

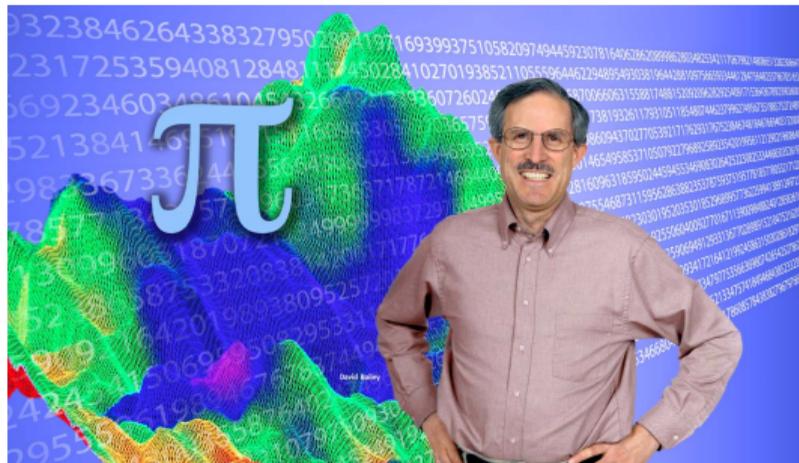
Fine tuning and Fermi's paradox

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A “freakishly” fine-tuned universe

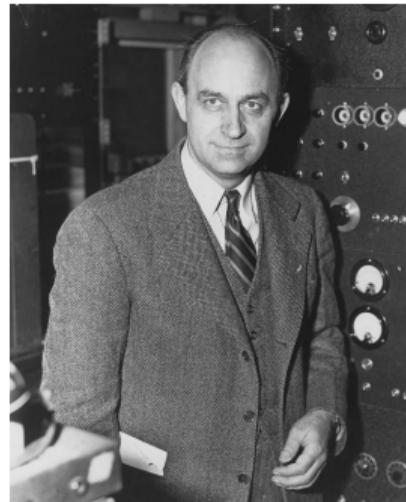
1. The synthesis of carbon depends sensitively on the value of the strong force.
2. The existence of protons and neutrons depends sensitively on the strong and weak forces.
3. If the electromagnetic force were not roughly 10^{40} times stronger than gravity, the heavier elements would not form.
4. If the neutron mass were very slightly less, the universe would be entirely protons.
5. The cosmic microwave background is just nonuniform enough (one part in 10^5) to permit galaxies to form.
6. The positive and negative contributions to the vacuum energy density cancel to within one part in 10^{120} (the cosmological constant paradox).
7. The positive and negative contributions of the Higgs boson mass cancel to within one part in 10^{19} to give the anomalously low value we observe.
8. Shortly after the big bang, the universe must have been flat to within one part in 10^{15} .
9. The overall entropy of the universe is “freakishly lower than life requires.”

- ▶ G. F. Lewis and L. A. Barnes, *A Fortunate Universe: Life in a Finely Tuned Cosmos*, CUP, 2016.
- ▶ M. J. Rees, *Just Six Numbers: The Deep Forces that Shape the Universe*, Basic Books, 2000.

Fermi's paradox

In 1950, while having lunch with colleagues, Enrico Fermi asked, **Where is everybody?**

- ▶ Presumably there are thousands if not millions of other technological civilizations in the Milky Way galaxy alone.
- ▶ Any technological civilization is, almost certainly, many thousands or millions of years more advanced than us.
- ▶ Within a few million years after becoming technological (an eye-blink in cosmic time), a society could have explored and/or colonized most if not all of the Milky Way.
- ▶ So why don't we see evidence for the existence of even a single extraterrestrial (ET) civilization?



Credit: Wikimedia

My thesis

- ▶ Recent dramatic developments in technology have all but destroyed the most common and plausible solutions to Fermi's paradox.
- ▶ Fermi's paradox significantly deepens the conundrum of universal fine tuning.

In the following, we will assume only that:

- ▶ The laws of physics, as currently understood, apply over several billion light-years of space and several billion years of time.
- ▶ Any technological ET civilization consists of a society of individuals, has arisen via Darwinian evolution, and thus is subject to principles of diversity and natural selection.

We do NOT assume:

- ▶ ET individuals are carbon- or water-based, or that their biology is based on DNA.
- ▶ ET societies have invented exotic communication or transportation technologies (e.g., space-warp travel) beyond what we can envision from well-known physics.

