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The history of evolution and origin of life on Earth – a review

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Abstract
Evolution is an ongoing process throughout the entire universe ever since the universe appeared 14 billion years ago. Galaxies, stars, and planets eventually appear in the universe and there is continuous debate whether life originated in space or in Earth, or perhaps on other planets. This review paper will outline how the universe and life appeared, and how life keeps evolving and becoming more complex. Major known events on Earth that led to significant changes will be pointed out starting from our last universal common ancestor (LUCA) to today's humans.

Keywords: Evolution, universe, galaxies, stars, planets, last common ancestor

1. Introduction

There are so many unanswered questions about the existence of life and how did it begin? Not everything is discovered in the universe, and it is not entirely clear whether life began on earth or somewhere else. Many discoveries were made to understand the universe better and how life appeared, yet there is still so much to discover. Because the universe is composed of more than 200 million galaxies in which each galaxy is composed of 100-200 billion stars. It takes millions of light years to travel in another galaxy [1] as it is currently unimaginable to consider traveling to another planet let alone to another galaxy. However, on the other hand, it might be possible as many scientists are working on sending probes to further distances as technology is becoming more advanced. Another important fact to mention is that only 18% of the ocean is discovered even though the earth is composed of more than 70% of the ocean [2] [3]. All the seven continents are mostly explored except for Antarctica which means that not all species are discovered. Today there are more than 8 million species on Earth and are classified into three domains: bacteria, archaea, and eukaryote [4]. This review paper provides information on how life appeared and keeps evolving while the environmental conditions are changing as time passes. There are several theories about how life began as many scientists as possible for thousands of years were working on making discoveries and conducting experiments. There will be as well discussion based on how life was simple and how it became more complex and diverse. It is possible that all species have evolved from the Last Universal Cellular Ancestor (LUCA) as Charles Darwin proposed this theory more than 150 years ago [5].

2. Fossil analysis methods

To create the timeline of evolution from the beginning of the universe till today, paleontologists must observe, reconstruct, and interpret the fossils [6]. Fossils are remains of species from the past that existed at a certain period and preserved in a rock or sediment. Scientists may collect DNA (deoxyribonucleic acid) from fossils and compare it to those of modern species as they provide evidence for evolution as the organisms did not look the same as today. They can tell whether these organisms lived on the land or underwater as well whether the water was deep or shallow and which type of climate [7]. Fossils usually have skeletal remains such as bones and remains of skin, feathers, or even soft tissues. Some fossils such remains of insects and plants can be found inside the amber, which is rare but some dissolve entirely, deserting a cavity which is filled with another substance, forming a cast. Also, animals may leave traces/ faeces as marks which can be detected.

Not every living organism has a chance to become a fossil as they can decompose entirely or being consumed by another organism. The way fossil forms depend on which traces it has and the environment. Skeletal remains and plants are usually covered by sediment such as mud or sand. The sooner it is covered in wet sediment, the more likely it will turn into a fossil as it is more protected from microorganisms. Sediments are made in layers in which the newest one is at a top layer while the oldest one is at the bottom [8]. As millions of years would pass by, more layers would form and cover which buries the traces under the ground turning into a stone. The ground water may dissolve skeletal remains and replace them slowly with minerals such as pyrite and calcite. In some other cases, groundwater and minerals can penetrate tiny pores and voids of substances that are made from shell, skeletons, and wood [9]. Also, the erosion that occurs through natural forces of wind and water may transport or destroy the sedimentary rock with fossils which leave no record of the organism [8].

Using radioisotopic dating, the age of fossils is determined ranging from 10,000 to 3.5 billion years old and when was the layer made. Relative dating compares the strata of earth with different fossils, thereby gives out the events in the exact order but does give the exact time [10]. To study the locomotion, behavior, and posture of an animal, and whether the animal was bipedal or quadrupedal, animal tracks are studied. These tracks also give information about the in which kind of environment the animal lives and are formed in two ways. One way is that the animal walks on moist sediment which dries out hardening the track and it is covered with more sediment. Another way is that animals create footprints in a soft, muddy soil and another material covers it forming underprints. Animal tracks can be easily observed by determining the size and shape of the footprint and how many of their toes [11].

To understand the history of evolution, paleogeology (study of earth's history) [12] and the changes of the environment must be studied. It is based on how the atmosphere, biosphere, oceans and 7 continents evolved that had major impact on organisms. To study the earth's previous climate, mapped data obtain the approximate temperature and usually includes tropical soils, desert and salt deposits, glacial tills, as well as various coals and organisms that are sensitive to climate changes such as palm trees [13].

