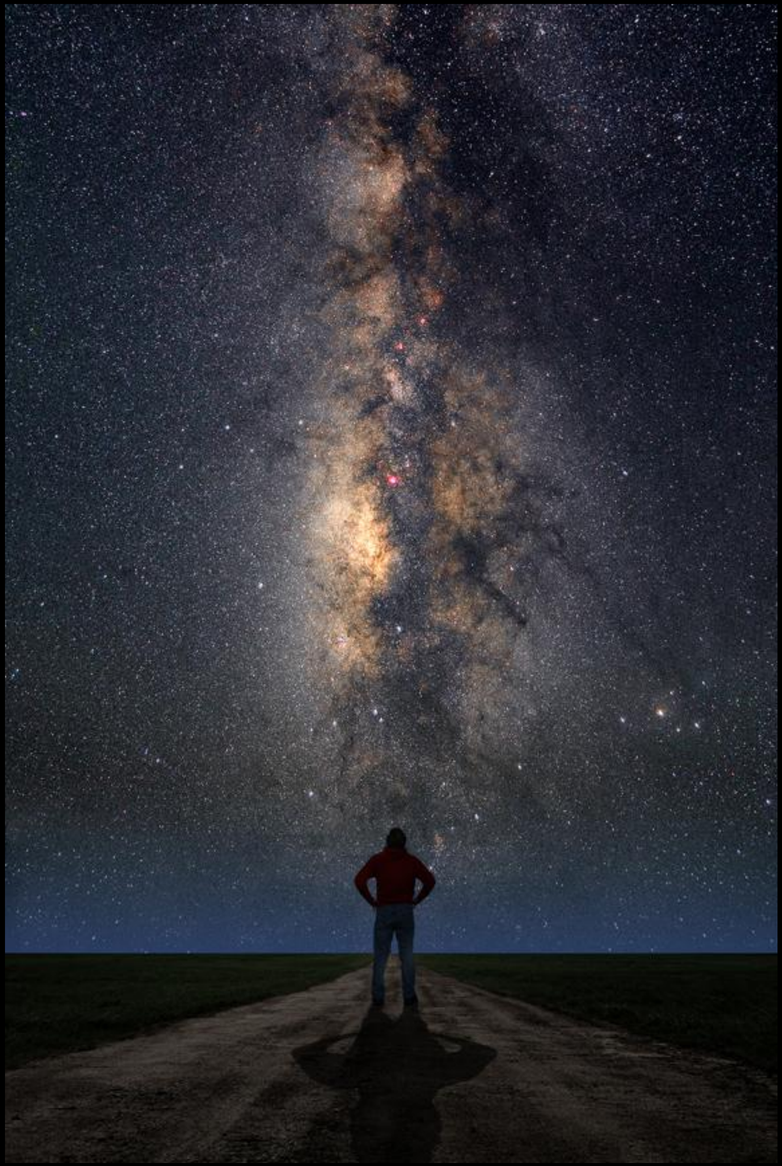
Today in Astronomy 106: the number of civilizations in the Milky Way.

- ❑ Recap: the Drake Equation quantities, and the number of the communicable civilizations we expect in the Galaxy.
- ❑ Future of life in the SS
- ❑ Issues of communication, visits, exploration.
- ❑ Principles of interstellar communication.



Larry Landolfi

The Drake equation

$$N = R_* f_p n_e f_\ell f_i f_c L$$

N = number of communicable civilizations in our Galaxy

R_* = rate at which stars form.

f_p = fraction of stars that have planetary systems.

n_e = number of planets, per planetary system, that are suitable for life.

f_ℓ = fraction of planets suitable for life, on which life actually arises.

f_i = fraction of life-bearing planets on which intelligence develops.

f_c = fraction of intelligence-bearing planets which develop a technological phase during which there is a capacity for, and interest in, interstellar communication.

L = average lifetime of communicable civilizations.

See also Evans, appendix 5.

