can contact | Rate of formation of Sun-like stars | 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 |
| | **50** | **1** | **1** | **1** | **1** | **1** | **5 x $10^9$** |

Birthrate of 50/year!



## Drake Equation For Pessimist

= 7.5 x $10^{-6}$

Communicating Civilizations

Must wait $10^7$ years for one!

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

| N | $R_*$ | $f_p$ | $n_e$ | $f_l$ | $f_i$ | $f_c$ | L |
|---|---|---|---|---|---|---|---|
| # of advanced civilizations we can contact | Rate of formation of Sun-like stars | 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 |
| | **5** | **0.1** | **0.15** | **0.01** | **0.01** | **0.01** | **100** |

Birthrate of 7.5 x $10^{-8}$ /year!



## Drake Equation For Average

= 9.3 x $10^5$

Communicating Civilizations

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

| N | $R_*$ | $f_p$ | $n_e$ | $f_l$ | $f_i$ | $f_c$ | L |
|---|---|---|---|---|---|---|---|
| # of advanced civilizations we can contact | Rate of formation of Sun-like stars | 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 |
| | **10** | **0.5** | **0.89** | **0.5** | **0.7** | **0.6** | **1x$10^6$** |

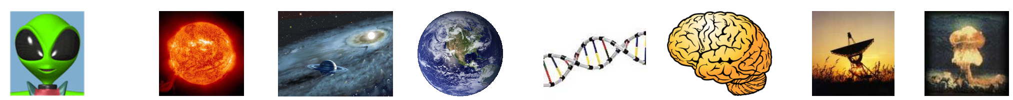
Birthrate of 0.93 /year!



## Drake Equation

Frank Drake

**That's 2.1 communicating life/century**



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

| N | $R_*$ | $f_p$ | $n_e$ | $f_l$ | $f_i$ | $f_c$ | L |
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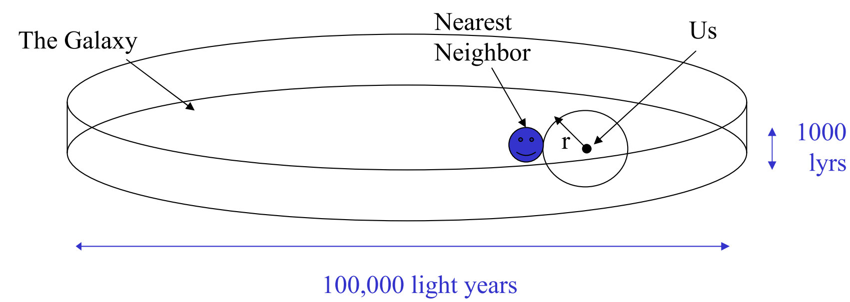
# Hmm..

- None of these results are wrong.
- The average results of around 1/year would suggest that any life that is contacted is presumable older and therefore more advanced.
- It is interesting to note that for our values lifetimes greater than around 80 years, gives more than 10 civilizations with which to talk.
- Our number was **?** years.



# Distance to Nearest Neighbor

- Assume that the alien civilizations are uniformly scattered in our galaxy and N > 8000.
- We can then assume spherical volume to find ET, i.e. flatness of Galaxy not an issue.

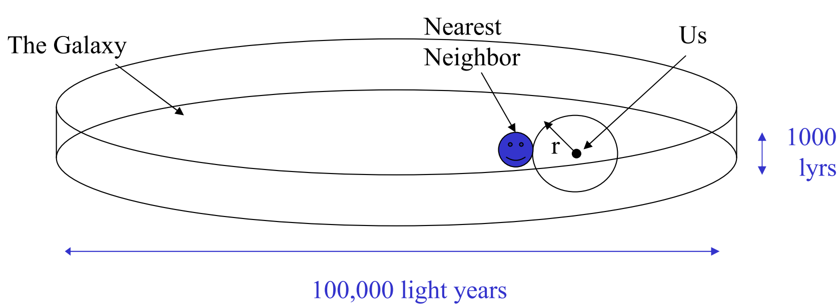





# Distance to Nearest Neighbor

- Assume N > 8000

$$\frac{Average\ \ Galactic\ Volume}{Number\ of\ Civilizations} = \frac{\pi\, r_{galaxy}^2 h_{galaxy}}{N} = \text{alien density}$$

