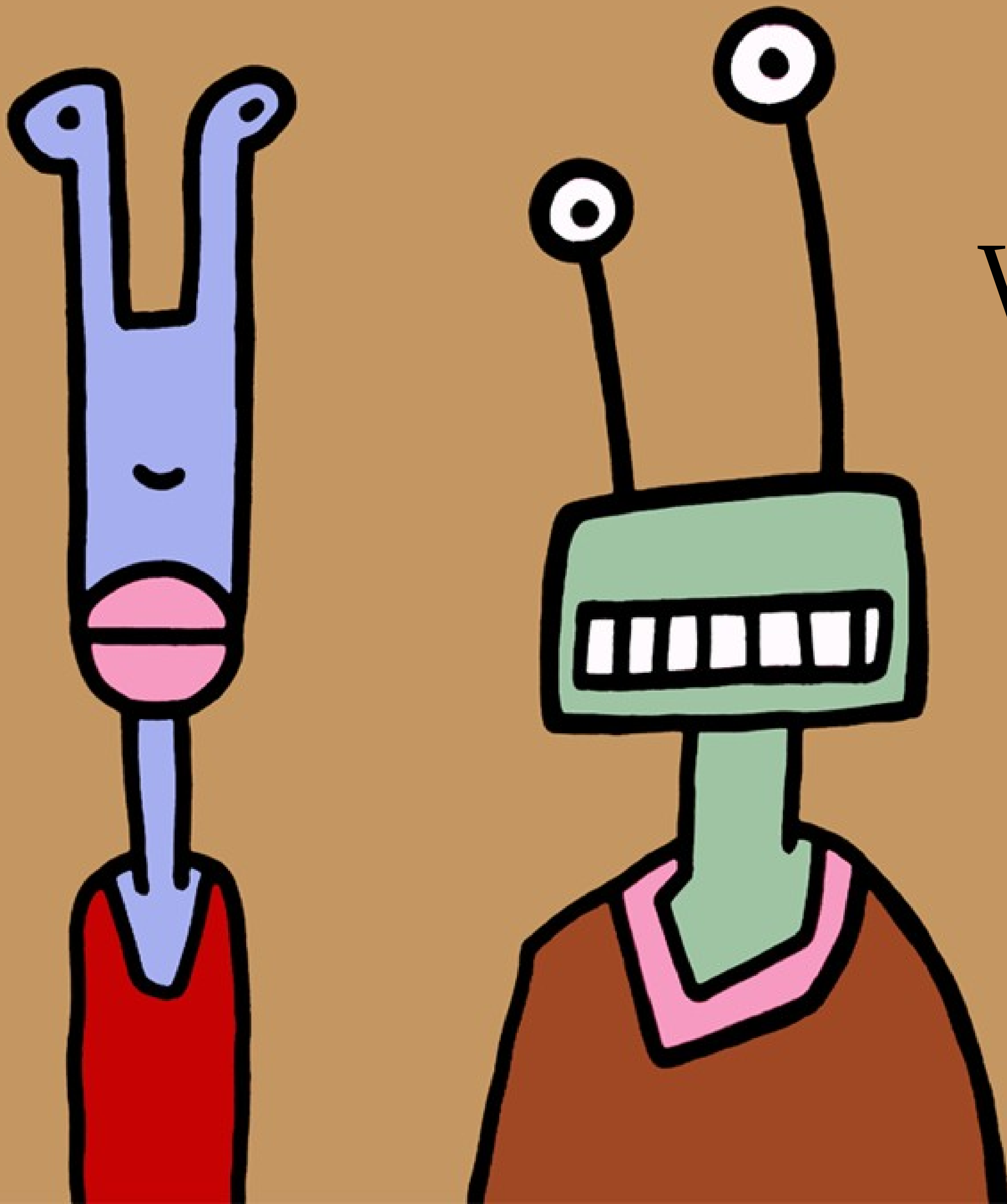
Group Project due now, hardcopy.

Life in the Universe



What are the chances that life exists elsewhere?

Life in the Universe

In 1961, Frank Drake created an equation to parameterize the likelihood of life in the Universe. This is now known as **the Drake Equation**.

$$N = R \cdot f_s \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

- N = Number of civilizations that are able to **communicate** with us right now, within our own galaxy.

Important: This equation requires an intelligent civilization which is broadcasting signals into space.

All we have to do is listen.

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I will provide values for this equation.

