Statistical Analysis of Earth's Evolutionary History Reveals Earth is likely the only Civilization in the Observable Universe

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Abstract

Earth took ~3.8 billion years to evolve from single celled organisms to intelligent animals capable of inventing civilization. Because the sun will render Earth uninhabitable in 1 billion years, any aspect in Earth's history that sped up Earth's evolution to civilization by 30% or more was crucial to the development of civilization on Earth (this is called the "30%-Rule"). Because of the principle of mediocrity, we can infer that aspects in Earth's history that follow the 30%-Rule happened in the most likely way possible. This means that to estimate the probability of civilization in the universe, we simply must estimate the combined probability of all "30%-Rule candidates". There are three distinctly improbable events in Earth's history that almost certainly follow the 30%-Rule: "Theia's Collision", the "End-Devonian Tetrapod Transition", and the "Dinosaur Extinction Event". This paper uses in-depth and novel analysis of these three crucial events to ultimately argue that Earth is likely the only civilization in the observable universe.

Method: The 30%-Rule

It took at least 3.8 billion years for life on Earth to evolve from single-celled organisms to civilization. Additionally, current estimates suggest that we have about 1 billion years before the Sun's increase in luminosity renders Earth uninhabitable. If we compare these two numbers it implies that Earth barely evolved fast enough to become civilized; if Earth's evolution speed was even 30% slower, the Sun would have destroyed life on Earth before it could evolve into civilization. This phenomenon is known as the "30%-Rule"; anything that follows this rule was necessary for the evolution of civilization on Earth. There are already numerous known aspects about Earth that follow this rule, almost all of which are mentioned in the book “Rare Earth: Why Complex Life Is Uncommon in the Universe” (source). Aspects like Earth being in the habitable zone, Earth’s Moon, plate tectonics, Jupiter’s role in protecting Earth, Earth’s evolutionary history (and many others) are mentioned.

The principle of mediocrity states: “if an item is drawn at random from one of several sets or categories, it's likelier to come from the most numerous category than from any one of the less numerous categories”. In our case, Earth is effectively a random civilization, which means Earth is most likely one of the most numerous types of civilizations (mammal dominant). Any aspect that allowed Earth to become mammal dominant 30% faster (or more) likely happened in the most numerous (or “likely”) way possible. Therefore our probability of existing can serve as a general probability for other civilizations, which we can determine by estimating the combined probability of all 30%-Rule aspects.

Dinosaur Extinction and the 30% Rule

The dinosaur extinction event is particularly notable because it killed all non-avian dinosaurs while leaving mammals alive. Arguing the dinosaur extinction event to follow the 30%-Rule makes three predictions.

1. Dinosaurs (large reptiles) always exist before mammals and are always more dominant than mammals.
2. Mammals naturally create civilization if they are dominant in an ecosystem.

3. Dinosaurs likely cannot create a civilization given any amount of time.

If these conditions are true, it would be true that the dinosaur extinction event would follow the 30% Rule, because killing the dinosaurs while leaving mammals alive would be necessary for the creation of a civilization. These conditions are possible to prove, and there is evidence that they are all true.

Dinosaurs will always be dominant over mammals for a couple of reasons. Firstly, dinosaurs lay eggs. Egg laying species evolve and adapt faster because they can have orders of magnitude more offspring. Live birth does not scale with size, which is the main reason dinosaurs tend to be an order of magnitude larger than mammals, as described in this video. Therefore, it's more dominant to simply bury an embryo and not care about it because that increases your individual chances of survival and allows you to grow to almost any size. Secondly, dinosaurs came first. Dinosaurs and mammals both evolved from reptiles; dinosaurs were reptiles that evolved large size and mammals are reptiles that evolved live birth. Because evolving large size was much easier, faster, and more beneficial, the first dinosaurs existed 20 million years before the first mammals. Therefore it is clear that under normal circumstances, terrestrial egg laying reptiles will always be more dominant in an ecosystem than their live-birth giving counterparts.