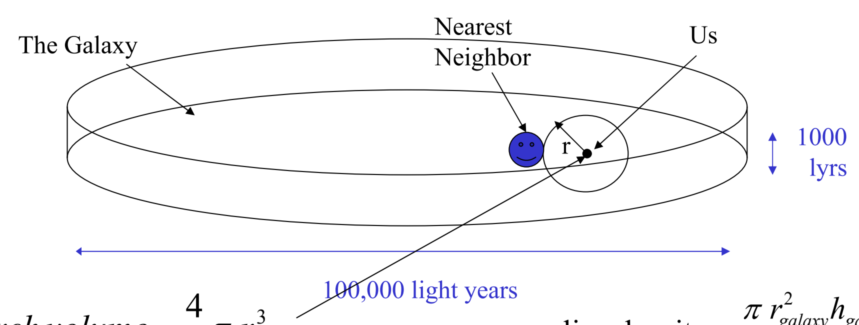





# Distance to Nearest Neighbor

- Assume N > 8000

$$alien\ density = \frac{\pi\, r_{galaxy}^2 h_{galaxy}}{N} = \frac{7.85\times 10^{12}\ \text{lyrs}^3}{\text{N}}$$



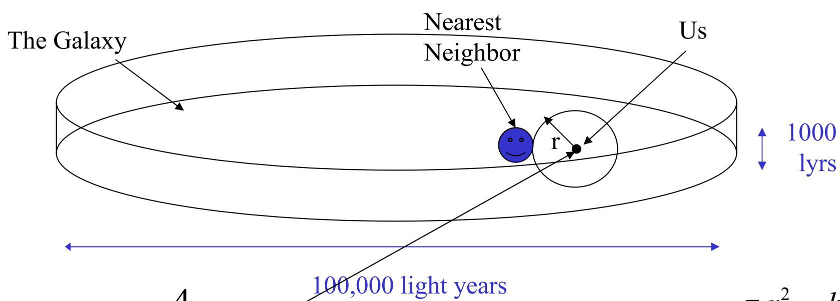

$$search\ volume = \frac{4}{3}\pi\, r^3$$

$$\text{alien density} = \frac{\pi\, r_{galaxy}^2 h_{galaxy}}{N}$$

# Distance to Nearest Neighbor

- Assume N > 8000

$$\frac{4}{3}\pi r^3 = \frac{7.85\times 10^{12}\ \text{lyrs}^3}{N}$$




$$search\ volume = \frac{4}{3}\pi\, r^3$$

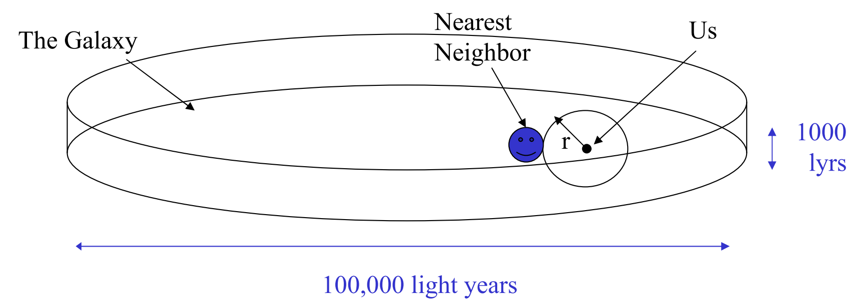
$$\text{alien density} = \frac{\pi\, r_{galaxy}^2 h_{galaxy}}{N}$$



