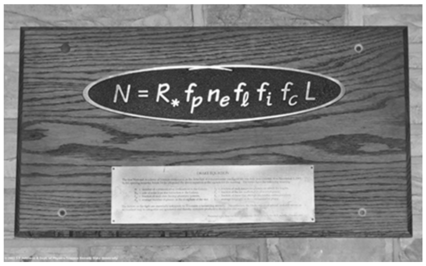
Lecture 39

The Drake Equation



Astronomy 141 – Winter 2012

This lecture explores the question of intelligent life in the universe by way of the Drake Equation.

The Drake Equation is a way to estimate the number of advanced, communicating civilizations in our Galaxy.

Observational inputs into the Drake equation include the star formation rate and the frequency of exoplanets.

Conjectures include the emergence of life, intelligence, communications, and the lifetime of civilizations.

Even optimistic estimates suggest that intelligent, communicating life may be rare in the Galaxy.

Is there intelligent life elsewhere in the Universe?

What do we mean by “Intelligent Life”?

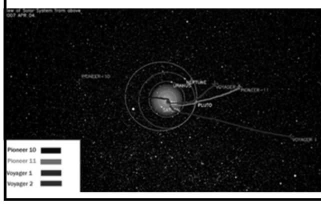
- A highly advanced technological civilization
- Capable of communicating across interstellar distances.
- Capable of interstellar travel by spacecraft.
- Interested in finding and communicating with other intelligences.

In other words: life like us...

Do we qualify as intelligent beings with advanced technology?

You have to wonder sometimes…

We've had radio communications technology for ~100 years.



Limited (short-duration) manned spaceflight for ~50 years.

Robotic spacecraft to the edge of the Solar System only in the past few years.

One reason we think intelligent life must have arisen elsewhere is the sheer number of stars

~200 billion galaxies in the visible Universe

~100 billion stars per galaxy

Total of ~2x10^{22} (20 billion trillion) stars

Even a chance of 1 in 10^{12} would yield mean than 20 billion possible sites for life.

The Drake Equation estimates the number of advanced, communicating civilizations in our Galaxy

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

R_* = rate of star formation

f_p = fraction of stars with planets

n_e = number of Earth-like planets per system

f_l = fraction with life.

f_i = fraction with intelligence

f_C = fraction with communication technology

L = lifetime of an advanced civilization

Frank Drake

R_*, the rate of star formation per year, is known from extensive observations.

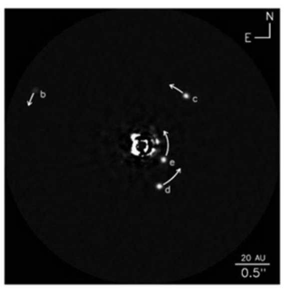
A reasonable estimate:

$$R_* \approx \frac{N_*}{Age}$$

$N_* \approx$ 100 Billion Stars
Age ≈ 13 Billon Years
$R_* \approx$ 7 stars/year

$$N = N_* \times f_p \times n_e \times f_l \times f_i \times f_c \times \frac{L}{Age}$$

f_p, the fraction of stars with planets, is becoming known from exoplanet searches.



Present observed fraction is

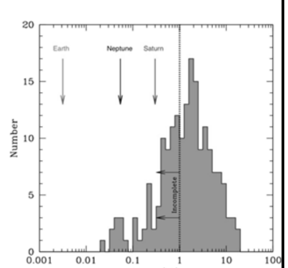
$f_p \approx 0.15$

But, this is mostly giant planets – rocky planets may be more common.

Optimistic Estimate:

$f_p \approx 0.5$

n_e, the number of planetary systems with Earth-like planets is unknown, but will soon be measurable.



Should become known in the next decade or so.

Depends on the detailed distribution of rocky planets around stars.

Right now, we don't know.

Optimistic Guess:

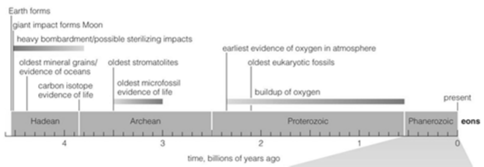
$n_e \approx 1$

Allows us establish an upper limit…

f_l, the fraction of Earth-like planets with life, is currently unknown and conjectural.

Some guidance from the history of Earth

Life arose within ~100 Myr of the end of the epoch of Heavy bombardment.



Optimistic Guess: $f_l \approx 1$

f_i, the fraction of life that is intelligent, is even harder to guess.

Clues from Earth's history:

- First life arose ~3.8 Gya
- Multi-cellular life ~1.2 Gya
- Cambrian explosion ~545 Mya
- Land colonization ~475 Mya
- *Homo sapiens* emerged ~100,000 years ago

Took 100 Myr for life to emerge, but ~40x longer for an intelligent species (us) to appear.

Wild Guess: $f_i \approx 0.1$ (is it rarer, or just take longer?)

f_c, the fraction of intelligent life that is capable of (or interested in) communication, is purely conjectural.

The rise of science and technology is very recent cultural development.

It entails the ability (and willingness) to make sense of the world in terms of logic and physical principles.

Shameless and baseless optimism: $f_c \approx 1$

L, the lifetime of an advanced, communicating civilization, is difficult (and uncomfortable) to guess

Only example is us…

Lower Bound:
We've only had radio technology for ~100 years

Upper Bounds:
Next year?
100 years?
When habitable zone moves past Earth in 0.5 – 3 Gyr?
When the Sun runs out of core Hydrogen (5 Gyr)

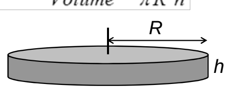
A shamelessly optimistic guess…

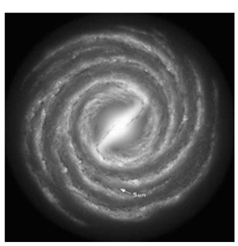
N_* = 100 Billion stars
f_p = 0.5
n_e = 1
f_l =1
f_i =0.1
f_c =1
L =100 years (we made it this far … so far …)
Age = 10 billion years

$$N = N_* \times f_p \times n_e \times f_l \times f_i \times f_c \times \frac{L}{Age}$$
$$= 100 \text{ Billion } \times 0.5 \times 1 \times 1 \times 0.1 \times 1 \times \frac{100 \text{ yr}}{10 \text{ Gyr}}$$
$$= 50$$

Even a fairly optimistic set of numbers gives a relatively low density of advanced civilizations

$$density \approx \frac{N}{Volume} = \frac{N}{\pi R^2 h}$$





Milky Way:
$R \approx$ 50,000 ly
$h \approx$ 1000 ly

$$density \approx \frac{50}{\pi (50{,}000 ly)^2 \times 1000 ly} \approx 6.4 \times 10^{-12} \text{ per cubic ly}$$

The low density of civilizations implies a large average distance between them.

If 50 advanced civilizations were spread evenly around the Milky Way galaxy:

$$\pi d^2 H \approx \frac{1}{density}$$

$$d \approx \sqrt{\frac{1}{\pi H \times 6.4 \times 10^{-12}\ ly^{-3}}}$$

$d \approx$ 7000 light years

A two-way conversation would take about 14,000 years.

The Drake Equation is open to numerous criticisms, and not without its detractors.

Relies on many unknown quantities, and so it is heavy on conjecture.

Doesn't account for population dynamics if interstellar colonization is possible.

But, it provides a reasonable starting point for discussing what to look for and how.