

Where are the Extraterrestrials?

What the Fermi Paradox can tell us about
alien civilizations.

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Slide 1

Albany Area Amateur Astronomers
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Notes for slide 1:

Salutations and introduction:

1. This talk is about what has come to be called “The Fermi Paradox.”
2. The Fermi Paradox was named after Physicist Enrico Fermi, who in 1943 asked: “Where are the Extraterrestrials?”
3. By this, Fermi meant that if there were advanced, extraterrestrial Intelligences, we should expect to seem them here, now.
4. But, we don’t—hence the paradox.
5. This is a bold statement, but Fermi was a smart person, and he meant the question seriously.
6. And, I take it seriously, but you are right to be skeptical—at least until the Paradox is explained in more detail.
7. Fermi has been taken seriously by active SETI (Search for Extraterrestrial Intelligence) researchers.
8. We’ll get back to Fermi’s paradox in more detail, but first an overview of what I hope to accomplish with this talk.

Overview

- What is the Fermi Paradox?
 - Why is the Fermi Compelling?
 - The Number Game
 - Proposed Resolutions
 - and their problems
 - The data so far
 - Is there room to hide?
 - Conclusions and Speculation,
 - Are we alone?
 - Further Reading
- Slide 2**

Notes for slide 2:

Overview, or “what this talk is about.”

1. What is the Fermi Paradox? Of course. I’ve given the gist, but it needs to be put in context to be understood.
2. Why Fermi’s simple question is so compelling?:
 - To understand this, you have to understand “The Number Game.”
 - Briefly put, The Number Game is that when we are talking about a large number of trials, or a long period of time, even low probability events are common.
 - For example: An event with a 1 in 1,000,000 probability of occurring each year:
 - (a) A 1 in 1000 chance of occurring once in 1000 years.
 - (b) A 1 in 1.58 chance of occurring once in 1,000,000 years.
 - (c) And, a 1 in 1 chance (to ≈ 44 decimal places) of occurring once in 100,000,000 years.
 - Even a 1 in 1 billion event is reduced to about 1 in a million after 1000 years—not bad.
3. Proposed resolutions to The Fermi Paradox, and the problem with those resolutions. (Not to give away the ending, but most fail The Number Game.)
4. The data so far, particularly is there still room for advanced civilizations to hide?
5. Conclusions and Speculation, particularly I’ll ask: “Are we alone?”
6. No single talk could cover Fermi in detail. The best I could hope to do is spark interest. So, I’ll put up a list of suggested Reading.

Underview:

Exobiology
UFOs, etc.
Critique of SETI

Slide 3**Notes for slide 3:**

There are a couple of topics this talk is *not* about.

1. Exobiology:

- Except by implication. That is, an intelligence will need an physical manifestation.
- But, those manifestations don't concern me, at least not in this talk. You may assume biological, mechanical, mammal/fish or reptile, or some combination of all or none of the above.

2. UFOs, etc.

- Some might suggest that we have seen the extraterrestrials, they are all around us. Opra had one on last week. Suffice to say I'm not convinced. 45 years of UFOs have given us *nulla*, zilch, zip in the way of evidence.
- This could be the topic of many other talks.
- Suffice to say, if you believe in UFOs, I'm asking you to suspend belief for the duration of this talk.

3. This is also not a critique of SETI.

- I think SETI is an important part of scientific inquiry, it deserves our support.
- In fact, as I hope to make clear, SETI is an integral part of research into the Fermi Paradox.

- Despite the lack of success to date, SETI has placed limits on the kind and number of extraterrestrial intelligences in our galaxy.
- But, I do think some SETI researchers are overly optimistic about their chances of success. Perhaps that's a prerequisite for the job.

Everywhere around us we see the infinite diversity of life on our planet, but nowhere else in the vast universe has any life been found. This remarkable fact—at once a measure of our ignorance and a cry of loneliness echoing through the centuries—is decidedly not a result of indifference on the part of *Homo sapiens*. . . . We have been to the Moon and Mars; we have explored the solar system to its outer limits; we have begun to listen for intelligent radio signals from our stellar neighborhood. And everywhere we find—in terms of life—desolation and silence. Still, there is no abatement in the quest for cosmic companionship; in many ways, the search has only begun.