# Distance to Nearest Neighbor

- Assume N > 8000

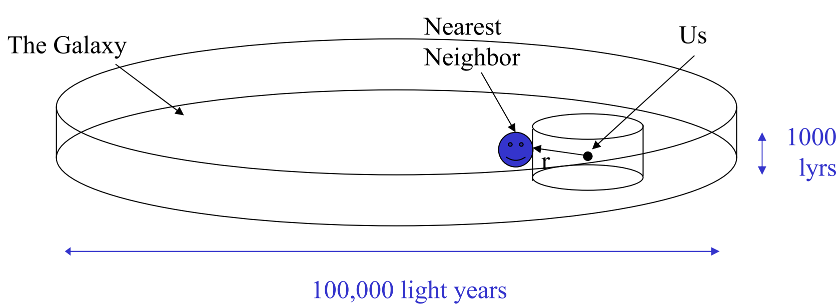
Then $$r \approx \frac{12000\ ly}{N^{\frac{1}{3}}}$$






# Distance to Nearest Neighbor

- Assume that the alien civilizations are uniformly scattered in our galaxy and N < 8000.
- Then, the flatness of Galaxy is an issue.

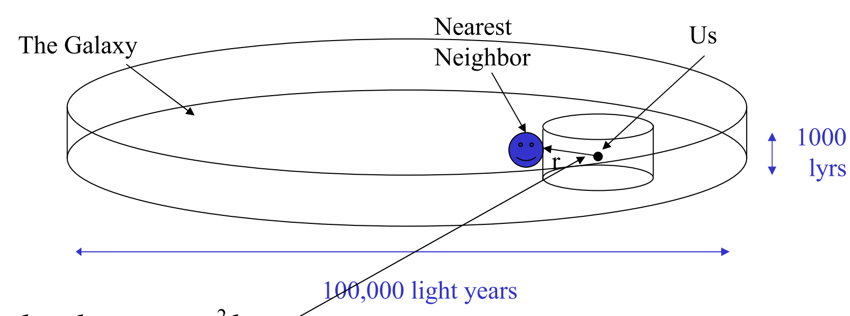





# Distance to Nearest Neighbor

- Assume N < 8000

$$\frac{Average\ \ Galactic\ Volume}{Number\ of\ Civilizations} = \frac{\pi\, r_{galaxy}^2 h_{galaxy}}{N} = \text{alien density}$$