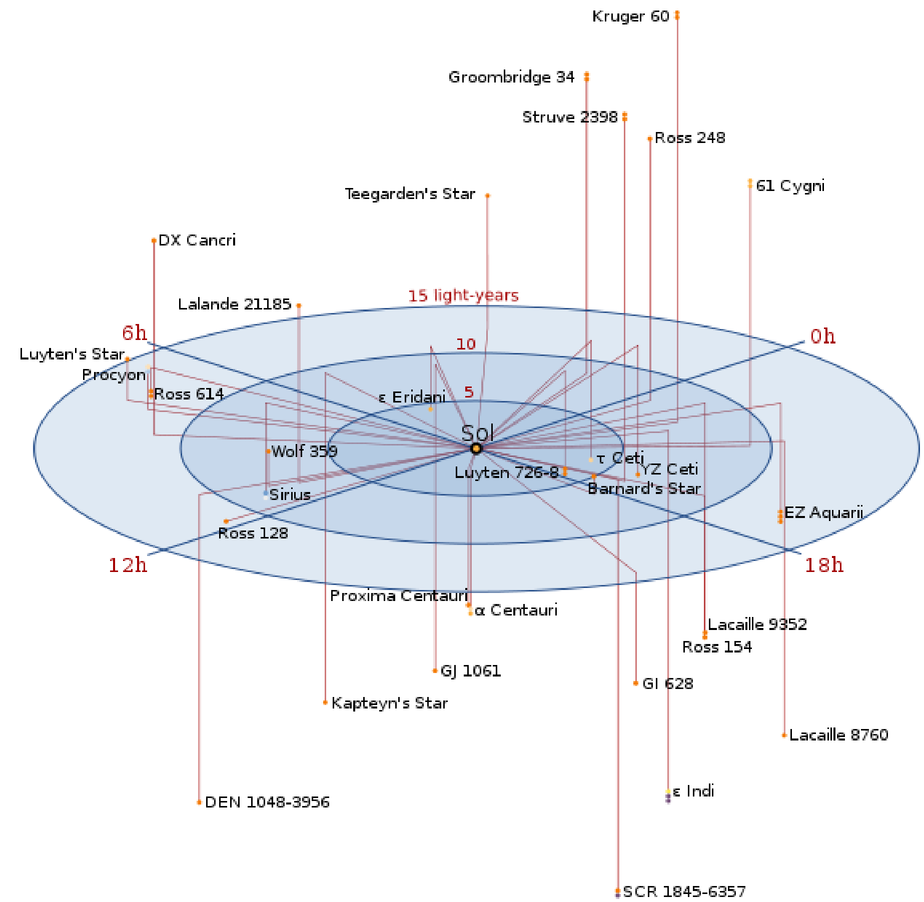
Recap of Drake Equation quantities

Quantity		Likely range	Laura's bet
Star formation rate	R_*	50 ± 25 per year	50 per year
Fraction of stars with planets	f_p	$1 > f_p > 0.14$	0.8
Number of habitable planets per planetary system	n_e	1 ± 1	0.5
Fraction of habitable planets that evolve life	f_ℓ	0.3 ± 0.2	0.33
Fraction of life-evolutions that evolve intelligence	f_i	$0.1 > f_i > 10^{-7}$	0.01
Fraction of intelligence-evolutions that evolve civilizations capable of interstellar communication	f_c	$1 > f_c > 0.1$	0.5
Typical lifetime of communicable civilization	L	10^9 years $> L > 0$	1000 years
Number of civilizations in Galaxy	N	$3.8 \times 10^9 > N > 0$	33

Finding and visiting other civilizations

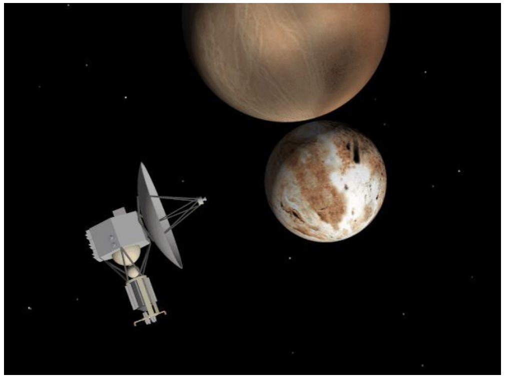
The main issues:

- Most stars are far away. Closest star system, α Centauri: r = 4 light-years (ly). Within 14 ly lie 32 stars.
  1 ly = 9.46×10^{17} cm.
- Neither information nor astronauts can travel any faster than light:
  $c = 2.99792458\times10^{10}$ cm/sec
  = 1 ly/yr.