Why do mammals naturally create civilization? Because mammalian parents are vulnerable during pregnancy and their offspring are weak as babies, mammals spend a lot of time and energy parenting their young. This emphasis on care and parenting leads to complex social structure which leads to intelligence. We can see many examples of intelligent mammals with family units and/or complex social structures such as chimpanzees, orangutans, big cats, elephants, orcas, and dolphins. Most important is the fact that social structure and parenting creates selective pressure for intelligence. Individuals who are fast learners, good parents, or good socializers are more likely to benefit a family (and therefore are selected for), and those qualities also happen to require intelligence. Because knowledge is passed down in the form of parenting and social structure, mammalian family units can progressively get more complex social structures which further increases selection (cycle continues). Because our ancestors happened to be bipedal and also the smartest land mammals, we were the first to create tools and invent civilization. On the other hand, dinosaurs buried and abandoned their eggs, which suggests they lacked complex social structure. We can also look at the fact that dinosaurs were dominant for 165 MY, whereas it only took mammals 66 MY to evolve from rats to civilization.

Dinosaur Extinction Event: Evidence and Probability

Figure 1: This shows all relevant events in the fossil record that happened during this extinction event.

The dinosaur extinction event follows the 30%-Rule, so we know that this set of events was one of the most probable ways to kill dinosaurs while leaving mammals alive. Of the four events in the fossil record in **Figure 1**, three are clearly significant to this extinction event. The first event that occurred was the eruption of the Deccan traps, which would go on to erupt for a total of ~3 Million years. Just ~150 KY later, the Chicxulub impact, with an estimated diameter of 10 KM, struck the sulfur deposits in the Yucatán Peninsula. This impact was significant for two reasons. First of all, the 11 magnitude earthquake would have reached the Deccan Traps and magnified the eruption (source). Secondly, the released sulfur dioxide would have caused a 10-year-long extreme cooling effect (source). The next most important event was the Shiva impact, which was a ~40 KM diameter impact that hit the Deccan Traps (source), notably the largest known impact. The Earthquake from this impact would have also magnified the Deccan Traps eruption, but in a much stronger way than Chicxulub. The Boltysh crater, on the other hand, doesn't seem as significant because it was only 1 KM in diameter and does not appear to have hit anything important (maybe a broken piece of Shiva?).

Therefore, an accurate lower bound probability for this event would be to estimate the probability of these three significant events happening in the timeframe that we observe. For simplicity purposes and due to the uncertainty of Shiva's age, this paper will estimate the probability of these events happening in a 1 MY timeframe.

1. Deccan Traps Eruption - once per 100MY => 1 in 100
2. Chicxulub impact 10KM - once per 500 MY => 1 in 500
3. Chixculub hits Yucatán sulfur deposit at 60° angle=> 1 in 1000(?)
4. Shiva impact 40KM - once per 2 BY(?) => 1 in 2000
5. Shiva hits India => 6.4 in 1000
6. Dinosaur dominance + mammals exist => 1 in 10
    a. Assumes dinosaurs exist ~350 MY longer

Combined probability: 1 in (1.56 * 10^14)

End-Devonian Tetrapod Transition and 30%-Rule

The evolutionary transition from fish to tetrapods took place during the End-Devonian extinction, which was punctuated by two separate events. The Kellwasser Event 372 MYA was a period of ocean anoxia, and the Hangenberg Event 359 MYA was a period of both ozone depletion and ocean anoxia. The cause for the Kellwasser event is not known with certainty, but was likely submarine-volcanism. The Hangenberg event, on the other hand, could have been caused by a supernova, as described in this article. If the End-Devonian tetrapod transition followed the 30%-Rule it would imply that these two events aided the transition from fish to land animals in some lucky way, which there is evidence for. It would also imply that civilization must take place on land.

Figure 2: This image shows the tetrapod transition lineage before and after the Kellwasser event.

Both the Kellwasser and Hangenberg events were known to be periods of ocean anoxia. Importantly, the oldest concrete example of the tetrapod transition was named Tiktaliik, which was a lungfish 375 MYA. Anoxia during the Kellwasser would make conditions for Tiktaliik and its evolutionary lineage ideal because anoxia would weaken non-lunged competitors. Additionally, anoxia would incentivize Tiktaliik to waddle around in the shallows while keeping its head above water to get oxygen from the air. This would have caused this lineage to evolve more efficient legs for walking around, illustrated in **figure 2**.