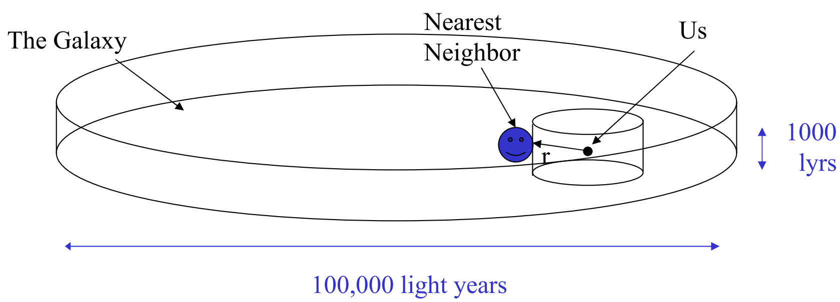



$$search\ volume = \pi\, r^2 h_{galaxy}$$

# Distance to Nearest Neighbor

- Assume N < 8000

$$\pi r^2 h_{galaxy} = \frac{7.85\times 10^{12}\ \text{lyrs}^3}{N}$$

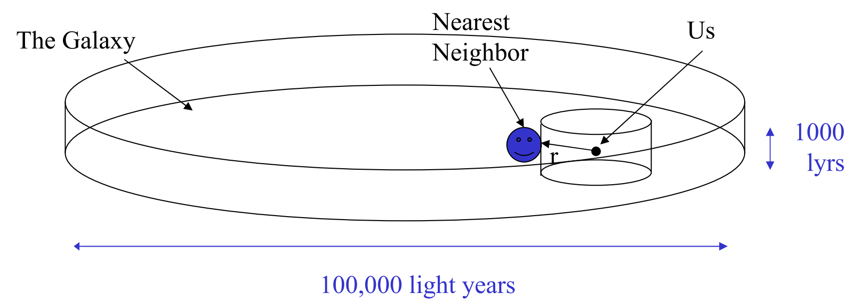





# Distance to Nearest Neighbor

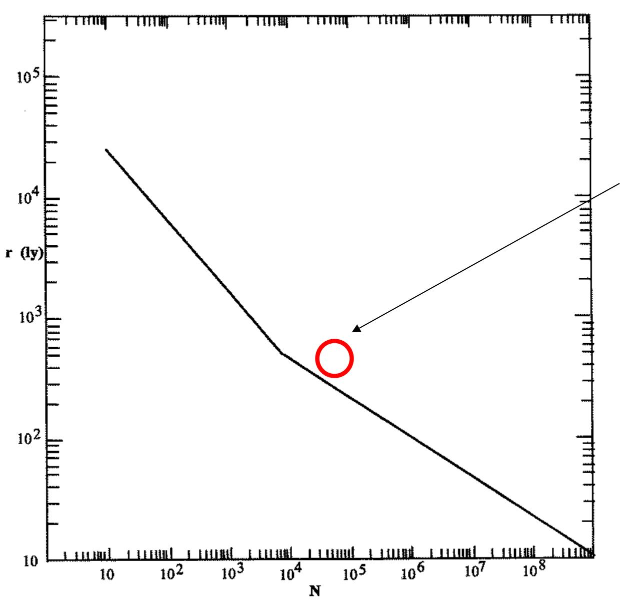
- Assume N < 8000

Then $r \approx \dfrac{50000\,ly}{N^{\frac{1}{2}}}$






# The Neighbors




We need to look at every star within ~ 350 lyrs for one detection!



# Interesting Points

1. We assumed uniform density of civilizations.
   - Underweights the galactic center, but maybe that's okay– supernovae.
2. Distance away is the average.
   - Could be closer, but unlikely to be much closer.
3. Note that r is better defined than N.
   - R depends on $N^{1/2}$ or $N^{1/3}$.
   - If we are wrong in N by a factor of 100, then only off in r by factors of 10 or 4, respectively.
4. For communication, it may be that the distance there and back is longer than L.

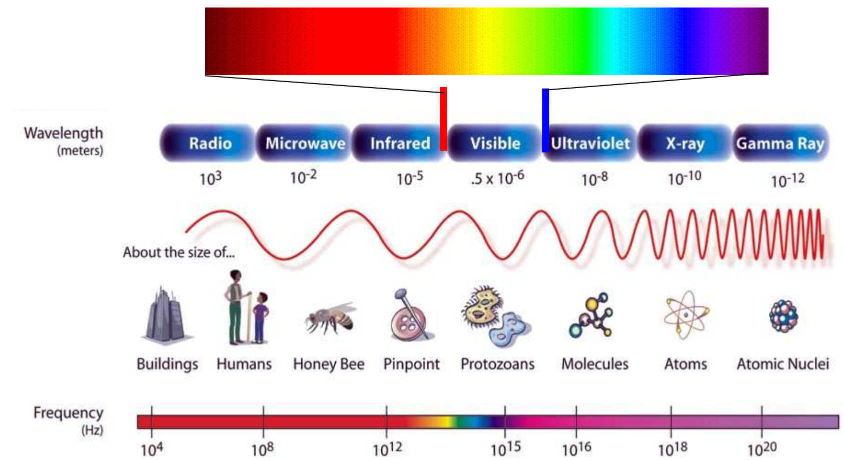
# How to Communicate?

- Okay, our estimate is optimistic.
- So, how do we go about detecting our neighbors?
- Are we seriously sending out messages now?
- No.
- We are relatively a young civilization, with radio technology for only a hundred years.
- Right now, we are mostly a passive “lurker” civilization.
- Okay, so what will an advanced civilization use?