Slide 4

Steven J. Dick, *The Biological Universe*, 1996

Notes for slide 4:

Before explaining the Fermi Paradox, I would like to put it in some historical context.

This quote, by Steven J. Dick, of the U.S. Naval Observatory, is from the opening paragraph of his book *The Biological Universe*. I think it sums up well the motivation for this talk.

1. First, the quest to find others, “like ourselves.”
That is, intelligent beings with which we can communicate. This is an old quest, going back to the ancient Greeks.
2. Second, the technical limits of our search—only just started.
So how can we say anything with certainty—especially, as I’ll claim later, that we might be alone?
3. Finally, the silence that we here extends beyond just radio signals. A universe even moderately populated with intelligent life would likely look far different than the universe we observe.

The Biological Universe, by the way, is a history of our ideas about extraterrestrial intelligences. It is a fascinating read, and about far more than just the Fermi Paradox.

What is the Fermi Paradox?

Drake equation estimates: 10–10 Million communicating civilizations

Even 1000 implies billions have existed in the past

Enrico Fermi asked: Where are they?

Slide 5 If extraterrestrials exist, should be obvious

Serious SETI Discussion
(Hart, 1975; Viewing, 1975)

Many proposed solutions, most fail “numbers game”

Even one advanced civilization could populate galaxy

Notes for slide 5:

Introduction:

1. Using Drake equation, SETI researchers estimate from 10 to a 10 million communicating civilizations.
2. But, even a modest 1000 advanced civilizations today, implies billions since formation of galaxy.
3. This question, “where are the extraterrestrials?” was asked by Physicist Enrico Fermi in 1943, and so has come to be known as Fermi’s paradox.
4. If this is true, most would be far in advance of us and have made their presence know—directly or indirectly.
5. This became a serious discussion among SETI researchers in 1976 when two independent articles were published about the Fermi Paradox.
6. Most proposed solutions, however, fail The Number Game.
7. Given enough time, enough trials, somewhere, somehow a civilization will break out, and expand. Even one advanced civilization could populated the galaxy in a blink of the astronomical eye.

The Drake Equation:

$$N = R_* \cdot f_p \cdot n_e \cdot \underbrace{f_l \cdot f_i \cdot f_c}_{\text{Complex life develops}} \cdot L$$

where:

N = Number of civilizations

R_* = Rate of star formation

f_p = fraction of stars with Planets

n_e = “Earths” / planetary system

f_l = frac. Life develops

{ $f_l * f_c$ = Complex life develops}

f_i = frac. Intelligence develops

f_t = frac. Technology develops

L = “Lifetime” of civilizations

Slide 6

Drake Equation is an estimate of Communicating Intelligences.

The total lifetime may be many times longer, both before and after.

Notes for slide 6:

The Drake equation is an attempt to elucidate some of the parameters that affect the number of communicative civilizations.

N The number of communicative civilizations in the Milky Way Galaxy whose radio emissions are detectable.

R_* The rate of formation of stars with a large enough “habitable zone” and long enough lifetime (“Sun-like”).

f_p Fraction of those “Sun-like” stars with planets.

n_e The number of “earth-like” planets per planetary system. E.g., liquid water, oxygen, other?

f_l The fraction of those planets where life develops. However, this may need to be subdivided into “life” and “complex life.” The earth had life almost as soon as it could develop, but complex life appeared 3 billion years later.

f_i The fraction life sites where intelligence develops. Life on Earth began over 3.5 billion years ago. Intelligence took a long time to develop.

f_c The fraction of planets where technology develops.

L The “Lifetime” of communicating civilizations.

It is important to note that the Drake Equation is an estimate of communicating Intelligences.

The longevity of the civilization as a whole may be many times L .

- Before L , as technology is developed, and
- After L as technology advances—fiber optic cables, low-power transmission, directed transmission, and so on.

Longevity vs. Number:

Drake: $N =$ Number of civilizations now.

Fermi: $T_N =$ Total over lifetime of galaxy.

$$T_N \propto \frac{1}{L}$$

Smaller L implies larger T_N for given N .