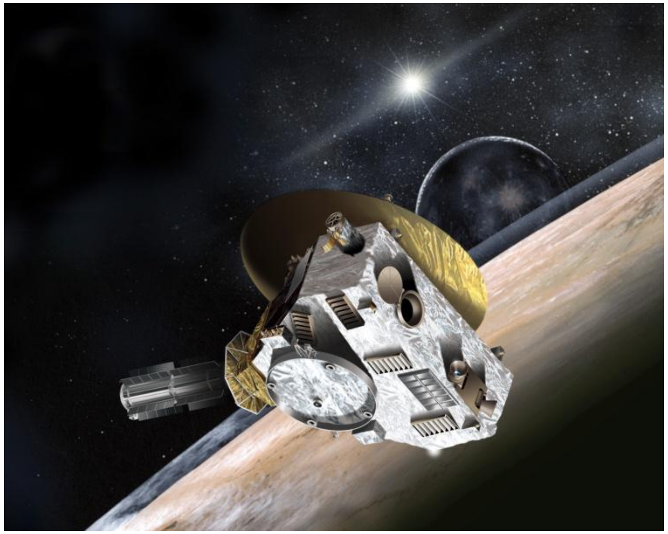


The 32 nearest stars ([Wikimedia Commons]())

Finding and visiting other civilizations (continued)



- At present we can't get astronauts to speeds anywhere near *c*; the fastest current spacecraft rolls at 1.8×10^{6} cm/sec = 40,265 mph = 6×10^{-5} *c*.
  - NASA Pluto-Kuiper Express – cancelled in 2004
  - New Horizons – launched in 2006 will rendezvous with Pluto in July 2015



- So the first thing to try is communication rather than visits. As we will see, this is considerably cheaper too.

Finding and visiting other civilizations (continued)

- ❑ And until we find a civilization with which to communicate we should both talk and listen…
- ❑… and account for the extreme delay between responses, on the scale of our usual attention spans. Even for relatively nearby civilizations, "conversations" would take many human lifetimes.
  - Time is the issue again:
    If $L < 2 \times r$, a conversation is impossible.

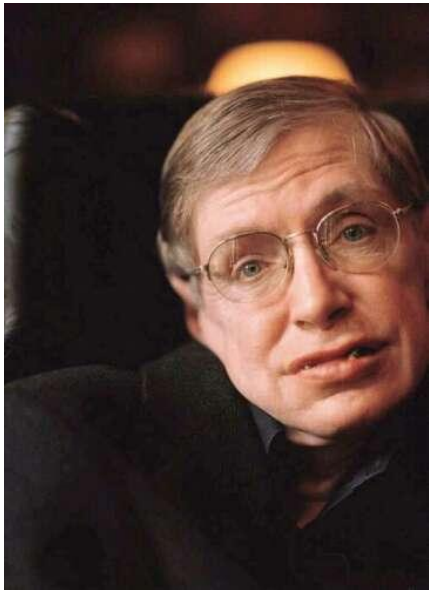
If there are other civilizations nearby in the Galaxy, should we try to communicate with them?

A = yes B = no.

Communicating with civilizations

"To my mathematical brain, the numbers alone make thinking about aliens perfectly rational. The real challenge is to work out what aliens might actually be like…. If aliens visit us, the outcome would be much as when Columbus landed in America, which didn't turn out well for the Native Americans."

