

The Drake Equation (1962)
parameterizing our ignorance

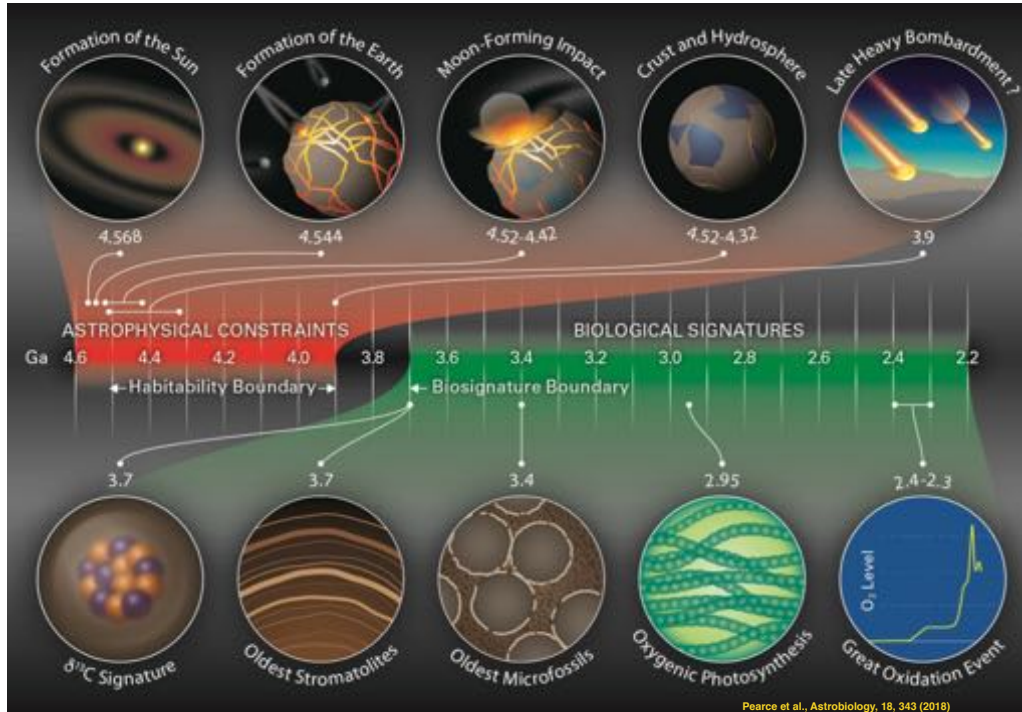
$$N = R_s \times f_p \times n_p \times f_L \times f_i \times f_c \times L$$

N is the number of communicating civilizations in the Galaxy today

Astronomical factors	= R_s (annual rate of star formation) × f_p (fraction of stars with planets) × n_p (# of planets with conditions for life)
Biological factors	× f_L (fraction on which life develops) × f_i (fraction that develop intelligent life)
Sociological factors	× f_c (fraction that develop communication) × L (# of years communication continues)

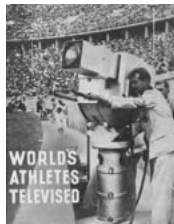
Question from Lecture 27 Quiz:

- The TESS spacecraft, currently looking for planets around stars, observes each star for 24-48 days.
- Two transits are needed to certify discovery of a planet.
- If TESS finds **habitable** planets around a star, how will that star compare to our Sun?
 - Habitable Zone: close to low L (cool) main sequence stars
 - $P_{orb} < 24$ days - Habitable Zone much closer to star than Sun
 - so the TESS targets are lower mass K, M stars



Sociological Factors

- $f_c = 1/2$?
 - at least 1, maybe 3 intelligent species on Earth
 - 1 with technology for remote communication
- $L > 85$ years
 - “Longevity” - how long are they detectable?
 - leakage of VHF/UHF signals into space
 - we have been detectable for over 80 years



Putting it all Together:

$$N \approx 8 \times 0.9 \times 1 \times 0.5 \times 0.5 \times 0.5 \times L$$

$$N \sim L$$

The number of other technical civilizations **in our galaxy** equals the number of years that they are able (and willing) communicate