The second piece of evidence is the supernova 359 MYA and its specific timing compared to the fossil record. The closest transitional fossil preceding this event is named Acanthostega, which lived 365 MYA. Acanthostega's limbs had leg-like qualities, but its bone structure suggests its limbs were used primarily as fins (**figure 3**). In fact, all fossils of this lineage before the supernova seem to be primarily aquatic animals, whereas after the supernova, we observe the first non-aquatic tetrapods. Additionally, we observe that all lineages after the supernova have 5 digits and asymmetrical metatarsals, illustrating the completion of this crucial transition.

Figure 3: This source shows the difference between Tulerpeton and Pederpes. Notably, Pederpes is the first evidence in the fossil record of asymmetrical metatarsals and 5 digits, making it the oldest known primarily terrestrial tetrapod.

Tetrapod Transition: Evidence and Probability

Because of the principle of mediocrity, we know that this transition from lungfish to non-aquatic tetrapods must have happened in the most likely way possible. Therefore, we must make the assumption that these two significant events in this specific manner and time frame were necessary for this transition to be successful.

The most in-depth analysis of the cause of the Kellwasser event appears to be this source which states, "Two peaks of kimberlite-like eruptions and/or orbital modulation have led eventually to the catastrophic Kellwasser events". It's clear that the anoxia from this event was necessary, but unclear if other unlikely factors were also at play.

Assuming the Hangenberg event was caused by a supernova, it would have emitted 100KY of ionizing gamma and UV rays. Apart from the anoxia during this time, the radiations from the gamma rays were also likely necessary, as they would effectively temporarily increase evolution speed during this time. Ionizing gamma rays damage DNA, which would create an increased mutation rate, which would create more variation in offspring, making the transition possibly orders of magnitude faster. According to this hypothesis, we should expect to see an uncharacteristically large difference between fossils from this lineage immediately before and after the supernova.

1. Tiktaliik exists => ~5 MY timeframe
2. Kellwasser happens - once every 500 MY (?) => 5/500
3. Acanthostega exists => ~5 MY timeframe
4. Ideally distanced supernova occurs - once per 5 BY(?) => 5/5000
5. Fish exist on Earth (with enough time left over) => 1/5

Probability estimate: 1 in 500,000

<u>Theia's Collision: 30%-Rule</u>

Given the extremely specific and unlikely nature of the Dinosaur extinction, we would expect Theia's collision to have happened in the most perfect and unlikely way possible. We can therefore make predictions about this collision:

1. Theia had an ideal elemental composition, meaning as much water, volatiles, and elemental diversity as possible.

2. Earth's obliquity, which resulted from the collision, is ideal.

3. Theia's collision was ideal for plate tectonics formation.

Scientists in this study looked at molybdenum on Earth to determine where Earth got its volatiles. Molybdenum is thought to bind with iron and sink to the core during planetary accretion, which means molybdenum on Earth's surface has extraterrestrial origin. Their results suggest that 30-60% of the molybdenum on Earth's surface came from one large collision, which they deduce to have been Theia's collision. This would in turn indicate that 30-60% of the volatiles on Earth's surface also came from Theia's collision. Their computer models predicted that Theia was an icy planet near Neptune that was destabilized by Jupiter, which would notably allow Theia to have the most water and elemental diversity possible (outer solar system = less solar wind). There are many other studies that corroborate the claim that Earth got volatiles from Theia's collision (one two three).

The next two predictions can be satisfied by this study, which notably is the only model of Theia's collision that explains the Moon's 5° orbit angle and the identical isotopes of the Earth and Moon. This model proposes that preceding the collision, Earth's obliquity and the Moon's orbit angle started at 75°. As the Moon got further from Earth, the Sun's gravity pulled the Moon's orbit angle down to 0°, which in turn dragged Earth's obliquity with it over millions of years to the level we observe today (until the Moon was too far away about 50 MY later).

Determining whether Earth's tilt was ideal is somewhat subjective, but there are certain clues that suggest it was. First consider two extremes: 90° and 0° degree obliquity. As obliquity approaches 90°, seasonal temperature swings get more and more extreme. Conversely, as obliquity approaches 0°, temperature differences between the equator and poles get more and more extreme. If our obliquity was less than its current level, this would result in the equator being hotter and the poles being colder, which could have caused a slower evolution speed. Additionally, if our current seasons were harsher, this could also cause a slower evolution speed. For all we know, even one degree higher or lower could have made a huge difference in Earth's evolution speed, so we should assume that our obliquity is ideal. We also know that because our Moon is unusually massive, its tidal forces stabilize Earth's obliquity to remain at this ideal level.