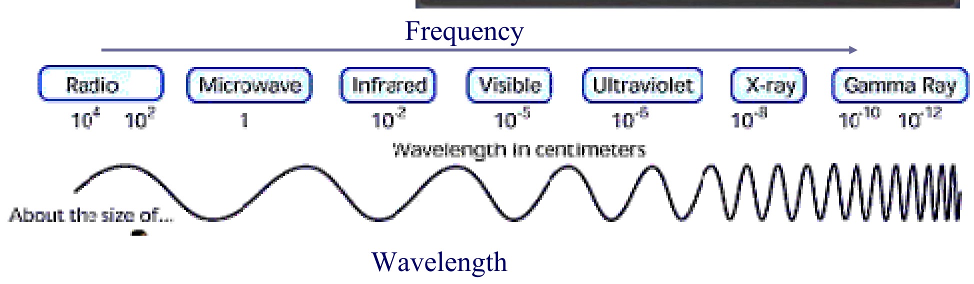
# Light me up

- Visible light is only a tiny portion of the full electromagnetic spectrum
- Red light has longer wavelength and lower frequency than blue light.
- Divisions between regions are from biology or technologies.




# Frequency

- The frequency of light depends on its color.
- The unit is Hertz, equivalent to 1 cycle a second.
- For radio waves, we normally use larger units
  - 1 kHz = 1000 Hz
  - 1 MHz = $10^6$ Hz
  - 1 GHz = $10^9$ Hz

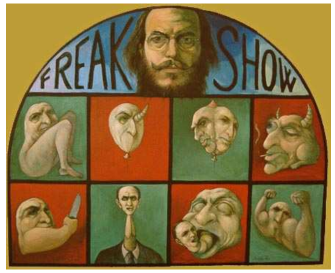

# What’s the Frequency Kenneth?

- We can’t broadcast over the whole range– too expensive.
- So what kind of reasoning can we use to limit our search or any broadcasts?
- Keep in mind that ET must make the same decisions.
- Interstellar dust attenuates light that is shorter than infrared wavelengths– a few microns.
- Energy required for the photon increases with frequency.
- Argues for low frequency or long wavelength operation– radio.

http://www.beautydish.com/

# Freq Show

- Keep in mind that radio stations fade as you get further away.
- In fact, light decrease in amplitude as the square of the distance traveled.
- And like your radio, there can be noise from competing stations or noise from the radio receivers.
- The galaxy emits lots of emission at low frequencies.




http://www.micka.cz/f8.jpg



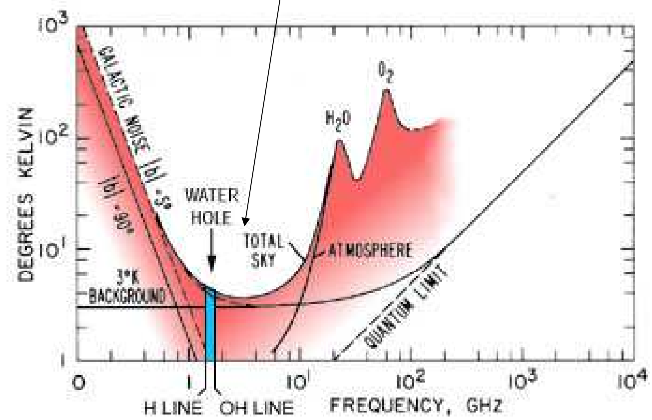
# Freq-ing Out.

The best place to listen– in the "quiet" part of the spectrum

1. The galaxy emits lots of emission at low frequencies.
2. The Big Bang background noise– CMB.
3. Noise of receivers. The perfect receiver has a quantum limit of one photon noise.
4. The Earth's atmosphere blocks many frequencies.

Wavelengths of 3 to 30 cm!

Frequencies of 1 to 10 GHz!

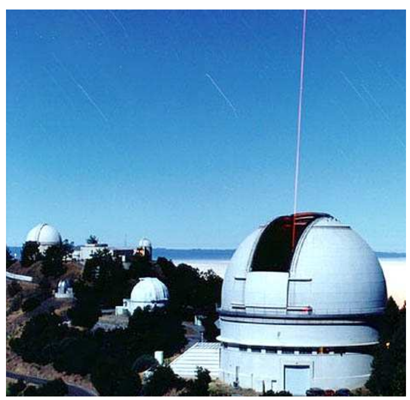



http://setiathome.ssl.berkeley.edu/about_seti/radio_search_2.html



# Or Lasers?

- Charlie Townes has pointed out that sending pulses of laser light could be competitive.
- A number of searches are now underway using visible light– optical SETI.
- The light must be distinguishable from the star.
- It is easy for planets to overwhelm their suns in radio waves, but not visible.
- Powerful lasers have a certain defined wavelength.