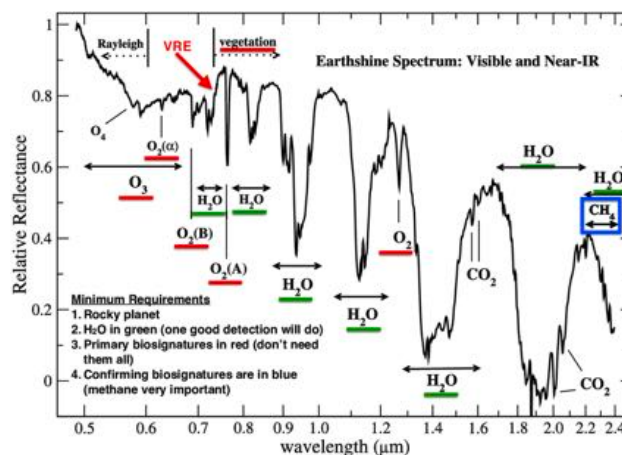
Could be ~ 85 in our galaxy right now!



Prospecting for life on exoplanets (f_L)

• Exoplanet biosignatures

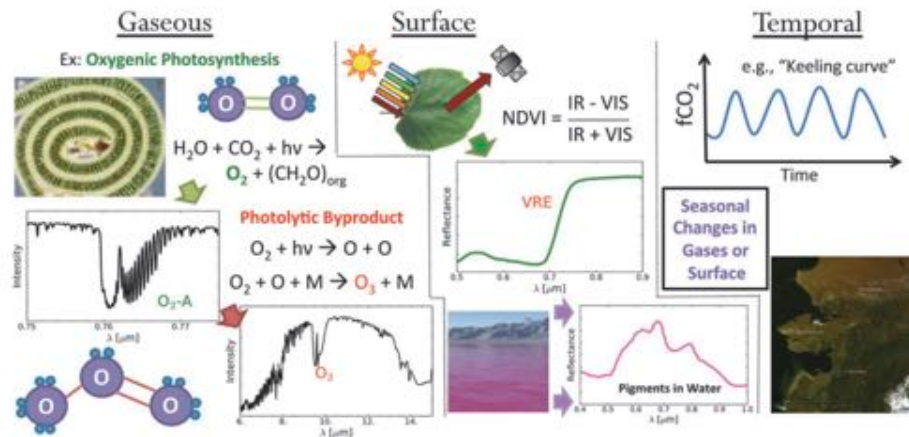
- observe exoplanets in transit across host star, or directly.
- use **spectroscopy** to look for for 'non-equilibrium' molecules of biological origin
- Oxygen, ozone, chlorophyll pigmentaiton, methane, ...



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Contact or 'just' communication ?

- To go to a star 10 light years away ... and back in one (long) lifetime:
 - need 6×10^{28} ergs (20 years of Earth's total energy production!)
 - most efficient fuel: matter+antimatter (100 tons each way)
 - shielding against gamma rays...
 - nah...
- **Contacting and communicating with other civilizations must be a generation-to-generation effort**

Communication?

consider... value in one-way communication

Culture	separation in	common language	medium	an example
 Ancient Egyptians	time (4000 years)	hieroglyphics	tomb carvings papyri	
 ET: The Extra-Terrestrial	space (light years)	universal truths: science, math	light, radio, sentinel spacecraft	

SETI: Search for Extraterrestrial Intelligence

- (Radio) Searches for narrowband signals
 - **narrow band = non-natural origin**
- need to scan billions of frequencies
 - we don't know their "standards"
 - FM radio - only 200 indep. frequencies
- need to point at LOTS of **solar-type** stars

SETI: Why Radio?

- **cheap** to produce high-power beam
- **easy** to detect with simple technology
- **long-range**
 - Galaxy transparent to radio waves
 - Galaxy relatively noise-free at useful wavelengths

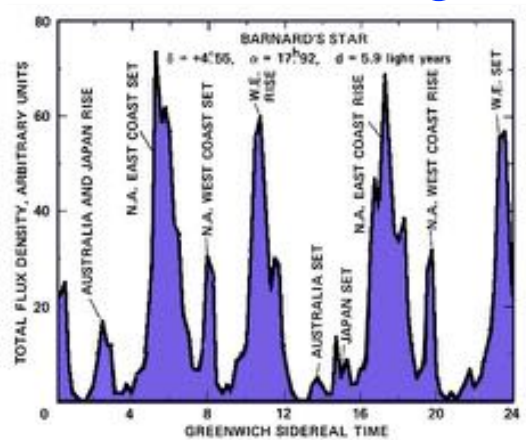


And we already have some huge radio telescopes!