- Lucasian Professor of Mathematics, Stephen Hawking, on Discovery Channel show *Into the Universe*



Mid-lecture Break

- Homework #5 is due Wednesday at 5PM.

Ellie hears the first signal from intelligent extraterrestrials. From *Contact* (1979).

Has intelligent extraterrestrial life deliberately contacted us?

- From 15 June 2011, Intelligent civilizations must have technology as well as a specific worldview to develop interstellar communication:
  - Appreciation of size and nature of the universe
  - Realization of species' place in the universe
  - Belief that odds of communication are reasonable
- Civilizations could have science and technology without the correct astronomy, e.g.:
  - Very cloudy planets
  - Planets in molecular clouds

Types of communication

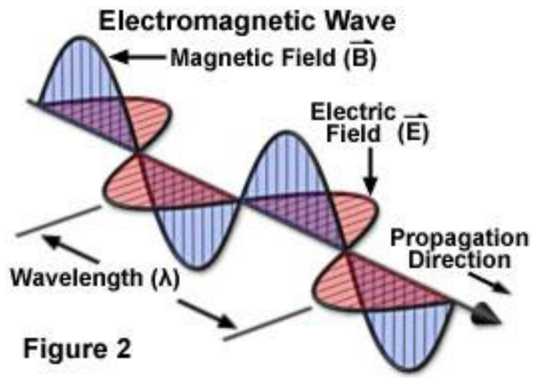
Signals from communicable civilizations could be:

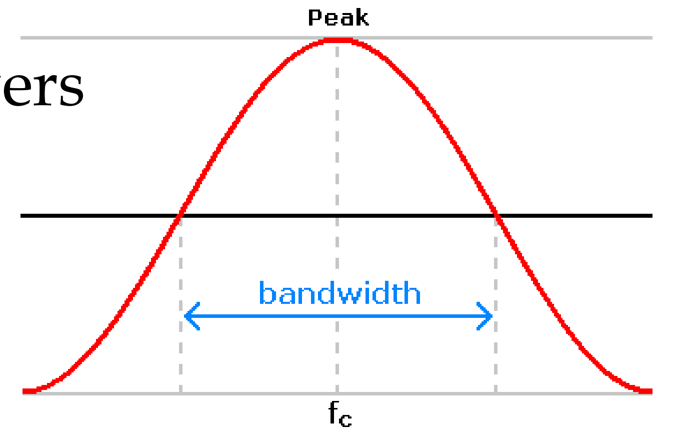
1. Signals used for local communication on a world where intelligent beings live.
2. Signals used for communication between a home world and another site, such as a colony or spacecraft.
3. An intentional signaling beacon

Communication with other civilizations

How would intelligent life communicate?

- ❑ One thing seems clear: communication will involve light.
- ❑ Need a precise wavelength (frequency) of light at which communication would be reasonable, though, is *not* naturally determined.
    - The electromagnetic spectrum covers many orders of magnitude of wavelength, and a *signal* would cover a very small range of wavelengths around some central wavelength, called *bandwidth*.