The grim mathematics of Fermi's paradox

Let p be the probability that an individual on a given planet in a given year launches an interstellar exploration, m be the number of individuals on a typical planet, n be the number of planets, and t be the number of years. Then the probability P that a civilization has explored the Milky Way can be estimated as:

$$P = 1 - (1 - p)^{mnt}$$

Conservative estimates for the Milky Way:

$$m > 10^9, \quad n > 10^{11}, \quad t > 5 \times 10^9.$$

For the universe as a whole, $n > 10^{22}$ and $t > 10^{10}$.

In other words, if the probability of the rise of a space-faring civilization anywhere is even microscopically nonzero (given the instance of human civilization), then after billions of years, on many billions of planets, with billions of individuals, ET should be everywhere. **Where is everybody?**

Proposed solutions to Fermi's paradox: The “zookeeper” solution

Solution 1: They exist, but are under strict orders not to communicate with a civilization such as Earth.

Rejoinder: In numerous vast, diverse ET civilizations (or even in just one ET civilization), each spanning multiple planets or stars, and, most likely, consisting of millions of individuals, it is hardly credible that a galactic society could impose a global ban on communication to Earth that is absolutely 100% effective.



Credit: Huffington Post

Once a signal has been broadcast and is on its way to Earth, there is no way to call it back, within known laws of physics. And for a civilization that is thousands or millions of years more advanced than us, such communication would be vanishingly cheap.

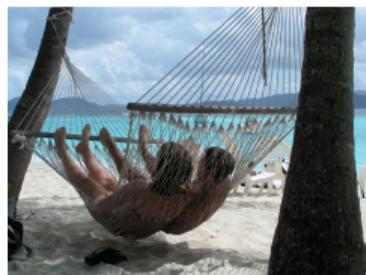
For the next several viewgraphs, see:

- ▶ Paul Davies, *The Eerie Silence: Renewing Our Search for Alien Intelligence*, Houghton Mifflin Harcourt, New York, 2010.
- ▶ John Gribbin, *Alone in the Universe*, John Wiley, New York, 2011.
- ▶ Stephen Webb, *If the Universe Is Teeming with Aliens... Where Is Everybody? Fifty Solutions to Fermi's Paradox and the Problem of Extraterrestrial Life*, Copernicus Books, New York, 2002.

The “beach bum” solution

Solution 2: They exist, but have lost interest in scientific research, exploration and expansion.

Rejoinder: Darwinian evolution strongly favors organisms that think, explore and expand. Thus it is hardly credible that every individual in every ET civilization has lost interest in scientific research, exploration and expansion, or that a global ban on such activities is absolutely 100% effective.



Credit: Wikimedia

What's more, any ET society's long-term existence crucially hinges on having an in-depth scientific understanding of all potential perils in its cosmic environment:

- ▶ Asteroids, meteorites and solar flares.
- ▶ Supernovas.
- ▶ Gamma ray bursts.
- ▶ Neutron star mergers.
- ▶ Potentially dangerous biological systems.
- ▶ Potentially hostile neighbors.

The “humans are ants” solution

Solution 3: They exist, but have no interest in a primitive, backward society such as ours; to them, we are as ants.

Rejoinder: Perhaps 99.99% of an ET society is not interested in primitive societies such as ours. **But, as before, it is hardly credible that every individual in every ET civilization has no interest.**

In our society, perhaps 99.99% of the public has little or no interest in ants. But many thousands do. There is even a full-fledged scientific field (myrmecology) to study ants, and researchers have meticulously catalogued and studied every known species.



Credit: Wikimedia

The “advanced communication” solution

Solution 4: They exist, but have progressed to more sophisticated communication technologies.

Rejoinder: This does not apply to signals that are specifically targeted to societies such as ours, in a form (optical, microwaves) that could be easily recognized by a newly technological society.

Again, it is hardly credible that a galactic society could enforce a global ban, over a vast array of inhabited planets, each with millions of individuals, on communication targeted to emerging technological civilizations, that is absolutely 100% effective.

As noted before, once a signal is on its way to Earth, it cannot be called back, within known laws of physics.