Some are known, some are estimated, and for others, I'll guess.

$$N = R \cdot f_s \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

- N = Number of civilizations that are able to communicate with us.
- R = Rate of star formation. About 20 for the Milky Way. This has been measured by astronomers. Life needs energy, which means stars.

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- N = Number of civilizations that are able to communicate with us.
- R = Rate of star formation. About 20 for the Milky Way.
- f_s = the fraction of those stars that are like our Sun. ~0.1 This has been measured by astronomers. Massive stars have brief lives, while low-mass stars may have too much activity (flares, spots, etc.).

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- f_p =the fraction of Sun-like stars with planets. ~0.9 This has recently been measured by astronomers.

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- N = Number of aliens able to communicate with us.
- R = Rate of star formation. About 20 for the Milky Way.
- f_s = the fraction of those stars that are like our Sun. ~0.1
- f_p =the fraction of Sun-like stars with planets. ~0.9
- n_e = the number of planets in the *habitable zone*, where liquid water exists. All life as we know it (only our Earth-bound example) requires water. For our solar system we could use 3 (Venus, Earth, Mars) or 7 (places where liquid water exists today, including Europa, Titan, etc.!)

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The factors f_p, and n_e are often called η Earth and is currently estimated at about 0.4-0.6.

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- n_e= the number of planets in the *habitable zone*, where liquid water exists. 3
- f_l=fraction of those planets on which life develops. Assume 50% **Now I'm just guessing. So I choose middle-of-the-road values.** **This factor is biological.**

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- f_l =fraction of those planets on which life develops. Assume 50%
- f_i =fraction of developing life that evolves intelligence. Assume 50% **I'm guessing again. This factor is biological.**

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- f_c =fraction of intelligent life that creates interstellar communication. Assume 50% Another guess. Sociologists should determine this factor.

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- f_i=fraction of developing life that evolves intelligence. Assume 50%
- f_c=fraction of intelligent life that communicates. Assume 50%
- L = lifetime of societies that can communicate with us. We have inadvertently been making signals into space for a bit over 100 years. So I'll use that number.

$$N = R \cdot f_s \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

Put it all together:

$$N = (20)(0.1)(0.9)(3)(0.5)(0.5)(0.5)(100) =$$

67.5

civilizations in our own galaxy that are able to communicate with us right now.

This is 1 star out of every 3 billion.

It would be very unlikely any aliens would be near to us.

$$N = R \cdot f_s \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

Put it all together:

N = (20)(0.1)(0.9)(3)(0.5)(0.5)(0.5)(100)=

67.5

After the first 3 factors, which have all been determined by astronomy, I used estimates. So they can vary a lot!

What if….

- I’ll start by taking an optimistic approach.

$$N = R \cdot f_s \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

Put it all together:

N = (20)(**0.8**)(0.9)(3)(0.5)(0.5)(0.5)(100)=

540

After the first 3 factors, which have all been determined by astronomy, I used estimates. So they can vary a lot!

Most stars are less massive then our Sun, so can easily choose $f_s = 0.8$ (the fraction of stars acceptable for life to develop in that solar system)

Massive stars are still excluded, but they're a very small fraction.

$$N = R \cdot f_s \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

Put it all together:

N = (20)(**0.8**)(0.9)(3)(**1**)(0.5)(0.5)(100)=

1080

After the first 3 factors, which have all been determined by astronomy, I used estimates. So they can vary a lot!

Fossil evidence on Earth suggests that life appeared almost as soon as there was water, perhaps making life very likely if the right ingredients (just water in this example). So could choose f_l=1

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Put it all together:

N = (20)(**0.8**)(0.9)(3)(**1**)(0.5)(0.5)(100)=

1080

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NOTE: There are 7 places currently with liquid water in our own solar system- f_l can be tested locally!

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Put it all together:

N = (20)(**0.8**)(0.9)(3)(**1**)(**1**)(0.5)(100)=

2160

After the first 3 factors, which have all been determined by astronomy, I used estimates. So they can vary a lot!

If you think evolution is a very strong outcome (Darwinism), you could easily choose $f_i=1$

That is, intelligent life is always an outcome of evolution, given enough time.

$$N = R \cdot f_s \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

Put it all together:

N = (20)(**0.8**)(0.9)(3)(**1**)(**1**)(**1**)(100)=

4320

After the first 3 factors, which have all been determined by astronomy, I used estimates. So they can vary a lot!