Laser for adaptive optics, not optical SETI.

http://www.ucsc.edu/news_events/download/images/laser-lg.jpg



# ETs with Lasers?

- Reines and Marcy in 2002 searched 577 nearby stars with sensitivity to detect >60 kW lasers focuses from a 10m telescope.
- Nothing was detected.
- Seems unlikely SETI tool as the laser is a very small beam of light, only a few stars in transmission beam, so back to radio.

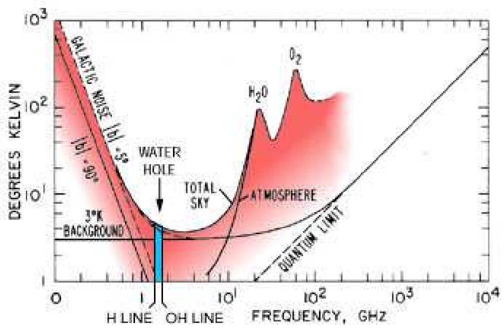
Are aliens trying to contact us with LASERs?

http://www.insomniacmania.com/news/news_771_1.jpg

# How to Communicate?

Radio is probably best.

1. Dust extinction is reduced.
2. Lower frequency means less energy/photon, so cheaper.
3. There is a natural dip from about 1 to 10 GHz in the radio where the atmosphere and the galaxy are the quietest.




http://setiathome.ssl.berkeley.edu/about_seti/radio_search_2.html



# Big Band

- Still, 1-100 GHz or even 1-10 GHz is a lot of frequency to search.
- Is there a magic frequency that advanced civilizations would choose?
- Morrison and Cocconi (1959) suggested the first magical frequency of 1420 MHz or 1.420 GHz.
- It's the frequency at which H atoms in space emit and absorb radiation.
- Not a bad choice as H is the most abundant atom in the Universe.
- But, now we have detected over 100 molecular transitions, some crucial to life, so maybe not as an important argument as it once was.


http://www.stamps.net/40band.jpg

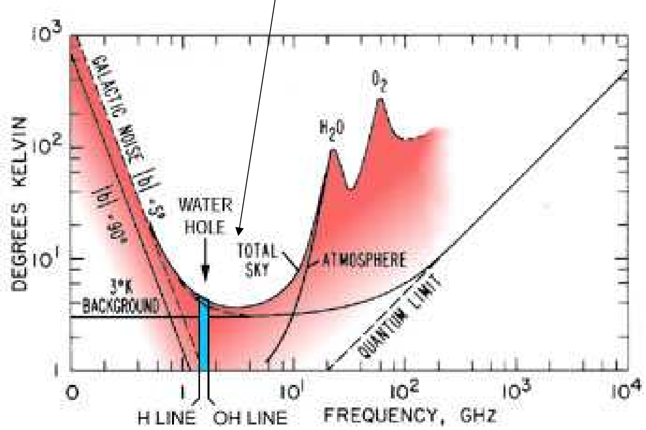


# The Water Hole?

- Carl Sagan and Frank Drake suggested that species on Earth always gathered around the water hole.
- There is a molecular fragment of OH that absorbs at 4 frequencies between 1.612 and 1.720 GHz.
- These molecules were well studied at the time, so it was biased.
- And, now we know about more exciting transitions at higher frequencies.

Wavelengths of 3 to 30 cm!