Credit: Australian National Telescope Facility

Diversity and Fermi's paradox

Similar diversity arguments defeat a wide range of other proposed solutions:

- ▶ Darwinian evolution is the only known or hypothesized mechanism whereby high-information organisms and species (carbon-based or not) can form.
- ▶ Diversity is a fundamental, inescapable law of Darwinian evolution.
- ▶ Diversity is also a law of economics, political science, organizational behavior, and even physics (quantum superposition, sum over histories, chaos, anisotropy in the CMB, etc.).
- ▶ Highly conformist species, societies and organizations inevitably fail.
- ▶ All great figures of history were nonconformists: Albert Einstein, Martin Luther King, Susan B. Anthony, Nelson Mandela, Steve Jobs. Jobs' motto was "think different."

In a vast, diverse society, there will be exceptions to any rule. Thus claims that "all ET are like X" have no credibility, no matter what "X" is.

It is ironic that while most scientists would reject stereotypes of religious, ethnic or national groups, some seem willing to hypothesize sweeping, ironclad stereotypes for ET societies.

- ▶ Stephen Webb, *If the Universe Is Teeming with Aliens... Where Is Everybody? Fifty Solutions to Fermi's Paradox and the Problem of Extraterrestrial Life*, Copernicus Books, New York, 2002.

The “no evidence of humans” solution

Solution 5: They exist, but are not aware of our existence yet — our first TV signals have only passed 80 light years' distance.

Example: Lawrence Krauss (Canadian physicist/cosmologist), on the PBS show “The Farthest — Voyager in Space” (aired 26 November 2017 in the U.S.):

Over the last four and a half billion years, the only evidence of intelligent life was in the last 50 to 60 years, by watching Star Trek or I Love Lucy, or whatever — signals we sent out. So even if someone told you “look at that star, and look at the third rock from that star, that’s where you will find life,” even if [you] knew which object to look for, there is only a 50 year period over 5 billion years, almost, where you would be able to find intelligent life.



Credit: J. Vangiel

The “no evidence of humans” solution, continued

Rejoinder: Ample evidence of an emerging technological civilization on Earth has been on display for much longer:

- ▶ Our atmosphere has contained methane, oxygen and other chemical signs of life for at least three billion years.
- ▶ Images of Earth would have shown dinosaurs and countless other large species for at least 300 million years.
- ▶ Images of Earth would have shown bipedal hominins for at least 5 million years, and humans for at least 200,000 years.
- ▶ Images of Earth would have shown large human structures (Mesopotamia, Egypt, China, Rome) for at least 10,000 years.
- ▶ Urban lights have been on display for at least 2,000 years, and especially in the past 200 years.
- ▶ Atmospheric carbon dioxide has been on the rise for 200 years.



Credit: NASA

Again, it is hardly credible that *all* of this evidence has been overlooked by *all* ETs.

The “technological” solution

Solution 6: They exist, but travel and communication are too difficult.

Rejoinder: Recent dramatic and largely unanticipated developments in technology in the past few years have all but destroyed this solution:

- ▶ New energy sources.
- ▶ New propulsion systems.
- ▶ New space exploration vehicles.
- ▶ Supercomputers (currently run at 10^{17} flop/s).
- ▶ Artificial intelligence.
- ▶ Robotics, 3-D printing and nanotechnology.
- ▶ Exoplanet search and imaging technology.
- ▶ Gravitational lenses.
- ▶ von Neumann probes.



Credit: SpaceX

New energy sources

- ▶ German physicists have announced that have successfully contained helium plasma in a stellerator-type fusion reactor.
- ▶ Lockheed Martin is developing a 100-megawatt fusion reactor only 2×3 meters in size — small enough to fit in a spacecraft.
- ▶ TriAlpha Energy of San Diego has been developing a fusion reactor. They have reported heating a plasma of hydrogen fuel to 10 million C.
- ▶ Brillouin Energy of Berkeley claims, in a patent application, to generate thermal energy by “neutron generation and capture.”
- ▶ Andrea Rossi of Florida has publicly demonstrated a “low-energy nuclear reactor” process. The effect has been reproduced by a team of Swedish and Italian researchers, and has been granted a U.S. patent.

Numerous others could be listed.

Even taking a highly skeptical approach to these individual projects, one way or another new clean energy sources are coming, with compelling potential applications for space travel (and thus for Fermi's paradox).

New propulsion systems

- ▶ *Ion propulsion*: A high-energy electron collides with a xenon atom, releasing electrons, and the charged atom is then discharged at high speed (up to 150,000 kph).
- ▶ *High-power electric propulsion*: The xenon ions are produced by a combination of microwave and magnetic fields, using electron cyclotron resonance.
- ▶ *Fusion-driven rocket*: A fusion energy source releases its energy directly into a lithium propellant, without converting to electricity.