And if you think any civilization will want to communicate over a distance, you could easily choose $f_c = 1$

$$N = R \cdot f_s \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

Put it all together:

$$N = (20)(\mathbf{0.8})(0.9)(3)(\mathbf{1})(\mathbf{1})(\mathbf{1})(\mathbf{1x10^9}) =$$

43.2 billion!

After the first 3 factors, which have all been determined by astronomy, I used estimates. So they can vary a lot!

Our Earth will be habitable for about another billion years, so you could easily choose L=1 billion

If you think intelligent life begins earlier than our Earth-bound example, or for lower-mass stars, you could choose a much larger number, 100 billion even.

$$N = R \cdot f_s \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

Put it all together:

$N = (20)(\mathbf{0.8})(0.9)(3)(\mathbf{1})(\mathbf{1})(\mathbf{1})(\mathbf{1x10^9}) =$

43.2 billion!

This optimistic outcome would be a civilization every 4.6 stars in our galaxy.

This is clearly too much, or we would have heard them by now.

What if….

- You take a pessimistic approach?

$$N = R \cdot f_s \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

In the ‘rare Earth’ scenario, the chance of developing intelligent life is vanishingly small:

($f_i \sim 0$,)

$N \sim 1$.

Just us.

There can still be life on other planets, just not with the capability to transmit signals we could ‘hear’ (with radio telescopes).

$$N = R \cdot f_s \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

- R, f_s, f_p and n_e are astronomical. These variables are now all known or estimated for our local part of the galaxy.

$$N = R \cdot f_s \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

f_l and f_i are biological.

$$N = R \cdot f_s \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

f_c and L are sociological.

$$N = R \cdot f_s \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

R, f_s, f_p and n_e are astronomical.

f_l and f_i are biological.

f_c and L are sociological.

It takes scientists from all these disciplines to answer this question.

A New Take

"MIT exoplanet hunter" Sara Seager has generated a new equation (she's not the first, but hers seems to be catching on).

For her, N = the number of planets with detectable signs of life.

This is a change of position: In the Drake Equation, the aliens had to send out signals for us. In the Seager Equation, we can find life without them doing anything special.

The Seager Equation

$$N = N_* F_Q F_{HZ} F_o F_L F_S$$

N_* = the number of stars observed.

Careful here! This means *observed in the right way to detect what's coming in F_s.*

Kepler observed 150,000 stars, but $N_* = 0$ from Kepler observations!

The observation need to be high-resolution spectroscopic ones that can 'see' planet atmospheres. Currently N_*=0.

The Seager Equation

$$N = N_* F_Q F_{HZ} F_o F_L F_S$$

N_* = the number of stars observed.

F_Q = the fraction of stars that are quiet. This means that the star doesn't mask the signature being looked for. Estimated at 0.2 (20%)

The Seager Equation

$$N = N_* F_Q F_{HZ} F_o F_L F_S$$

N_* = the number of stars observed.

F_Q = the fraction of stars that are quiet. 0.2

F_{HZ} = the fraction of stars with rocky planets in the habitable zone. This is more commonly called η Earth. It is now estimated at 0.4-ish

The Seager Equation

$$N = N_* F_Q F_{HZ} F_o F_L F_S$$

N_* = the number of stars observed.

F_Q = the fraction of stars that are quiet. 0.2

F_{HZ} = the fraction of stars with rocky planets in the habitable zone. η Earth. 0.4

F_o = the fraction of those planets that can be observed. Angle, size, and other aspects that make them hard to find. Estimated at 0.001 (1 in 1,000 stars will have a planet in the right orientation for us to see it.

The Seager Equation

$$N = N_* F_Q F_{HZ} F_o F_L F_S$$

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F_o = the fraction of those planets that can be observed. 0.001

F_L = fraction with life (like before).