Communication with other civilizations

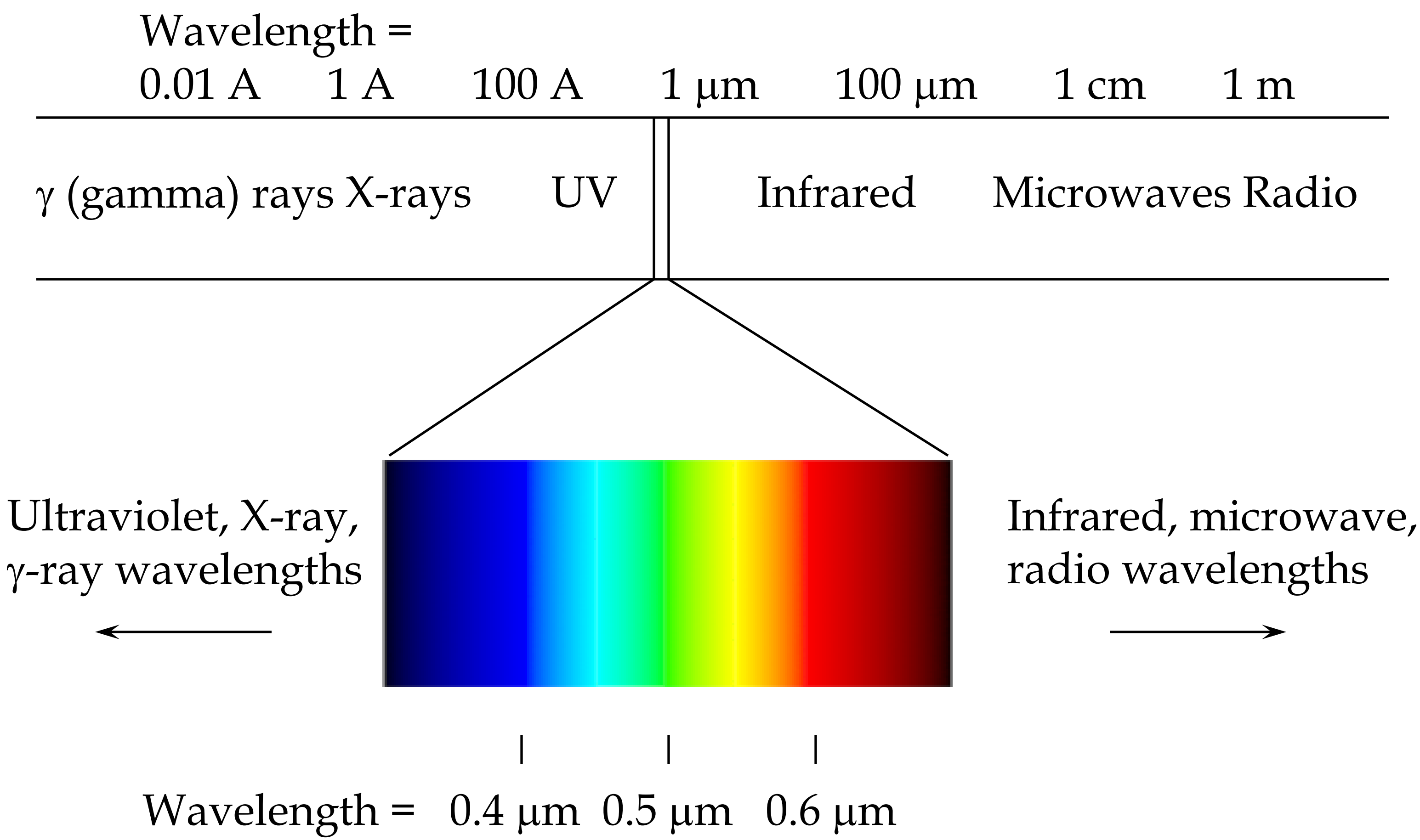
- Issues which decide communication wavelength:
  - Need to generate lots of broadcast power.

Doc Marten in
Back to the Future
(Universal Studios)

  - Need to broadcast that power in a narrow beam aimed at stars. (Expensive and wasteful to broadcast in all directions.)

The electromagnetic spectrum (light)

