Life on Exoplanets?—Summary

If life is common in the universe (even just microbial life), we may know “soon”

- Search for Extraterrestrial Intelligence
    - Listening for radio (or other) signals from a technologically advanced alien civilization
        - ✓ Other astrobiology research makes slow and steady progress. SETI seeks absolute proof in one fell swoop that **we are not alone**
        - ✓ Difficult to estimate chance of success. Nevertheless, we have no hope of success unless we try. Success would be one of the **greatest discoveries in human history**
        - ✓ Scientifically, SETI represents our **only current** hope of detecting alien civilizations (historically, SETI came first, before the kind of serious astrobiology we have today)

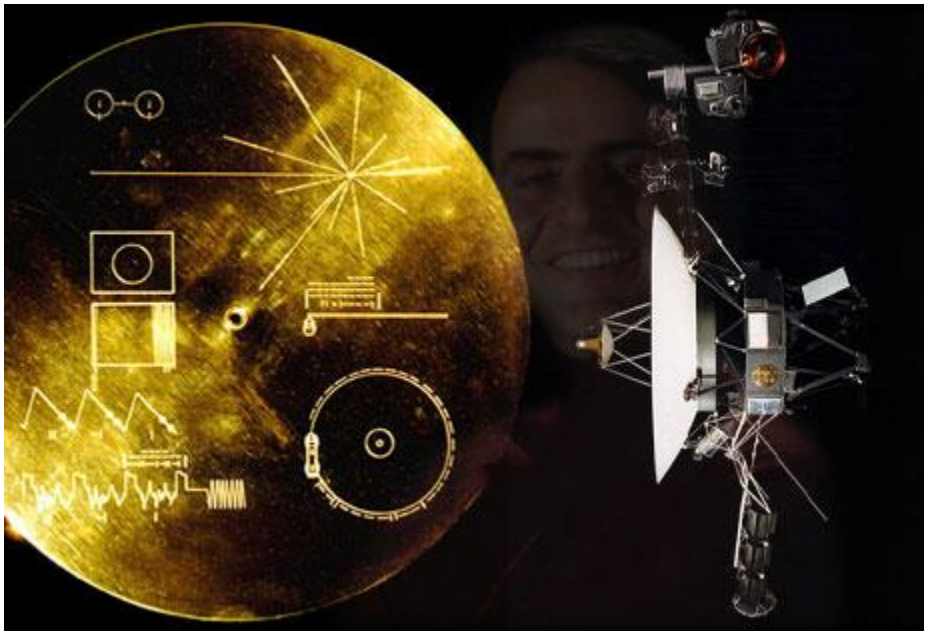
- Search for Extraterrestrial Intelligence
  - Listening for radio (or other) signals from a technologically advanced alien civilization

Are we an isolated, lone civilization, in an incomprehensibly vast cosmos?

Or is there another consciousness out there, amongst the stars?

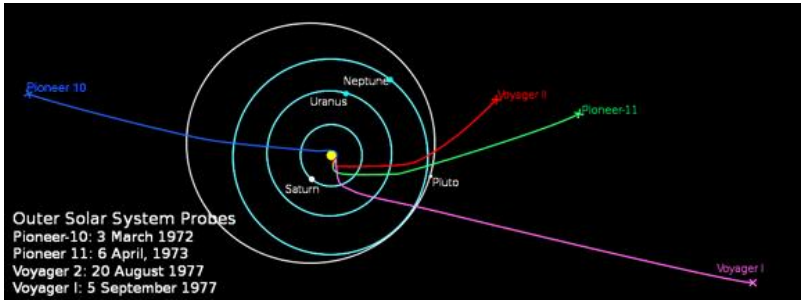
Humans are intelligent, curious, and aware of the cosmos: looking up, and listening.

- Search for Extraterrestrial Intelligence
  - Voyager 1 & 2: Galactic “message in a bottle” expresses human spirit of hope



Voyagers 1 & 2 were launched in 1977 to explore the outer solar system.

Now streaking through interstellar space (133 AU out), headed for the stars (reach in 10s of 1000s of years…).