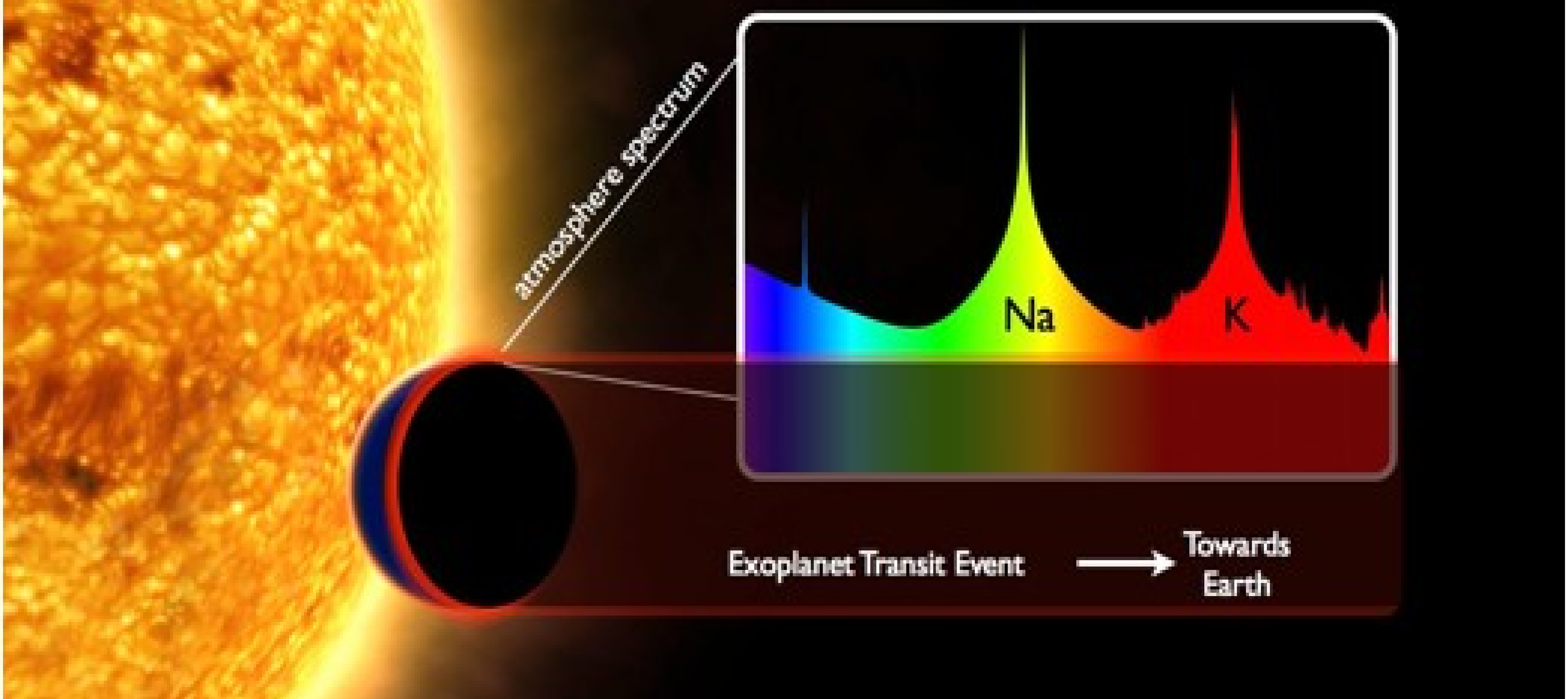
The Seager Equation

$$N = N_* F_Q F_{HZ} F_o F_L F_S$$

F_s = fraction on which life produces a detectable signature gas. Earth, Mars, and Titan all have methane out of equilibrium. The Earth has ozone (free oxygen). The Earth has chlorophyll.

So if we take a spectrum of the atmosphere, we can detect it.

Seager's interest: light from the star passes through the atmosphere of the planet. This could find a detectable signature of life.



The Seager Equation

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F_o = fraction of those planets that can be observed. 0.001

F_L = fraction with life (like before).

F_s = fraction on which life produces a detectable signature gas.

Currently there are few good numbers for the Seager Equation. However, the James Webb Space Telescope, when launched, should begin this work

What if….

- You take an optimistic approach like before?

The Seager Equation $N = N_* F_Q F_{HZ} F_o F_L F_S$

N_* = the number of stars observed.

F_Q = the fraction of stars that are quiet. 0.2

F_{HZ} = the fraction of stars with rocky planets in the habitable zone. η Earth. 0.4

F_o = fraction of those planets that can be observed. 0.001

F_L = fraction with life (like before). 1

F_s = fraction on which life produces a detectable signature gas. 1

For N to equal 1, N_* would have to be 12,500. That is, 12,500 stars would need to be observed before finding life just once.

Summary

We can estimate the likelihood of aliens existing.

- The Drake Equation has us as listeners. The aliens have to make the noise.
- The Seager Equation has us searching. We only have to measure the chemistry of planet atmospheres (currently not possible).