Billions of short-lived civilizations

Slide 7

Large L allows small T_N

A few billion year old civilizations

All possibilities in-between

None of these possibilities are satisfactory

Notes for slide 7:

1. The Drake equation estimates N , the total number of communicating civilizations right now.
2. With Fermi, we are interested in T_N , the total number of civilizations over the lifetime of the galaxy.
3. There is an inverse relation between Longevity, L and the total number T_N .
4. Smaller L implies larger T_N for a constant N .
5. Small L implies larger T_N , for a given Drake N .
This implies billions of short-lived civilizations in order for there to be 1,000 civilizations today.
6. Long L allows small T_N , but
that implies civilization with a longevity of billions of years.
7. Everything in-between.

8. From the standpoint of Fermi's Paradox, none of these possibilities are satisfactory.

- We have billions of civilizations, which fail to make a noticeable impact.
- Or, a few that sit twiddling their thumbs for a billion years.
- Or both—not an optimistic picture of intelligence.

Kardashev Civilization Types:

Type I: Power of sunlight on planet ($\approx 10^{16}$ W)

Type II: Power output of star ($\approx 10^{27}$ W)
Dyson Sphere

Type III: Power of galaxy ($\approx 10^{38}$ W)

Using Arecibo Earth is potential type log 0.7 (10^{14} W)
civilization.

Slide 8

Notes for slide 8:

Why is longevity Important?

1. Nikolai S. Kardashev proposed a hierarchy of Civilizations based on the power they could extract from their environment. This was later extended by I.S. Shklovskii and Carl Sagan, often described as “The Bible” of SETI.

Type I: Power of sunlight on planet ($\approx 10^{16}$ Watts)

Type II: Power output of star ($\approx 10^{27}$ Watts)

Type III: Power of galaxy ($\approx 10^{38}$ Watts)

2. A Watt is the SI unit of power, 1 joule of energy dissipated in 1 second. (A J. is one Newton/meter).
3. Earth is type log 0.7 civilization.
4. Type II and Type III civilizations, if they exist, should be noticable.
5. Even a measly type 0.7 like Earth (at our noisiest) sends out tremendous waste EM.

Advanced Technologies

Dyson Sphere, or other Astro-Engineering
by Type II and Type III civilizations
Kardashev & Sholomitskii, 1963
Drake & Sagan, 1976–1976

Longevity Research
Average lifetime increasing
Not yet extended maximum lifespan
What would a long-lived human do?

Slide 9

Fusion by-products
Propulsion by-products
Heavy metal enrichment of stars

Notes for slide 9:

What should we see?

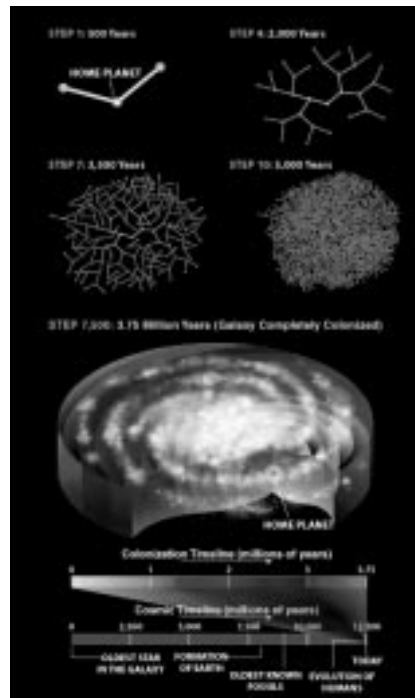
1. As civilization advances, it uses more power, seeks out more sources of power, and eventually begins to harvest power on a stellar scale.
2. In 1960 Freeman Dyson suggested that one method of providing this energy would be to collect more solar energy using a swarm of solar collectors and habitats. One side effect would be to shift a star's output towards the infrared.
 - Kardashev and Sholomitskii, 1963 searching 920 Mhz.
 - Drake and Sagan, 1975–1976 used Arecibo to search four galaxies for Kardashev Type II civilizations.
3. Longevity Research.
 - So far we have increased the average human lifespan, but we have not extended the maximum lifespan.
 - It is conceivable that in the next 100, or maybe 1000 years we will be able to greatly extend human life.
 - If humans lived to be 500, 1000, 10,000 or more years, a trip to another star system can be made in less than one lifetime.
 - Might be the only way to have children in a society of long-lived intelligence.
 - This is also a good way to appreciate The Number Game: Perceptions of Lottery, Investments, Games and Risk, all change.