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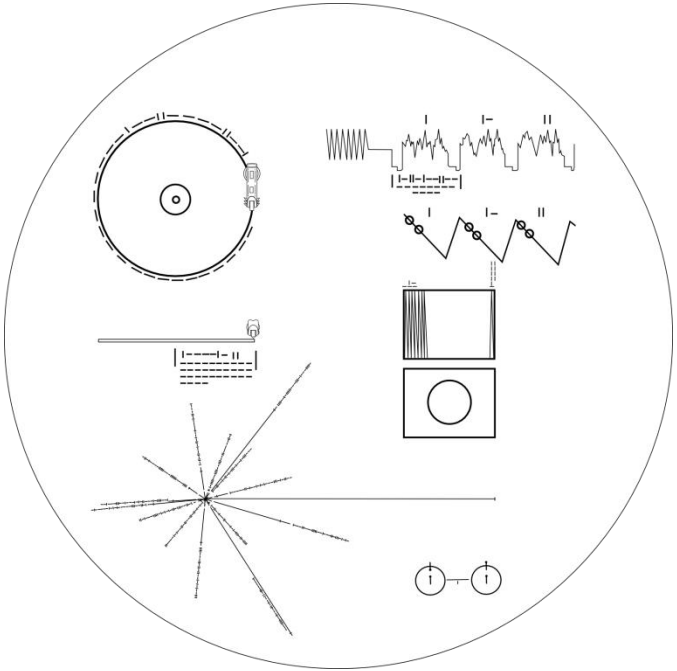
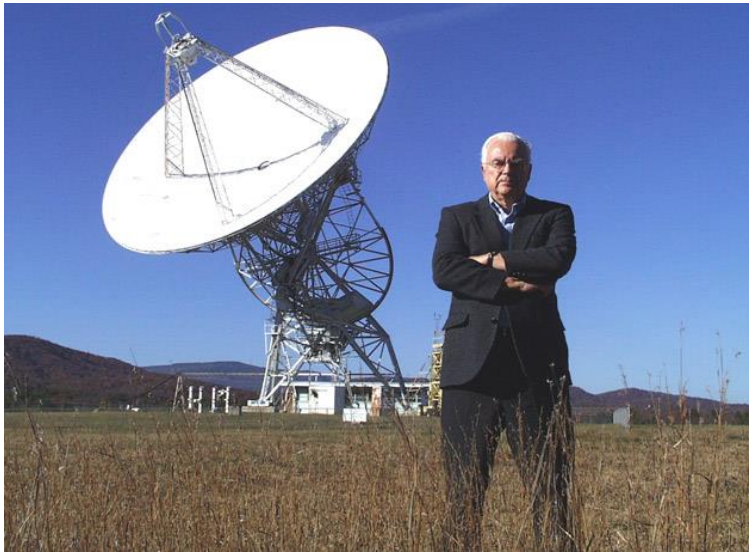


Bolted to the side of each is a gold record containing “sights and sounds of Earth”. And also a map: **How to find us**!

Info to play audio and video. Also defines **location of Sun** relative to 14 nearby pulsars.

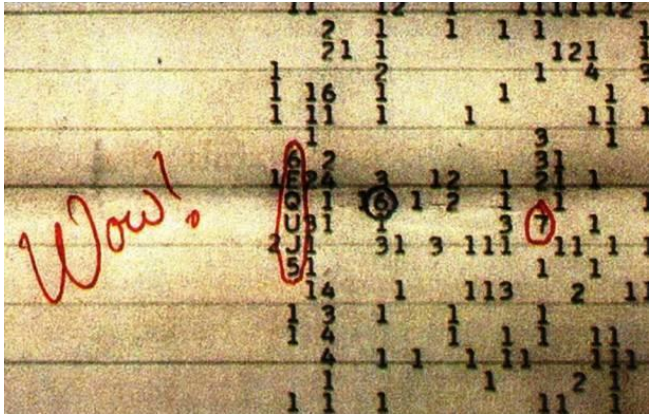
Frequencies coded in binary, relative to hyperfine 21 cm radio emission of hydrogen. (Hopefully, any civilization that knows physics would “get it”)

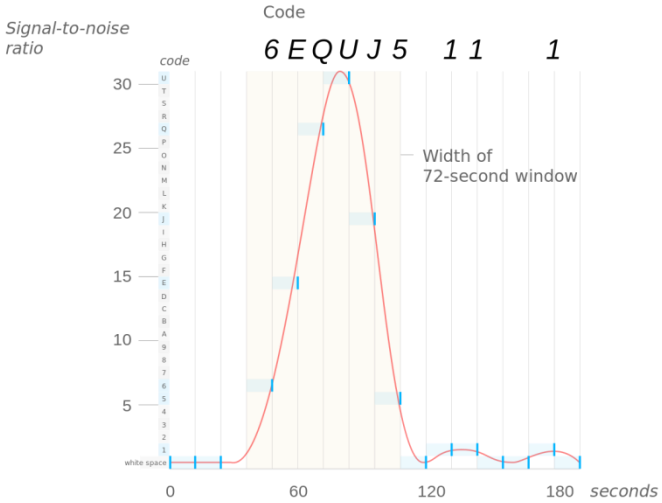
- Search for Extraterrestrial Intelligence
  - SETI originally proposed by physicists **Giuseppe Cocconi** and **Philip Morrison** in 1959
  - First organized search by astronomer **Frank Drake** in 1960 (Project Ozma)