Arecibo Observatory

- can detect “earthly” signals across the Milky Way
- scan thousands of nearby stars

Unintentional Signals



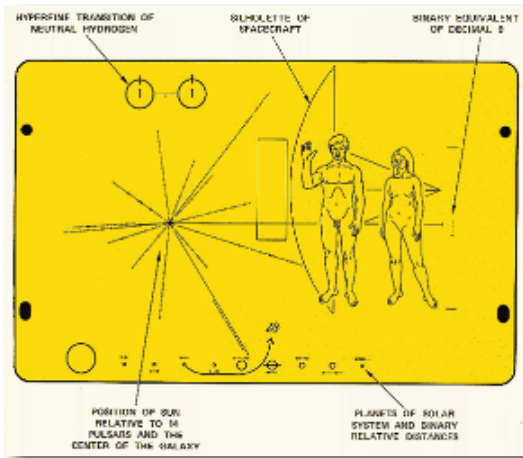
Earth UHF/VHF TV, viewed
from Barnard's star
(Sullivan et al. 1978)

- most radio signals will be unintentional
- Earth example -
 - TV broadcasts
 - Cell Phones
 - Military Radar
- all spilling out into interstellar space

Discovery would be profound even if never decoded

Examples: intentional messages

The plaque aboard Pioneers 10 and 11



now beyond our solar system
over 9 billion miles away

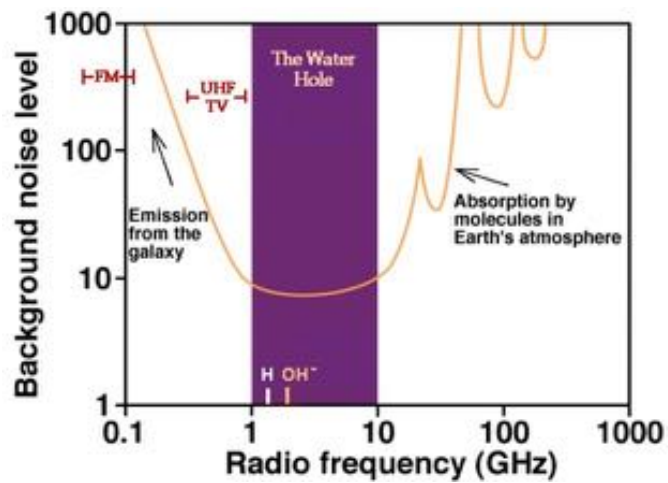
The Arecibo Message
(1974)



23x73

now 46 light-years away

What frequencies? the "Water Hole"



"Magic" frequencies: 1.42 GHz, 2.84, GHz ...

How far away? How many stars to search?

L	nearest civilization	number of stars to search
85	3,600 ly	365,000,000
1000	1,500 ly	100,000,000
1,000,000	150 ly	100,000