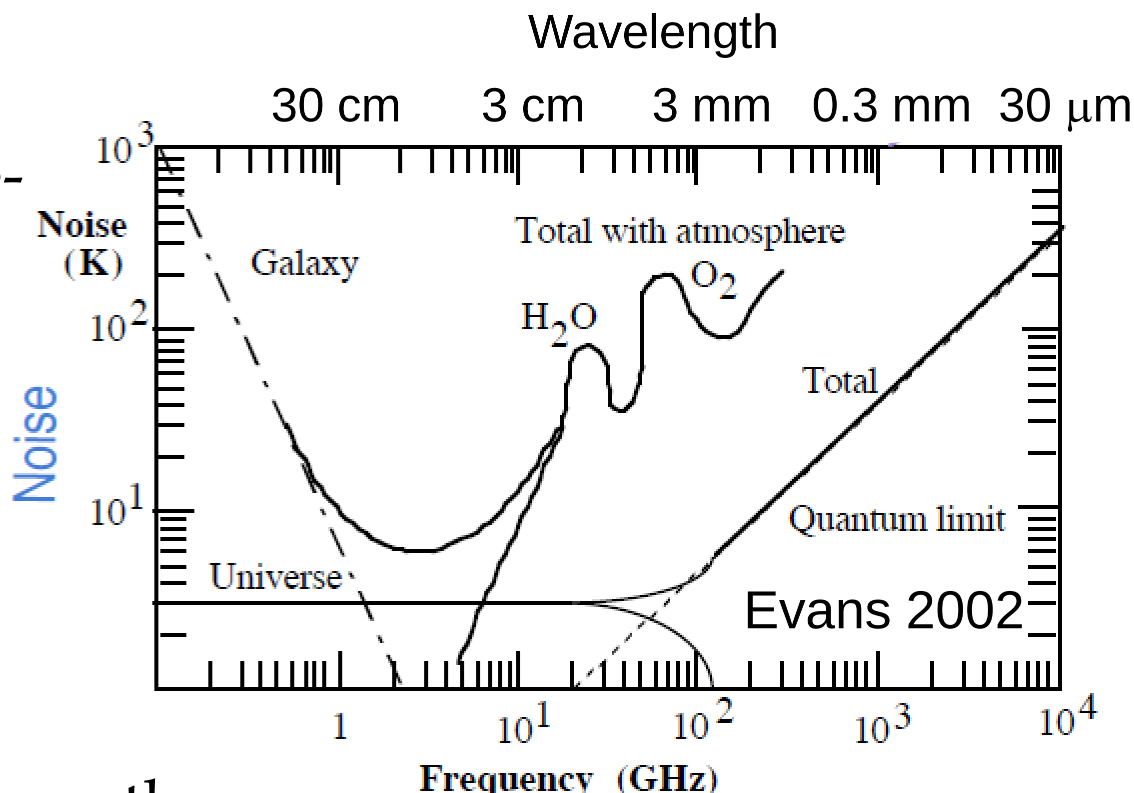
Visible light is actually just a tiny part of the spectrum of light.



Communication with other civilizations (cont'd)

- Need to detect and identify very small signals against natural backgrounds and noise.
- Need to avoid confusion with natural sources of light.
- Presuming at least come of the communications need to get to the surface of habitable planets, the wavelength should be one at which atmospheres are transparent.
- Our broadcast would probably attract more attention if it were near a wavelength of astrophysical significance, so that the astronomers of other civilizations might notice it. Other civilizations might be thinking that way too.

Detection and noise issues



For detection of coherent (steady wave-like) signals there is a quantum limit to the smallest detectable signal that is much smaller at radio wavelengths than shorter wavelengths.

- At wavelengths longer than about 30 cm, natural sources of noise from the Galaxy limit the sensitivity. Atmosphere gets worse < 1 cm.
- Therefore wavelengths **1 cm-30 cm** seem about right.

Getting noticed

The 1-30 cm band is already largely free of strong local interference, since stars aren't bright at these wavelengths, but it's still a lot of wavelength space to cover.

Special locations that astronomers would notice:

- **The water hole**. Two of the brightest spectral lines from interstellar gas, the 21 cm line of atomic hydrogen (H) and the 18 cm lines of hydroxyl (OH) would undoubtedly attract the attention of extraterrestrial astronomers. Frank Drake and Carl Sagan used to draw attention to the gap between them as a result. (H+OH = water.)
- **The real water hole**. Bright, natural maser emission from water itself, at 1.3 cm, would certainly attract attention.

But there are zillions of important spectral lines in the band.