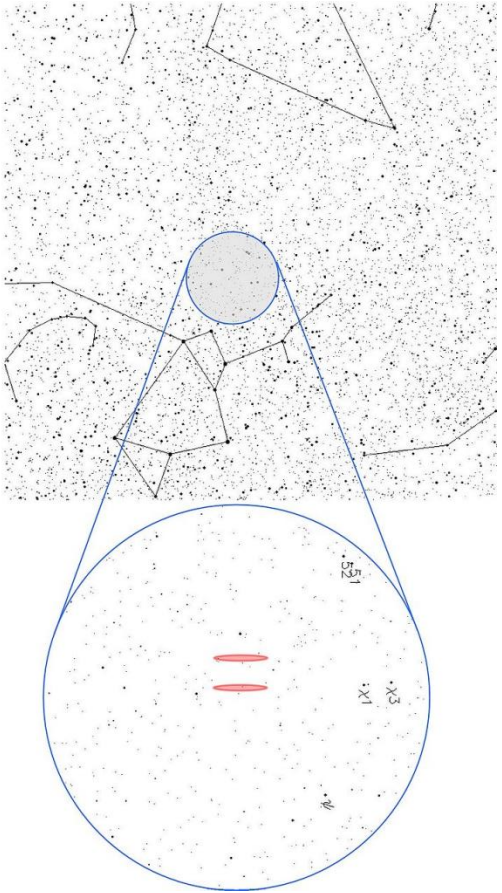
- Search for Extraterrestrial Intelligence
    - Current SETI radio search: Allen Telescope Array in California.
    - Operating near 21 cm, can detect alien civilizations (with power we have) within about a thousand light-years (about a million stars)

- Search for Extraterrestrial Intelligence
  - No success to date…but there is hope!
  - 1977 "**Wow! signal**":
    - ✓ Noticed by Jerry Ehman, a volunteer astronomer at "Big Ear Radio Observatory"
    - ✓ Peak intensity over 30 times the galactic background, at the natural, 21 cm hydrogen line (the wavelength SETI believes would be natural for aliens to communicate with)
    - ✓ Problem: Never repeated. No explanation. Not science. Just a curious anomaly…



