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

<table>
<thead>
<tr>
<th>Astronomical factors</th>
<th>( = R_s ) (annual rate of star formation)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \times f_p ) (fraction of stars with planets)</td>
</tr>
<tr>
<td></td>
<td>( \times n_p ) (# of planets with conditions for life)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Biological factors</th>
<th>( \times f_L ) (fraction on which life develops)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \times f_i ) (fraction that develop intelligent life)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sociological factors</th>
<th>( \times f_c ) (fraction that develop communication)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \times L ) (# of years communication continues)</td>
</tr>
</tbody>
</table>

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
  - \( P_{\text{orb}} < 24 \) 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 \(\sim 85\) in our galaxy right now!

There are 100,000,000,000 galaxies in our Universe...

Prospecting for life on exoplanets \(f_L\)

- Exoplanet biosignatures
  - observe exoplanets in transit across host star, or directly.
  - use spectroscopy to look for ‘non-equilibrium’ molecules of biological origin
  - Oxygen, ozone, chlorophyl pigmentaiton, methane, ...

![Exoplanet Spectrum](image)
Prospecting for life on exoplanets ($f_L$)

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**Contact or ‘just’ communication?**

- To go to a star 10 light years away ... and back in one (long) lifetime:
  - need $6 \times 10^{28}$ 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

<table>
<thead>
<tr>
<th>Culture</th>
<th>separation in</th>
<th>common language</th>
<th>medium</th>
<th>an example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ancient Egyptians</td>
<td>time (4000 years)</td>
<td>hieroglyphics</td>
<td>tomb carvings papyri</td>
<td><img src="image" alt="Hieroglyphs" /></td>
</tr>
<tr>
<td></td>
<td>space (light years)</td>
<td>universal truths: science, math</td>
<td>light, radio, sentinel spacecraft</td>
<td><img src="image" alt="Spacecraft" /></td>
</tr>
</tbody>
</table>

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!

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

Unintentional Signals

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

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

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)
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?

<table>
<thead>
<tr>
<th>L</th>
<th>nearest civilization</th>
<th>number of stars to search</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>3,600 ly</td>
<td>365,000,000</td>
</tr>
<tr>
<td>1000</td>
<td>1,500 ly</td>
<td>100,000,000</td>
</tr>
<tr>
<td>1,000,000</td>
<td>150 ly</td>
<td>100,000</td>
</tr>
</tbody>
</table>

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)
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

“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

“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