Power, beaming, and atmospheric transmission issues

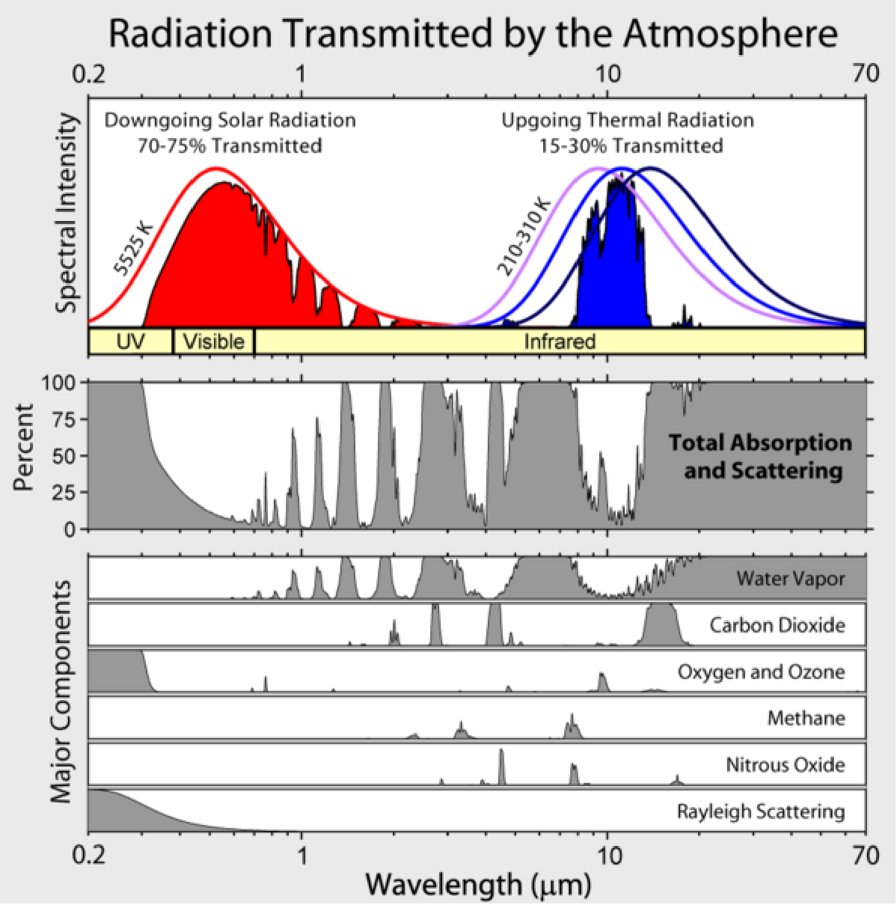
- It is easy to generate **huge** amounts of broadcast power at all radio wavelengths, especially 1 cm and longer, using electron-beam devices like old radio tubes.

Modern version of a vacuum tube radio

- Except at wavelengths longer than a few meters, our atmosphere is quite transparent in this domain.

Power, beaming, and atmospheric transmission issues

- It is easy to generate huge amounts of power at a set of special infrared and visible wavelengths, using **lasers**.
  - Especially in the 10 micron atmospheric window (CO_2 lasers), and at 3.4 and 0.6 microns (He-Ne lasers), 1 micron (Ar lasers) and 0.6-0.7 microns (ruby lasers).



Created for Global Warming Art by Robert A. Rohde

Power, beaming, and atmospheric transmission issues

- To concentrate the power in the same patch of sky, a longer wavelength would have to be broadcast with a larger telescope: size directly in proportion to wavelength.
- However, the larger the diameter of the disk, the smaller the beam.
- $\theta = \lambda / D$