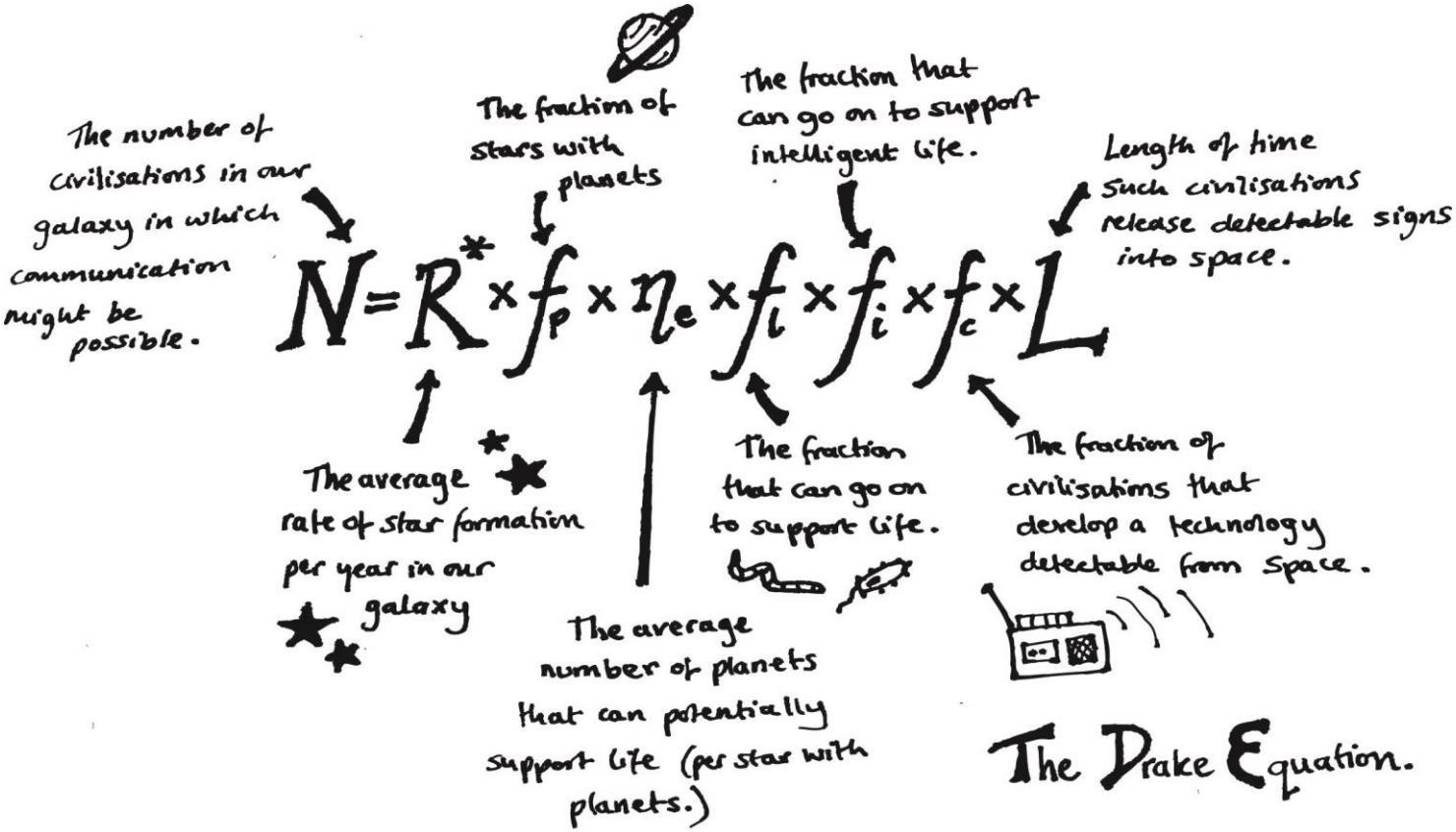


- Search for Extraterrestrial Intelligence
  - No success to date…but there is hope!
  - 1977 "**Wow! signal**":
    - ✓ 2012: Arecibo Observatory beamed a response, containing 10,000 Twitter messages



What happens if SETI succeeds?

What is the chance that SETI will succeed?


The number of civilisations in our galaxy in which communication might be possible.
The fraction of stars with planets
The fraction that can go on to support intelligent life.
Length of time such civilisations release detectable signs into space.
$N = R^* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$
The average rate of star formation per year in our galaxy
The average number of planets that can potentially support life (per star with planets.)
The fraction that can go on to support life.
The fraction of civilisations that develop a technology detectable from space.
The Drake Equation.

Drake Equation

Students come and go. The number of students in college **now** is:

$$N = (number\ of\ students\ entering\ college\ per\ year) \times (time\ they\ spend\ in\ college)$$

Stars come and go → Civilizations come and go. The number of civilizations present **now** is:

$$N = (number\ of\ civilizations\ born\ per\ year) \times (life\ span\ of\ a\ civilization)$$

$$= (stars\ born\ per\ year) \times (civilizations\ per\ star) \times (life\ span\ of\ a\ civilization)$$

$$= R^* \times (\ f_{planet} \times n_e \times f_{life} \times f_{intell} \times f_{comm}\ ) \times L$$

Drake Equation

$$N = R^* \times (f_{planet} \times n_e \times f_{life} \times f_{intell} \times f_{comm}) \times L$$

$$= (R^* \times f_{planet} \times n_e) \times (f_{life} \times f_{intell} \times f_{comm}) \times L$$

$$= \text{Astronomy} \times \text{Biology} \times \text{Sociology}$$

- **Astronomy:** Until we discovered exoplanets (especially the Kepler mission), f_p and n_e were just guesses. We now have good estimates:
  - ✓ $R^* =$ average rate of star formation in our galaxy ≈ 10 per year
  - ✓ $f_{planet} \times n_e =$ average number of planets (per star) that can potentially support life
    $\approx$ (10 billion Earth-sized planets in habitable zone of Sun-like stars) / (100 billion stars in the galaxy)
    $\approx 1/10$
  - ✓ Astronomy ≈ 1 per year

Drake Equation

$$N = R^* \times (f_{planet} \times n_e \times f_{life} \times f_{intell} \times f_{comm}) \times L$$

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- **Biology:** This is hard. We have no good estimates. ***Maybe***:
  - ✓ f_{life} = fraction of habitable planets that actually develop **simple life** at some point
    ≈ 1? (simple life seems maybe "inevitable", and on Earth began immediately)
  - ✓ f_{intell} = fraction of planets with life that actually develop **intelligent life** (civilizations)
    $\ll 1$ or ≈ 1? (is *complexity* inevitable? bottle neck? "Cambrian explosion")
  - ✓ f_{comm} = fraction of civilizations that develop sufficient communication technology
    $\ll 1$ or ≈ 1? (is technology inevitable? would they use it? could they avoid it?)