Frequencies of 1 to 10 GHz!




http://setiathome.ssl.berkeley.edu/about_seti/radio_search_2.html



# Fundamental Freqs

- What are constants that every civilization would be aware of?
- Speed of light
- Fine structure constant (1/137)
- Divide the speed of light as many time as necessary to get a frequency in the radio range.
- In that case you get 2.5568 GHz.
- First suggested by Kuiper and Morris.

$$\alpha = \frac{e^2}{\hbar c}$$

http://astronomy.swin.edu.au/sao/guest/davis/eqn_a.gif

# Magical Frequency?

- No.
- Nothing is really obvious.
- So, we're screwed.
- We have to look through a lot of radio frequencies.
- So, we better understand radio techniques a little.


http://www.funbrain.com/guess/magic.gif



# Radio

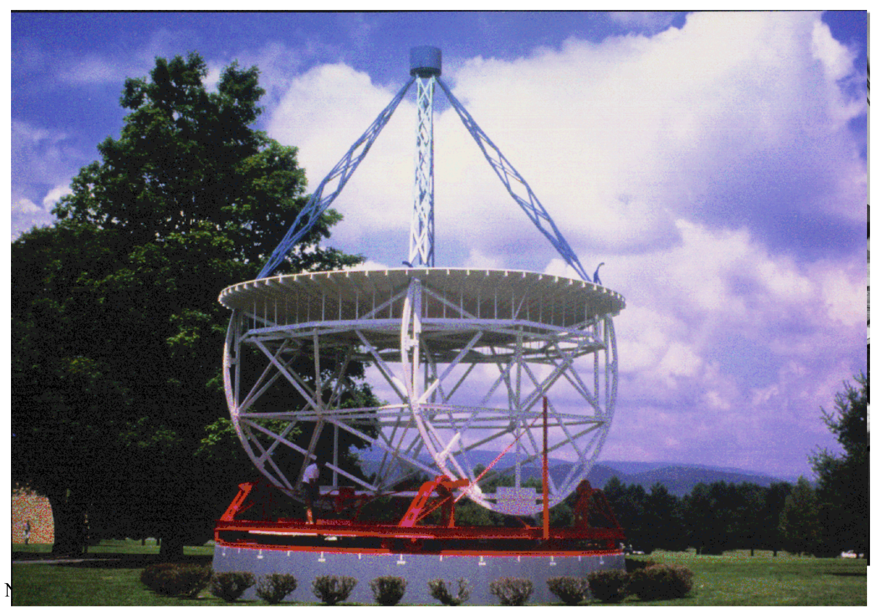
- The basic concept of radio astronomy, radio communications, television, mobile phones, etc. is the same.
- Information is transmitted by low energy light.
- How does the antenna on your car work?
- The electo-magnetic wave cause electrons to move up and down in your antenna.
- That signal is amplified and decoded.
- For frequencies in the band of interest, parabolic antennas are common used.

http://www.itsrealstuff.com/assets/images/antenna.jpg



# Radio telescopes

Pioneering work by Grote Reber in back yard, Wheaton, Illinois. (He died in 2002).

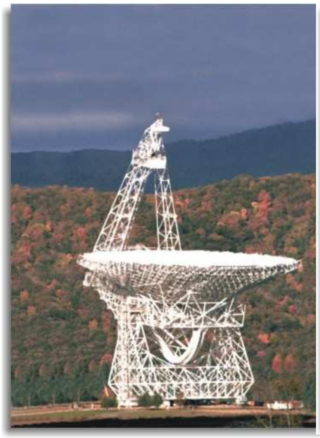


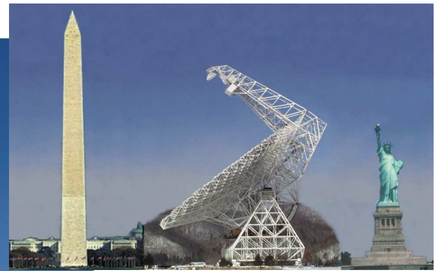
# Arecibo Observatory, Puerto Rico

Largest radio telescope– 300 meters.

# The Green Bank Telescope– W.V.

- The largest fully steerable dish in the world– 100 meters





http://www.gb.nrao.edu/epo/GBT/gbtpix.html



# Very Large Array, near Magdalena, NM