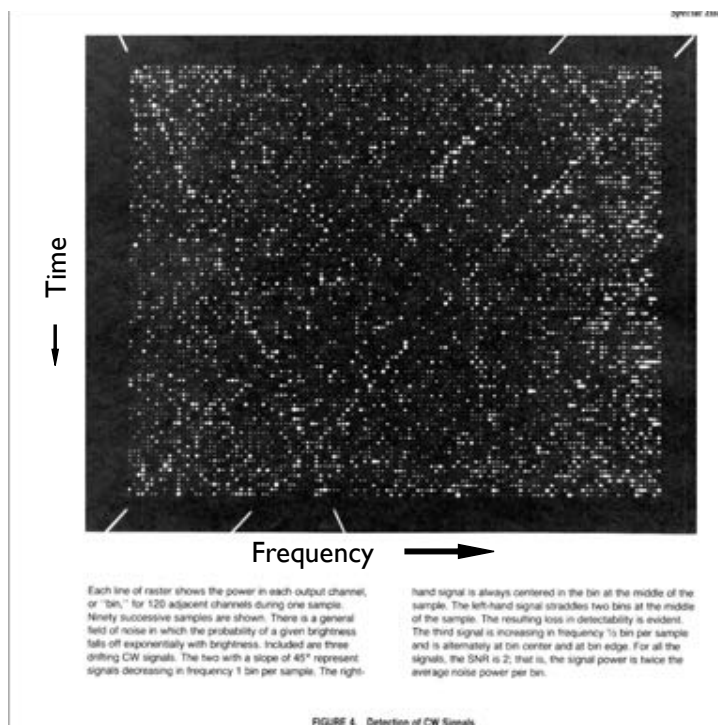
Project Ozma: the first search, 1960



- Frank Drake (again!)
- 85ft Green Bank Telescope
- 3 months, 6h/day
- 2 stars
- monitored 1 frequency
 - 1420 MHz, HI line
- found nothing
 - except a secret military radar

Modern Searches

- The more frequencies, the better
 - **Project Phoenix**,
@The SETI Institute
(Frank Drake is past Chair of the Board)
 - Paul Horowitz @ Harvard, project BETA
- Look for narrow bandwidth, pulsed signals
- Search LOTS of stars
- Automated data analysis
- Independent verification (lots of false alarms)



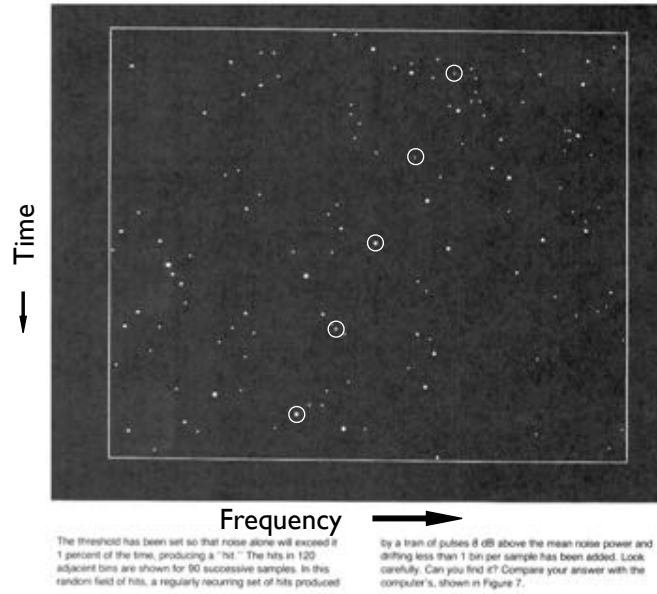
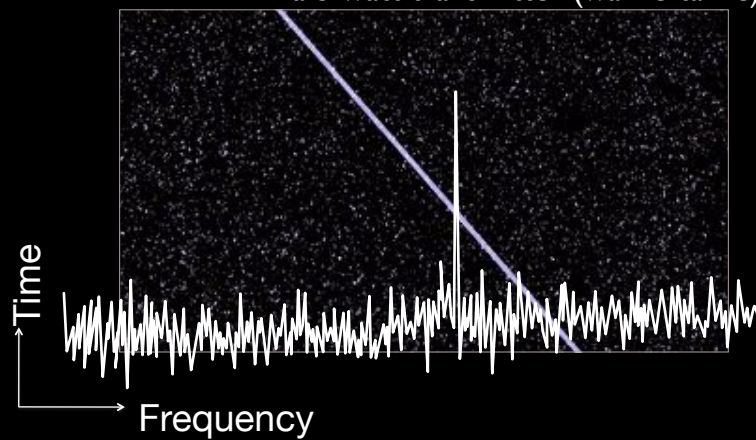