Drake Equation

$$N = R^* \times (f_{planet} \times n_e \times f_{life} \times f_{intell} \times f_{comm}) \times L$$

$$= (R^* \times f_{planet} \times n_e) \times (f_{life} \times f_{intell} \times f_{comm}) \times L$$

$$= \text{Astronomy} \times \text{Biology} \times \text{Sociology}$$

- **Sociology:** This is **even harder** to estimate. It is the real "**wildcard**".
  - ✓ $L =$ length of time for which such civilizations release detectable signals into space.
  - ✓ L may be **small**: 50 years after we invented radio, we invented the atomic bomb. Are advanced civilizations doomed to self-destruct? What about destruction by "natural causes"—we do, after all, live in a dangerous universe (asteroid impacts, etc.)
  - ✓ L may be **large**: Maybe civilizations can learn to survive their technological infancy and thrive (in spite of technology, or with its help) for millions or even billions of years, like Star Trek?

Drake Equation

$$N = R^* \times (f_{planet} \times n_e \times f_{life} \times f_{intell} \times f_{comm}) \times L$$

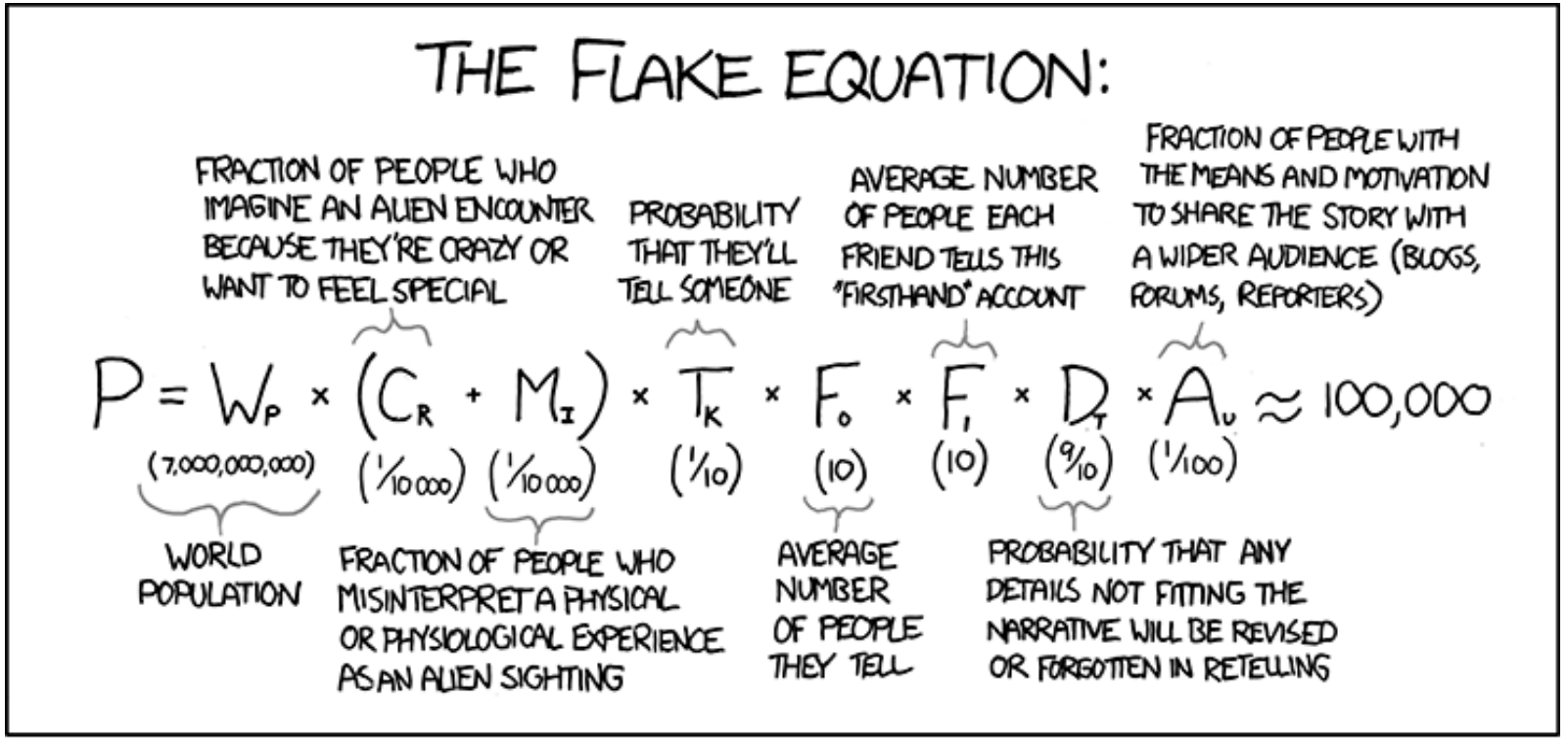
$$= (R^* \times f_{planet} \times n_e) \times (f_{life} \times f_{intell} \times f_{comm}) \times L$$

$$= \text{Astronomy} \times \text{Biology} \times \text{Sociology}$$

- **Main Point: $N \propto L$. N will be small unless L is large.**

  - ✓ If SETI succeeds relatively easily, it's because L is relatively large, i.e., not all technologically advanced civilizations are doomed to early self-destruction. This would be good news for us, since it gives us hope that the human race **can** have longevity.