4. Some other technologies:

- Fusion by-products.
- Propulsion by-products.
- Heavy metal enrichment as fusion waste is disposed of in stars.

Galactic Population Explosion

Slide 10



Crawford, *Scientific American*, July, 2000

Notes for slide 10:

This is all post Fermi.

1. When Fermi said “Where are they?” he meant “Why aren’t they here?”
2. The first civilization to develop technology would likely populate the galaxy in a blink of the astronomical eye.
3. This example is from the July 2000 *Scientific American*.
4. Sub-light, interstellar flight difficult, but possible. Numerous proposals have been made since the start of the space age.
5. Even slow expansion sufficient:
 - 10% light speed (Orion)
 - 10 light-year distance between colonies
 - 100 year trip to next colony
 - 400 years between foundation and first colonizing ship
 - wave front moves at 0.02 light speed
 - 5 million years to colonize the galaxy

- only 0.05 percent age of galaxy.

6. Why Expand?

- Growing population.
- Social and Religious causes
- Something to do during the first 1 million years of your youth—like our trips to Europe.
- Survival—before stellar evolution destroys planet. (If N is large, several civilizations have faced this already.)

7. But, it is not necessary to expand using natural bodies.

- Robotic probes.
- von Neuman machines.
- Artificial life adapted to interstellar travel (Dyson).

Proposed Resolutions:

Interstellar Travel Not Possible
(Expensive, Impossible, Hazardous)

Travel is too slow (Newman & Sagan, 1981)
Interaction slows colonization (Turner, 1985)

Civilizations Not Detected (Ball, 1973; Papiannis, 1978; Stephenson, 1979)

Slide 11

Limits to Growth (Morrison, 1985)

Lack of Interest (Finney, 1985; Wolfe, 1985)

Advanced Civilizations short lived

Chemical Enrichment of Galaxy
47 Ursus Majoris

Multicellular life is rare

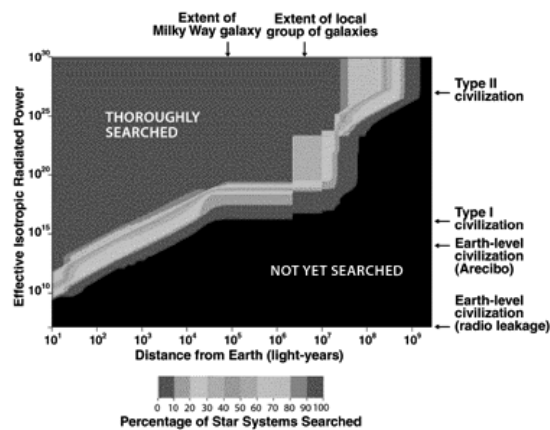
Notes for slide 11:

1. Interstellar Travel Not Possible: It is either too expensive, too hazardous. This is Drake's solution. The problem is, we see no technical obstacles, especially if lifespan is increased.
2. Interstellar travel might be taking place, but it is too slow, so they just have not gotten here.
3. Interactions (also known as competition, warfare, etc.) slows expansion. (Well, it didn't slow colonial expansion). Maybe, but for billions of years?

4. One possibility is they are here, but remain undetected. I said I wasn't going to talk about this, but would like to point out that Ball, Paginannis, and Stephenson are suggesting things like looking for signs of fusion or anti-matter drives, or checking the asteroid belt for extraterrestrial probes.
5. It could be that extraterrestrials just are not interested in travel or communication. Ok, maybe, but all of them for all time? This proposal fails The Number Game.
6. Advanced Civilizations short lived. Maybe, but all of them?
7. Chemical Enrichment of Galaxy: Maybe, but if 1/10th current enrichment enough then even older stars could form life.
8. 47 Ursus Majoris has Jupiter mass planet, but is 7 billion years old—3 billion more than our sun.
9. Multicellular life is rare: Took billions of years to evolve on Earth.

Results Of SETI Programs

Slide 12



LePage, *Scientific American*, July, 2000

Notes for slide 12:

Results Of SETI Programs are summarized in this diagram from the July 2000 *Scientific American*.