Also, physical laws are obeyed as they shape the evolution of the entire universe. The two laws of thermodynamics are applied as the universe started from simplicity and eventually became more complex. It is important to mention that energy is required for all organisms and stars. Stars would collapse and organisms would die without energy [14].

3. The theory

One of the most accepted theories based on the existence of the universe and how the universe is evolving is called the Big Bang theory. The universe started to appear with the lowest possible entropy, and it was hot and compact, however as time passed it got bigger and the entropy was increasing. This happened approximately 14 billion years ago, and Hydrogen ($H2$) was the first element in which other elements such as Helium (He) derived from it [15]. A few of these elements and mostly $H2$, assembled into a large cloud and eventually coalesced through gravity, forming galaxies and stars. Our galaxy known as the Milky Way Galaxy originated 0.8 billion years after the universe appeared [16]. As time passed, billions of galaxies were formed. From 8.4 to 5.4 billion years later the solar system formed in the center of our galaxy. While our galaxy has billions of stars, our solar system has anything that orbits within the sun. Sun is a G-2 type star [14] and with other planets it was formed from a cloud of gas (mostly $H2$ and He)) and dust called solar nebula [17]. The sun and the stars create an enormous amount of energy because of nuclear fusion. This fusion enables $H2$ to convert into He, in which the stars and sun give off energy [18]. The question is whether the universe will last forever and continue to expand, or will end?

To be able to answer this question, there are two laws of thermodynamics that are related to whether the universe will last or not. According to the first law of thermodynamics, the universe is seen as a closed system which means that the net amount of energy is the same as it cannot be created nor destroyed. According to the second law of thermodynamics, the entropy of the universe is increasing while the sun and other stars are constantly given away heat which eventually reaches thermal equilibrium [19]. Because reactions occur spontaneously and when nonspontaneous reactions occur, they are balanced by entropy being increased somewhere else. For example, a cup of hot coffee will cool down eventually reaching room temperature as the energy is transferred from hotter substance to cooler substance in which both eventually have the same temperature. When thermal equilibrium and maximum entropy are reached, then the universe will come to an end. Work will be no longer done as there is no temperature difference and as everything in the universe has cooled down and will be unable to support life. Also, the stars including our sun will eventually burst like supernova as there is no fuel to run out. It is predicted that in 5 billion years, the sun will turn into a red giant sun consisting of carbon core that is surrounded by hydrogen and expand in size [20]. But eventually the sun, like every other star, will contract and turn into a black dwarf in the next 10 billion years. If this happens, the organisms on Earth and on other planets of our solar system would not survive unless the whole of humanity finds a way to travel into another solar system.

Plants, some algae and bacteria need direct sunlight for photosynthesis while other living and dead organisms obtain energy from plants directly or indirectly. When dead organisms obtain energy, they are broken down into simpler molecules that are eventually consumed by decomposers or used by humans, e.g., humans use coal to generate electricity. The big question is how and where life originated, and how are distinct species being formed? It is important to mention that organisms are undergoing a process of evolution as a whole universe and everything in it is undergoing chemical reactions. Evolution is defined as alternations in the genome of population during generations that survived and adapted, which often results in forming new species.

It is important to mention that every organism has two goals in life and that is to survive and reproduce [21]. Also, every organism is an open system as every and each organism exchange matter and energy within their surroundings to survive [22]. The two main factors of evolution are due to changes of the environmental conditions and a random process known as mutation leading to changes in the genome and it is not possible to avoid it. So, if a mutation creates a new phenotype that is more suitable for an unfamiliar environment, these organisms may survive and continue to evolve. This happens as some newborn offsprings may receive mutated genes and may pass it on to the next generation [23]. Not only does the environment affect the species but species affect the environment as they use available resources such as food and water [24]. Therefore, the environment keeps changing and new species are forming. For example, a plastid must divide before the division of the plant cell and half of them are given out in the two daughter cells. If their division is too brisk, they can enslave the host cell or if their division is at low rate may, then plastid may disappear [25].

4. Geological Time Scale

By studying fossils and today's species, organisms are divided into 3 domains or clades and those are: The Archaea, the Eukaryota, and the Bacteria. The timeline will outline notable events based on how distinct species possibly evolved from their LUCA to humans. The timeline of evolving species on Earth is divided into 4 eras: Precambrian, Paleozoic, Mesozoic, and Cenozoic era.