  - ✓ Estimates for N range from $\ll 1$ (what does this mean?) to **millions**. Therefore, the Drake equation is *not* useful to estimate N. It *is* useful, however, to **focus our attention on interesting & important questions**.



EVEN WITH CONSERVATIVE GUESSES FOR THE VALUES OF THE VARIABLES, THIS SUGGESTS THERE MUST BE A *HUGE* NUMBER OF CREDIBLE-SOUNDING ALIEN SIGHTINGS *OUT THERE*, AVAILABLE TO ANYONE WHO WANTS TO BELIEVE!

However, the Drake equation *is* useful to **focus our attention on interesting & important questions**.

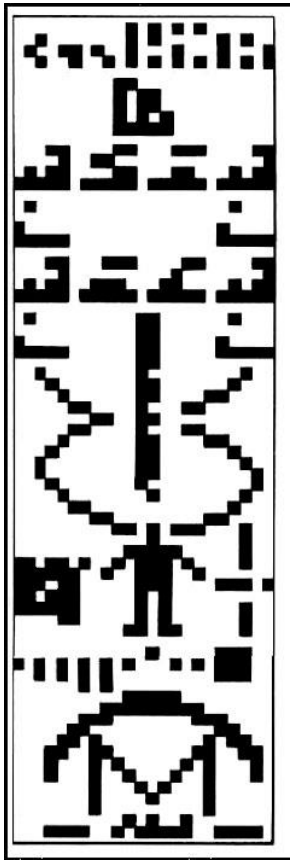
- **Questions:**

  - ✓ Even if complex life is widespread, would **intelligence** be common? Think about "**convergent evolution**" (e.g., fish body shape, eyes, brains, etc.)

  - ✓ How do we define intelligence, anyway? Would it **necessarily spawn science and technology** capable of, or even interested in, interstellar communication?

  - ✓ What **kind of communication** should we be looking for? Radio? Light? Other? What form? Could we **recognize/decode** intelligent messages?

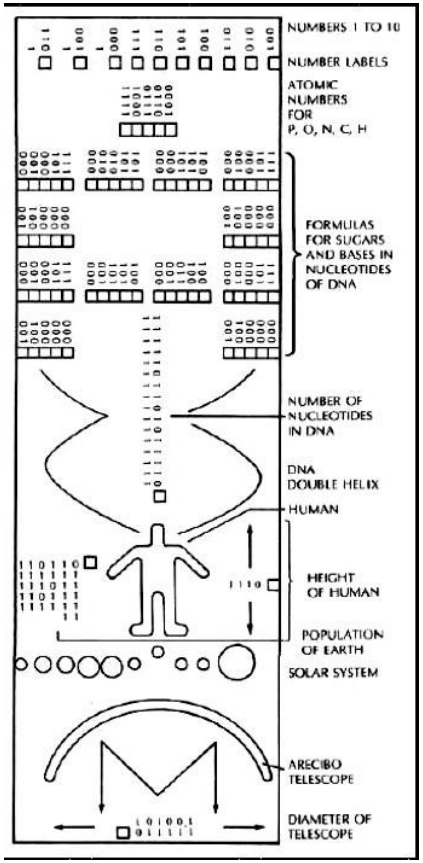
  - ✓ We've hardly transmitted anything. Why would we expect others to? Why might we **not** want to transmit anything? If we do, what **should** we transmit?



← If you detected this image…

(Beamed by the Arecibo telescope at the globular cluster M13 in 1974)

…could you figure out it meant this? →



The Fermi Paradox

- Assuming that neither we nor our planet is in any way special (Copernican principle), suggests that **aliens should have colonized the galaxy by now**. Why?

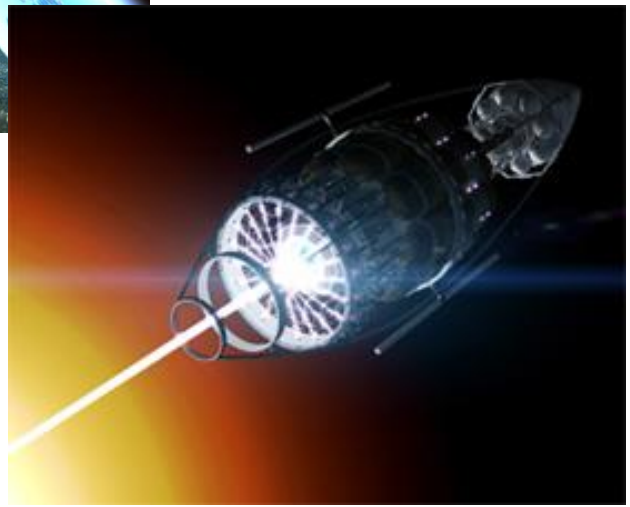
  - ✓ Not special → civilizations are common.