- Transmitter strength is on the vertical axis.
- Distance from earth is on the horizontal axis.
- Both scales are \log_{10} .
- The black area shows which civilizations could have eluded radio searches, either because:

- they are too far away, or
- their transmitters are too weak.
- To make sense of this diagram:
 - Choose a transmitter strength,
 - read across to the edge of the black area, and
 - trace down to find the distance from Earth.
- For example, an Arecibo-class transmitter of 10¹⁴ watts must be farther away than about 4,000 light-years to have eluded the searches altogether.

Obstacles to complex life:

Changing spin rate of planet
 Moving out of “habitable zone”
 Changing energy output of star
 Impact of comet or asteroid
 Nearby supernova
 Cosmic ray jets and gamma ray explosions
 Catastrophic climate change:
 Icehouse and Runaway Greenhouse
 The Emergence of intelligent organisms

Slide 13

Ward and Brownlee, *Rare Earth*, 2000

Notes for slide 13:

Obstacles to complex life:

I’ve already noted that while life appeared on the Earth almost as soon as it could, complex life didn’t appear for another 3 billion years. This implies that while life may be common, multicellular life is rare—and by extension intelligent life even rarer.

What barriers are there to multicellular life?

1. Changing spin rate of planet. We take 24 hour days for granted. But, looking at our neighbors we see large variability in spin rate. Spin rate affects temperature (tidal lock is an extreme).
2. Moving out of “habitable zone.” Life needs water, which implies a mean temperature between 0–100 C. Perturbation of orbits affects life.
3. Changing energy output of star. Also affects mean temperature and habitable zone.

4. Earth maintains temperature via homeostasis involving albedo and CO² cycle. (Gaia-hypothesis.)
5. Impact of comet or asteroid: Mass extinction. Large outer planets may be necessary to sweep up debris.
6. Nearby supernova: A supernova within 30 light years would strip the Earth's Ozone in 300 years. Estimates that at least one in the last 500 million years, frequency on order of 1 in 300 million years. More closer to the galactic center.
7. Cosmic ray jets and gamma ray explosions from colliding neutron stars. Physicist James Annis calculates such an explosion is lethal to life in much of the galaxy. Rate ≈ 1 every few hundred million years.
8. Catastrophic climate change:
 - (a) Icehouse: 600 million years ago, ended before Cambrian explosion.
 - (b) Runaway Greenhouse
9. The Emergence of intelligent organisms: Accumulating evidence that the presence of humans has triggered a 6th mass-extinction event. (Peter Ward.)

Summary and Conclusion:

Fermi's paradox does impose limits

Type II and III are rare

Type I not common

It is not easy to dismiss Fermi

T_N vs. L tradeoff

Fermi shows how much we don't know

Slide 14

Complex life might be rare

Intelligence might be very rare

Notes for slide 14:

Summary and Conclusion:

1. Fermi's paradox does impose limits
2. Type II and III are rare

3. Type I not common.
4. It is not easy to dismiss Fermi: Over long periods of time or billions of trials, even low probability events become common.
5. There is a tradeoff between T_N and L . When a SETI researcher guesses that there are 1,000 Communicating civilizations, this is very optimistic.
6. Fermi shows how much we don't know
7. Complex life might be rare
8. Intelligence might be very rare

... an analysis of the facts discussed precludes, with a high degree of probability, the possibility of super-civilizations existing, not only in our Galaxy but also in all the local systems of galaxies (e.g. the Nebula of Andromeda). Since some part of the more primitive civilizations of the terrestrial type, after overcoming numerous crisis situations, must take to the road of unlimited expansion, we must draw the logically inevitable conclusion that the number of civilizations of the terrestrial type in the local system is either insignificant, or, what is most probable, does not exist

Slide 15

Shklovskii, Interview *Moscow News Weekly*, 1978

Notes for slide 15:

Closing Quote:

1. This quote very well sums up the Fermi paradox, and it's implications.
2. It is by I.S. Shklovskii, the same Shklovskii who is Carl Sagan's co-author in *Intelligent Life in the Universe*.
3. It is interesting to note that the earliest attempts to find super-civilizations were soviet.
4. Early on, many researchers did expect intelligent life to be common with Type II and maybe even some Type III civilizations.
5. Are well alone?
 - Maybe, but

- that means what we do have Intelligence, should not be squandered.
- SETI researchers sometimes wax poetic about the implications of a positive finding.
- Maybe they should give more consideration to the even greater implications of a negative finding.
- We may be the custodians of Intelligence.

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