Plate tectonics are driven by convection currents in Earth's interior, which means more heat correlates to better chances of tectonic formation. Therefore it's clear that Theia's collision made plate tectonics more likely, because a violent collision would input lots of heat energy into Earth. This model even predicts that Earth was spinning fast before the collision, which was likely the result of a completely separate collision beforehand, which would also make Earth hotter. There's also the argument of tidal heating, which is known to have caused heating and volcanism on Io, one of Jupiter's moons (source). Tidal heating from the Moon would be especially strong immediately after the collision, which would have been strong enough to warp Earth into the shape of a potato (source). This tidal heating would add heat and also weaken Earth's crust, two more factors that would make tectonic formation on Earth more likely.

Theia's collision: Probability Estimate

Knowing an accurate estimate of the probability of this collision is impossible because we do not know how lucky it was. For example, how would our evolution speed change if Earth's obliquity was off by 1 degree? To know this we would need to be able to simulate evolution and life itself, which won't be possible for at least another decade (if ever). Our best bet is to use what we know about the event to compare it to a probability we do know. Based on the known lucky aspects, we can compare this event to the dinosaur extinction event to make a rough estimate.

1. Theia's impact angle and impact location
    a. Must lead to ideal obliquity
2. Theia's impact velocity
    a. Did not destabilize Earth's orbit
    b. Must produce ideal day length
    c. Faster => more tectonics
3. Theia and Earth's size
4. Theia's elemental composition
    a. Volatile and water rich
4. Earth's spin before the collision
5. Moon's mass and orbit angle

a. Smaller Moon would not stabilize obliquity

b. Larger Moon will drag obliquity closer to 0°

6. Stable Plate Tectonics

Probability estimate: 1 in 1 trillion (10^12)

Probability of the Solar System

Using the 30%-Rule and the principle of mediocrity, we can get a decent idea about which aspects of the solar system were necessary for our existence. For example, consider the fact that red dwarfs are more numerous and last longer than stars as massive as our Sun. This implies that the reason our star is not a red dwarf is because they are not luminous enough to produce bountiful plant life (photosynthetic efficiency is correlated to luminosity). We can apply similar logic to other aspects.

1. Sun's mass => 1 in 10
2. 8 planets + Theia => 1 in 100k
3. Jupiter and asteroid belt formation 1 in 10k(?)
    1. Jupiter maintains asteroid belt at perfect spot (dinosaur extinction)
    2. Jupiter is extremely massive + close => protects Earth from outer solar system
4. Galactic habitable zone => 1 in 5(?)

Probability estimate: 1 in (5 * 10^10)

Conclusion

Calculating the probability of civilization using these numbers would look like this:

P = (1/1.56 * 10^14) * (1/500,000) * (1/1*10^12) * (1/5*10^10) =>

Probability of civilization in the universe: **1 in (3.9 * 10^42) star systems.**

There are about 10^22 - 10^24 stars in the observable universe (source). For us to not be the only civilization in the observable universe would imply these numbers are off by more than 10^18, which is hard to argue. This finally solves the Fermi Paradox once and for all: we are the only civilization in the observable universe. Other civilizations likely exist, but are not within our sphere of causality (many-worlds interpretation + possibly infinite universe).

Plate Tectonics Causes Abiogenesis Hypothesis

Life forms require chemical energy, so where did life forms get chemical energy before photosynthesis? Answer: plate tectonics. When elements subduct into the mantle, they are exposed to heat and pressure and eventually resurface near divergent boundaries or hydrothermal vents, resulting in a constant source of free chemical energy to anything on Earth's surface.

Today we know that it is inconceivably improbable for abiogenesis to occur "randomly" (source), so it more likely occurred in an incremental process of increasing complexity. From the influx of random chemical energy created by plate tectonics, networks of chemical reactions would conserve the energy. Complex chemical constructions could persist and gain complexity that could be enough to eventually figure out how to self-replicate and become the first life form.

Constant recycling and free chemical energy are unquestionably ideal conditions for abiogenesis. Therefore, abiogenesis most likely occurred on Earth through plate tectonics. There are no other mechanisms that replicate the recycling and free chemical energy that is provided by plate tectonics, which would suggest that plate tectonics is a requirement for life to exist, and would imply that we will not find life anywhere else in the solar system.

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