Credit: NASA

For details, see:

<http://www.nasa.gov/centers/glenn/about/fs21grc.html>

<http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20040139476.pdf>

https://www.nasa.gov/directorates/spacetech/niac/2012_phaseII_fellows_slough.html

Yuri Milner's plan to explore Alpha Centauri

Russian billionaire Yuri Milner, backed by Stephen Hawking and Mark Zuckerberg, proposes to send “nanocraft” to explore Alpha Centauri and its planets:

- ▶ Thousands of credit-card-sized spacecraft.
- ▶ Launched by giant solar sails, pushed by earth-bound lasers.
- ▶ Travel at up to $0.2c$, arriving in 20 years.
- ▶ Upon arrival, send back images and other data via laser beams, which will arrive at Earth four years later.



Credit: Bloomberg

For details, see:

[http:](http://www.scientificamerican.com/article/100-million-plan-will-send-probes-to-the-nearest-star1/)

[//www.scientificamerican.com/article/100-million-plan-will-send-probes-to-the-nearest-star1/](http://www.scientificamerican.com/article/100-million-plan-will-send-probes-to-the-nearest-star1/)

Elon Musk's vision for space exploration

- ▶ SpaceX is designing a new, more powerful rocket that could transport humans to Mars.
- ▶ SpaceX plans to fly two cargo ships to Mars in 2022, and two crew ships and two cargo ships in 2024.
- ▶ The ship will feature 40 cabins, each of which would house two or three persons, with a capacity of 100 persons per flight.



Credit: SpaceX

The ultimate goal is to create a new society on Mars, making humans a true multi-planetary species.

For details, see:

[https:](https://news.nationalgeographic.com/2017/09/elon-musk-spacex-mars-moon-bfr-rockets-space-science/)

[//news.nationalgeographic.com/2017/09/elon-musk-spacex-mars-moon-bfr-rockets-space-science/](https://news.nationalgeographic.com/2017/09/elon-musk-spacex-mars-moon-bfr-rockets-space-science/)

A round trip to Mars with a human crew

Fuel for a return trip from Mars could be produced *in situ* on Mars (otherwise transporting fuel to Mars for the return trip is 90% of the outbound payload):

- ▶ CO₂ can be extracted from Martian atmosphere.
- ▶ H₂ can be produced by using electricity to electrolyze Martian ice (producing oxygen for astronauts as byproduct).
- ▶ Then this *exothermic* reaction can be used to produce fuel:
$$3 \text{ CO}_2 + 6 \text{ H}_2 \rightarrow \text{CH}_4 + 2 \text{ CO} + 4 \text{ H}_2\text{O}.$$

A fully fueled lift-off vehicle could be ready on Mars before the astronauts leave Earth.

For details, see:

<http://www.marssociety.org/home/about/faq/>



Credit: Mars Society

Artificial intelligence: DeepMind's AlphaGo Zero teaches itself to play Go

- ▶ Until two years ago, observers had not expected computer Go programs to defeat humans for years, if not decades. But in May 2017 DeepMind's AlphaGo program beat Ke Jie, the world's highest-rated player.
- ▶ In October 2017, DeepMind researchers programmed an AI computer with the rules of Go, then had the program play itself, teaching itself with no human input.
- ▶ After just three days of training, the resulting program "AlphaGo Zero" defeated AlphaGo 100 games to 0.
- ▶ Ke Jie's Elo rating is 3661. After 40 days of training, AlphaGo Zero's Elo rating was over 5000, as far above Ke as Ke is above a good amateur.
- ▶ "The latest AI can work things out without being taught," *The Economist*, 21 Oct 2017, <https://www.economist.com/news/science-and-technology/21730391-learning-play-go-only-start-latest-ai-can-work-things-out-without>.
- ▶ R. Parloff, "Why deep learning is suddenly changing your life," *Fortune*, 28 Sep 2016, <http://fortune.com/ai-artificial-intelligence-deep-machine-learning/>.