FIGURE 6. A Field of Hits



Voyager 1 Signal from 106 AU Away

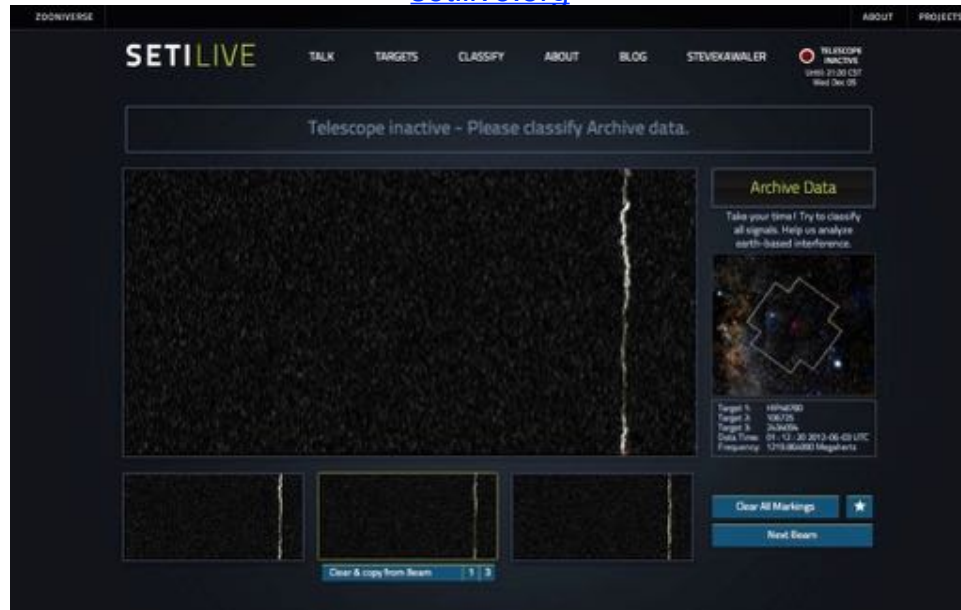
106 AU = 7.5 billion miles
a 5 watt transmitter (walkie-talkie)



from Jill Tarter - SETI institute

Data analysis example:

setilive.org

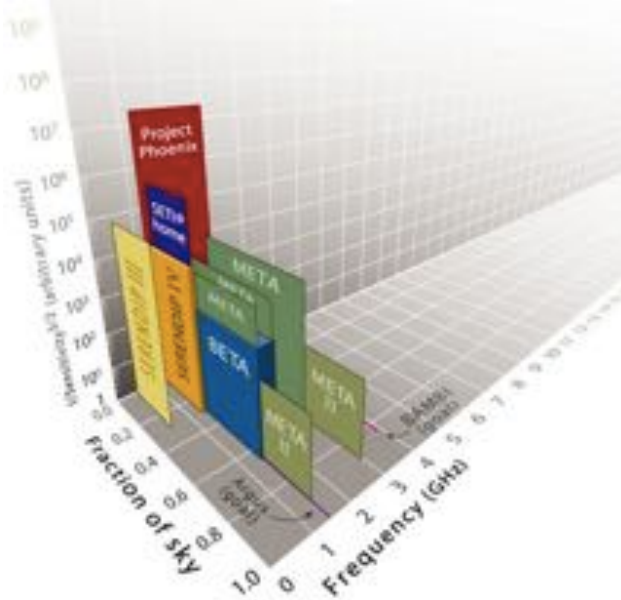


Now: The Allen Telescope Array

- A large array of ~350 20 ft. radio telescope dishes
- work together as a single telescope
- cover the whole sky at all frequencies
- funded by Paul Allen (Microsoft Gazillionaire)
- **400,000,000 stars within 30 years - with software!**



The Cosmic Haystack



- "(Current status is like) looking for a fish, any fish, in all of Earth's oceans by examining a single drinking glass of sea water"

Jill Tartar, 2010

- "Our current search completeness is extremely low, akin to having searched something like a large hot tub or small swimming pool's worth of water out of all of Earth's oceans."