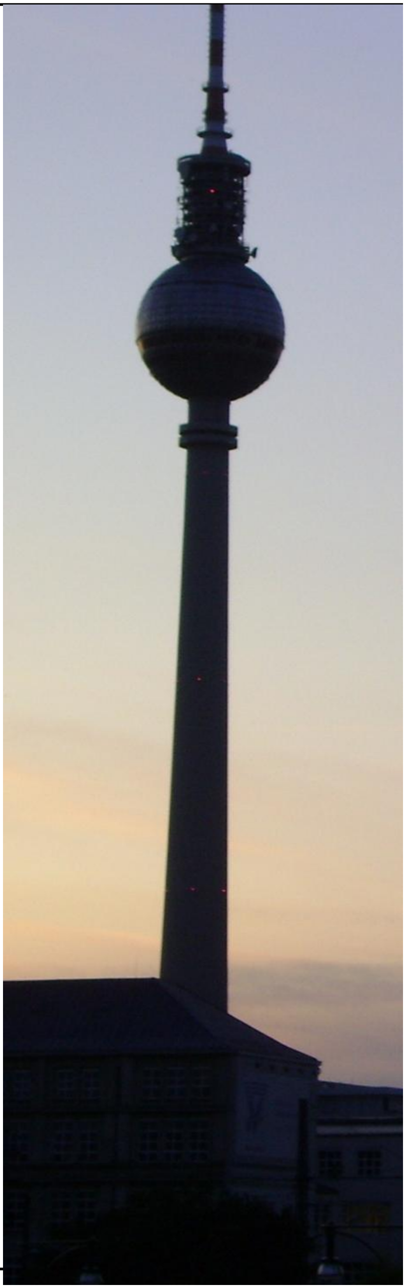
Aricebo Observatory, 300m (1000 ft) radio telescope in Puerto Rico. (NSF/Cornell)

Suppose you could generate the same amount of broadcast power at wavelengths of 10 microns and 1 cm. (A micron is 10^{-4} cm.) Suppose you had a 305 m diameter telescope for your 1-cm broadcast; how big a telescope would do the same job at 10 microns?

A. 3 cm B. 30 cm C. 305 cm (3 m)
D. 3050 cm (30.5 m)

The broadcast itself

- One does not just send a steady wave at a given wavelength; one **modulates** the wave, so that a stream of information at longer wavelengths/lower frequencies is obtained by removing the steady **carrier**. This is how all optical and radio transmission works.
  - In radio, the carrier is modulated at audio – voice – frequencies.
  - AM and FM refer to the methods of modulation common in radio.

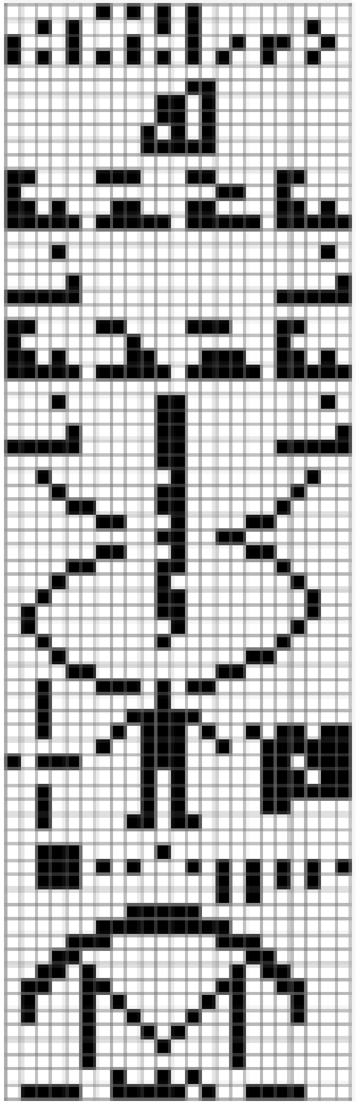


Fernsehturm, TV tower, in Berlin, Germany.

The broadcast itself

- One also would need to broadcast a **primer**: something that could help decypher our modulations.
  - Best if related to universal, natural or mathematical concepts, like prime numbers or the periodic table.
  - Humanity's referred method of interstellar communication is pictorial.

73 rows



23 columns

Contact

This whole process is nicely encapsulated in the movie *Contact* (1997), starring Jodie Foster and based upon the novel by Carl Sagan.

In class we will watch a DVD but you can get the relevant clip here.