Credit: Wikimedia

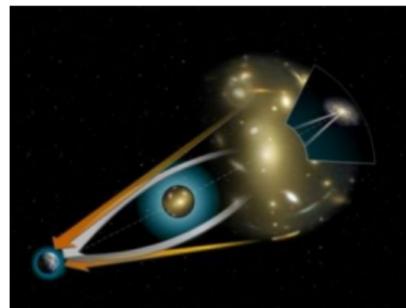
Gravitational lenses

Gravitational lenses, using the Sun as a lens according to general relativity, can be used to produce close-up images of distant planets and civilizations. Magnifications of 10^{15} may be achieved.

Since there is no chromatic aberration, gravitational lenses can also monitor a distant civilization's microwave communications (or any other form of electromagnetic communication).

What's more, we could send images and communications to them. Such a project would be quite costly today, but in 20, 50 or 100 years?

Are other civilizations using gravitational lenses to see close-up images of Earth? Or even to send messages to Earth? Why not?



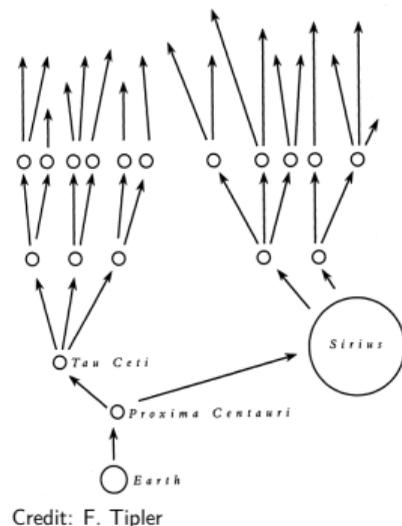
Credit: FOCAL project

- ▶ G. A. Landis, "Mission to the gravitational focus of the Sun: A critical analysis," NASA Glenn Research Center, <https://arxiv.org/pdf/1604.06351.pdf>.

von Neumann probes

“von Neumann probes” could be sent to distant solar systems, which could land and construct additional copies of themselves, using the latest software beamed from the home planet.

Detailed studies of a “slingshot” exploration scheme show that a single civilization could explore the entire Milky Way within five million years.

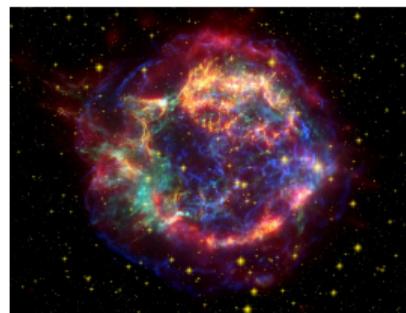


- ▶ A. Nicholson and D. Forgan, “Slingshot dynamics for self-replicating probes and the effect on exploration timescales,” *International Journal of Astrobiology*, 2 Jul 2013.

The “self-destruct” solution

Solution 7: Civilizations like us invariably self-destruct before becoming a space-faring society.

Rejoinder: In 200 years of technological adolescence, we have not yet destroyed ourselves through a nuclear, environmental or biological catastrophe. Further, we have developed sophisticated supercomputer simulations to foresee and control future perils.



Credit: Wikimedia

Thus it is hardly credible that societies such as ours **invariably** self-destruct before they become space-faring society, without any exceptions whatsoever.

In any event, within a few years human civilization will spread to the Moon, Mars and elsewhere, and then its long-term survival will be largely impervious to calamities on the home planet.

As before, galloping technology is destroying this solution to Fermi's paradox.

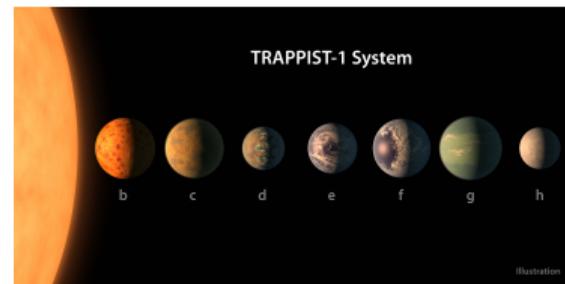
The “rare earth” solution

Solution 8: Earth is a unique planet with characteristics fostering a long-lived biological regime leading to intelligent life (see Ward, Brownlee below).

Rejoinder: Perhaps, although many recent discoveries point in the *opposite* direction:

- ▶ The universe contains over 100 billion galaxies.
- ▶ The Milky Way contains over 100 billion stars.
- ▶ Thousands of exoplanets have been found; more than 40 in the habitable zone.
- ▶ Recent work in biogenesis indicates that the origin of life was not a particularly unlikely event. This is also indicated by recent fossil finds, which show life arose almost immediately (over 3.8 billion years ago) after the formation of Earth.