Jason Wright, 2018

Conclusions

- It's hard to avoid the conclusion that life is abundant in the Universe
- It's easy to argue that intelligent life is common in our Galaxy
- We already have the technology to detect other intelligent civilizations at interstellar distances
- People are looking for them right now and will continue
- We may never succeed but we can't afford not to try

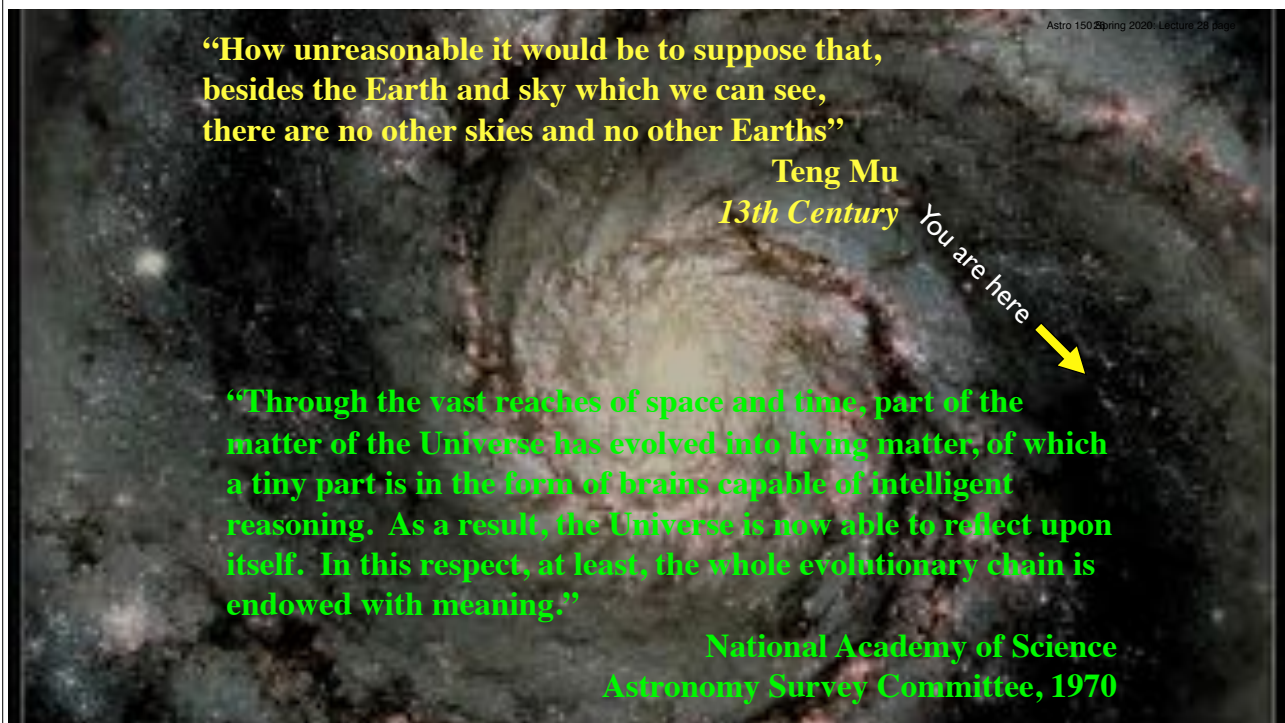
Messages from other stars are coming through this room, and they have been doing so for literally millions and billions of years. And nobody sensed it, no creature sensed it. You need special technology to do it but it is there, right here in this room.

Look around. Where is it?

It's here.

It's just that we're not using the right sensors, we're not looking in the right direction, we're not tuning to the right channel. But let's work on it and someday, we'll join the galactic internet, and learn a lot of good, fun things.

Frank Drake,
Mountain View, California
November 5, 2013

The image shows a dark, star-filled galaxy with a prominent spiral structure. Overlaid on the image is text in yellow and green. A yellow arrow points from the text 'You are here' to a specific location in the galaxy.

“How unreasonable it would be to suppose that, besides the Earth and sky which we can see, there are no other skies and no other Earths”
Teng Mu
13th Century You are here

“Through the vast reaches of space and time, part of the matter of the Universe has evolved into living matter, of which a tiny part is in the form of brains capable of intelligent reasoning. As a result, the Universe is now able to reflect upon itself. In this respect, at least, the whole evolutionary chain is endowed with meaning.”
National Academy of Science
Astronomy Survey Committee, 1970