  - ✓ Stars in our galaxy would have had Earth-like planets starting about 5 billion years before Earth was born…giving those aliens a **5 billion year head start on us**!

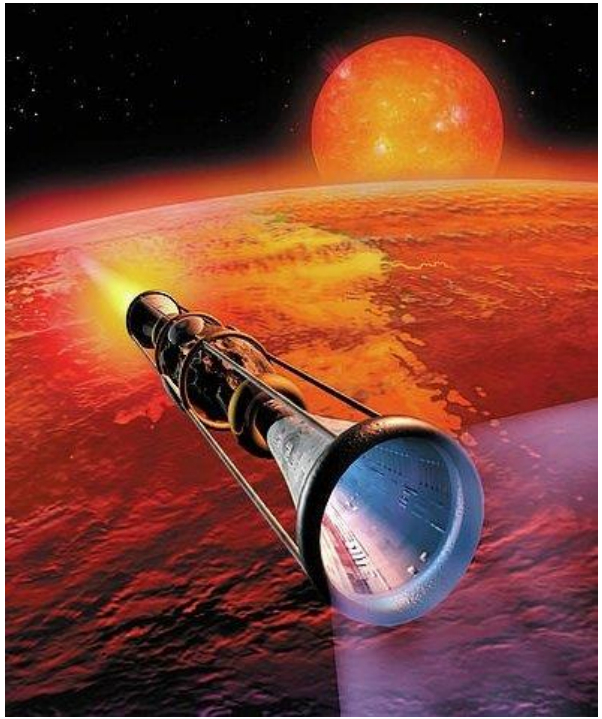
  - ✓ Interstellar space travel seems exceedingly difficult for **us**, but in just one century we have imagined **many possible ways**…