- ▶ P. Rincon, “Star’s seven Earth-sized worlds set record,” *BBC*, 22 Feb 2017.
- ▶ K. Chang, “Nearby star Ross 128’s planet may have conditions for life,” *NY Times*, 15 Nov 2017.
- ▶ R. F. Service, “‘RNA world’ inches closer to explaining origins of life,” *Science*, 12 May 2016.
- ▶ J. Cepelewicz, “Life’s first molecule was protein, not RNA, model suggests,” *Quanta*, 2 Nov 2017.
- ▶ P. D. Ward, D. Brownlee, *Rare Earth: Why Complex Life is Uncommon in the Universe*, Copernicus, 2000.
- ▶ C. Zimmer, “Scientists say Canadian bacteria fossils may be earth’s oldest,” *NY Times*, 1 Mar 2017.



Credit: NASA

Nick Bostrom's "great filter"

Nick Bostrom has suggested that a "great filter" may explain the eerie silence. Possible examples:

- ▶ The origin of life was extremely improbable.
- ▶ The jump from prokaryote to eukaryote cells was extremely improbable.
- ▶ Our combination of stable planetary dynamics and moderate temperatures, over billions of years, is exceedingly rare.
- ▶ A catastrophe (gamma-ray burst, neutron star merger, etc.) invariably ends species like ours before they explore the cosmos.

Rejoinder: Given that no gamma-ray burst or neutron star merger has destroyed Earth to date (over 4.5 billion years), it seems exceedingly unlikely that this will happen within the next 20–50 years, during which time we will have ventured to the cosmos.



Credit: Wikimedia

- ▶ Nick Bostrom, "Where are they? Why I hope the search for extraterrestrial life finds nothing," <http://www.nickbostrom.com/extraterrestrial.pdf>.

The “solitary” solution

Solution 9: WE ARE ALONE, within Milky Way if not beyond.

Rejoinder: It hardly seems credible that we are unique even in the Milky Way (with over 100 billion stars and planets), much less the entire universe (with over 100 billion galaxies).



Credit: publicdomainpictures.net

Solution 9 may be consistent with Occam's razor, but it is an extreme violation of the “Copernican principle,” namely the hypothesis that there is nothing special about Earth or humanity. Has the Copernican principle been completely overturned?

Many recoil at this solution (including the author), but what is the alternative?

Leading scientists on Fermi's paradox

Even before the recent explosion of technology, many researchers concluded we are alone.

Paul Davies (British physicist-cosmologist):

[M]y answer is that we are probably the only intelligent beings in the observable universe and I would not be very surprised if the solar system contains the only life in the observable universe.

John Gribbin (British astrophysicist):

They are not here, because they do not exist. The reasons why we are here form a chain so improbable that the chance of any other technological civilization existing in the Milky Way Galaxy at the present time is vanishingly small.

1. Paul Davies, *The Eerie Silence: Renewing Our Search for Alien Intelligence*, Houghton Mifflin Harcourt, New York, 2010.
2. John Gribbin, *Alone in the Universe*, John Wiley, New York, 2011.
3. Peter D. Ward and Donald Brownlee, *Rare Earth: Why Complex Life Is Uncommon in the Universe*, Copernicus Books, New York, 2000.
4. Stephen Webb, *If the Universe Is Teeming with Aliens... Where Is Everybody? Fifty Solutions to Fermi's Paradox and the Problem of Extraterrestrial Life*, Copernicus Books, New York, 2002.
5. P. S. Wesson, "Cosmology, extraterrestrial intelligence, and a resolution of the Fermi-Hart paradox," *Q. J. Royal Astronomical Society*, 31 (1990), pg. 161-170.

Fine tuning and Fermi's paradox

If we are truly alone in the Milky Way or beyond, this greatly magnifies the paradox of fine tuning — not only do we reside in an incredibly fortunate universe, but we occupy an incredibly unique time and place within that universe.

Even if we are “only” extremely rare in the universe, this is a most important finding, with truly cosmic implications.



Credit: NASA

Was the universe made for us? Or is our understanding of the laws of physics fundamentally in error?

Either way, human existence is far more significant than anyone could have imagined even a few years ago.

Thanks!

This talk is available at: <http://www.davidhbailey.com/dhb-fermi-2017.pdf>.