nuclear fission/fusion rocket

matter-antimatter
photon rocket

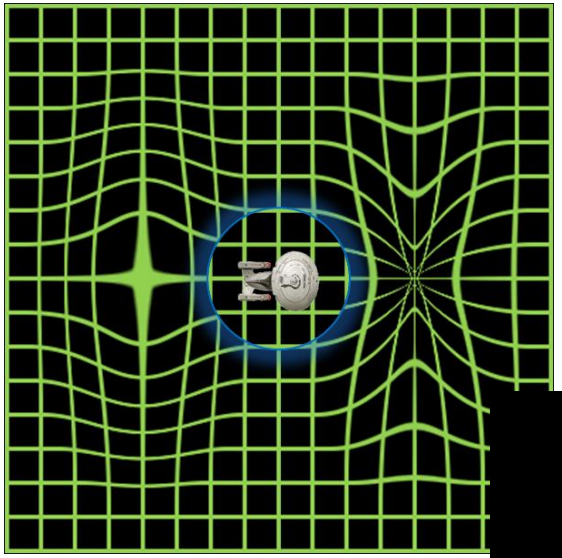


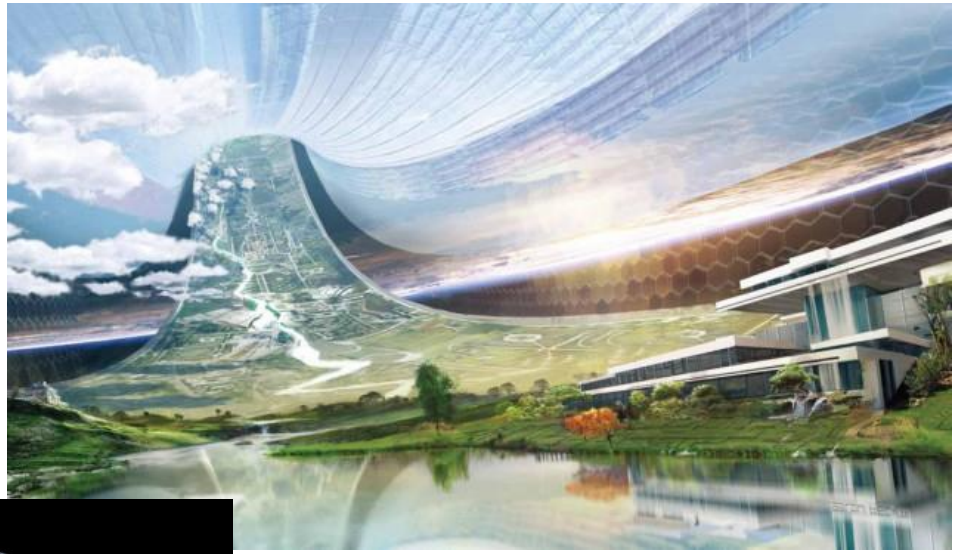
nuclear fusion ram-jet



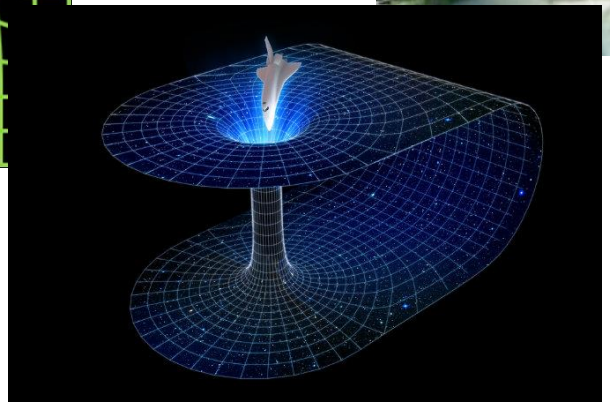
The Fermi Paradox

Einstein-friendly warp drive





Interstellar
biological ark



hyperspace/wormholes

The Fermi Paradox

- Assuming that neither we nor our planet is in any way special (Copernican principle), suggests that **aliens should have colonized the galaxy by now**. Why?

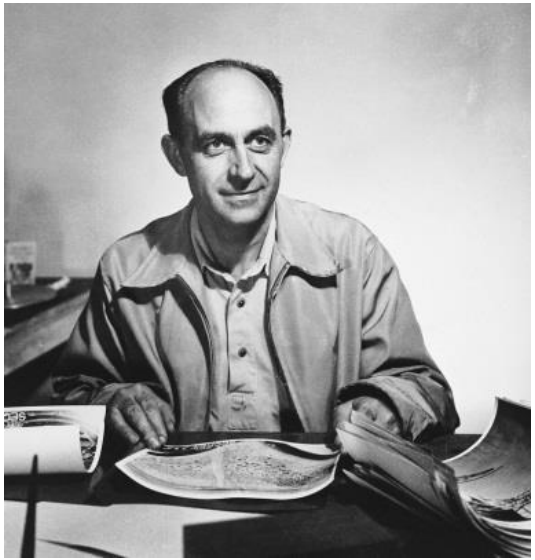
  ✓ Surely, with a 5 billion year head start, said civilizations could master interstellar travel

  ✓ …especially if they sent **self-replicating (Von Neumann) machines** instead of themselves

The Fermi Paradox

- On the other hand, if such a galactic civilization existed, we should be surrounded by evidence of it. But **apparently** we're not.

Where is Everybody?



Physicist Enrico Fermi

- **Fermi Paradox**:

  - ✓ Assuming that neither we nor our planet is in any way special suggests that aliens should have colonized the galaxy by now.

  - ✓ If such a galactic civilization existed, presumably we should be surrounded by evidence of it. But it appears we are not.

- Something is wrong with our assumptions. **What?**

- There either **is** a galactic civilization or there **is not**. There *is* a solution to the paradox, but what is it?

The Fermi Paradox

- **Possible Solutions**:
  - ✓ Galactic civilizations are extremely rare. Ours is the first. **We are alone**.
    - So what?
  - ✓ Galactic civilizations are common, but none have widely colonized the galaxy.
    - Why not? (Technology? Desire? Life Span?)
  - ✓ There is a galactic civilization, but it has deliberately avoided revealing itself to us.
    - Why?
- **Note:** Similar considerations apply to the **eerie silence** so far detected by SETI…

Extraterrestrial Life—Summary

One of these two statements is true:

- There are **billions** of habitable Earth-like worlds out there in the galaxy, and yet **we are alone**.

- There are **billions** of habitable Earth-like worlds out there in the galaxy, and **we are not alone**. There are others.

  Either way, the implications for us are **profound**

Life—Summary

- "Origin of Life," "Nature of Life," & "Extraterrestrial Life" are all very active areas of science

- Like poetry, science finds deep **connections** and **unity** between superficially disparate things:

    - *Biology & Chemistry*: Evolution & genetics have shown that all life on Earth is part of the **same family**: humans are cousins to chimpanzees, trees, fungus, etc. Biology & chemistry are even beginning to hint at how rocks themselves may have "come alive".

    - *Physics*: All physical processes, inanimate (rain and sunshine) or animate (life), obey the **same laws** of physics. At the level of basic physics, there is no distinction between a human and a steam engine. Both operate by the laws of thermodynamics; life ***may*** even be a **necessary consequence** of those laws!

- We will now extend these connections and unity even deeper, to the **entire universe itself**…