The Precambrian econ starts when earth was formed and has ended 542 million years ago [26], and this era is divided into Hadean, Archean, and Proterozoic [27]. During the Hadean Econ, earth formed 4.6 billion years and life may have appeared in the ocean 3.8 billion years [28]. During the Archean Econ, photosynthesis evolved from prokaryotes as they obtained energy from the sunlight. When cyanobacteria evolved from anaerobic bacteria, it started to produce oxygen (O2) as a waste product. During the Proterozoic Econ, the event called Great Oxidation Event (GEO) appeared causing the anoxic atmosphere to turn into oxygenic atmosphere [29]. Eukaryotes evolved from prokaryotes and diversified into 4 known groups: protists, algae, plants, and animals [30]. At that time, all animals were invertebrates and did not have any eyes or brains [31].

The Paleozoic era started 542 million years ago and ended 250 million years ago in which Mesozoic era begins [26]. This era is divided into the Cambrian, Ordovician, Silurian, Devonian, Carboniferous, and Permian. During the Cambrian period, there was a sudden appearance of a large diversity of animals in the ocean. During the Ordovician period, plants and fungi started to colonize the mainland. This led to major changes in the atmosphere and climate as plants were grown into trees, developed root systems, and produced seeds creating forests. During the Silurian period, anthropoids were the first animals to colonize the mainland. The Devonian period is known as the age of fishes in which fishes diversified into 3 groups: cartilaginous, bony, and armored vertebrates. Tetrapods evolved from bony vertebrates and eventually colonized the land. At the same time, gymnosperms evolve but some of them evolve into angiosperms [32]. During the Carboniferous period, amniotes evolved from tetrapods and they represent the ancestors of mammals and reptiles [33]. During the Permian period, the supercontinent Pangea formed [34].

The Mesozoic era is known as the "Age of the Reptiles/Dinosaurs" and is divided into: Triassic, Jurassic, and Cretaceous periods. This is the period where dinosaurs dominated the land during these 3 periods and ended 65 million years ago. During the Triassic period, amniotic evolved into reptiles and mammals. Some of these reptiles evolved into dinosaurs that became extinct at the end of the Cretaceous periods [26]. The only species that resemble dinosaurs and exist are birds as they evolved from dinosaurs during the Cretaceous period.
The Cenozoic era is known as the "age of mammals" which means more types of mammals including cats, dogs and even humans evolved. This era is divided into two periods: Tertiary and Quaternary [35]. During Tertiary periods, mammals diversified into monotremes, placentals, marsupials and multituberculates [36]. At that time humans evolved from apes, but the rise of human civilization began during the Quaternary period [35].

4.1. How did life appear?

During the Hadean Econ, the planet suffered from late heavy bombardment in which it was bombarded by comets, asteroids, and meteors delivering water. This caused the surface to melt and rocks to vaporize. The oldest known rocks are 4.2 billion years old. Low-density metals such as Silicon (Si) went toward the surface while high-density metals such as Nickel (Ni) went toward the core forming magnetic field [14]. The late heavy bombardment ended 3.8 billion years ago [37], the earth started cooling down causing the water vapor to condense and gravity captured some of the gases (mostly carbon dioxide (CO_2), but also methane (CH_4) and hydrogen disulfide (H_2S)) forming atmosphere [38]. The atmosphere starts to maintain a more stable temperature and protects the earth from cosmic rays and meteors [39], which allows better conditions for life on Earth. So, the question is how did life originate? Also, is it possible that life could exist on stars, moons and does life exist on every planet?
There are several possibilities on how life started to exist. One possibility is that life appeared after the formation of solar system as there is evidence of 3.7 billion years old stromatolites on earth and mars [40]. According to RNA (ribonucleic acid) world, ribozymes formed RNA in vitro in hydrothermal vents as the sunlight can only attain 200 m (about 656.17 ft) of the ocean. This is possible as Genald F. Joyce conducted an experiment in which he proved that ribozymes are multifunctional as they can generate peptide bonds, other ribozymes, mutate and have enzymatic properties. Also, it is not likely for RNA to survive in space as it can be damaged by cosmic rays. Eventually, DNA was formed as a more stable molecule that can store more genetic information and this nucleic acid was formed as RNA was deoxygenated without reverse transcriptase [41]. Later, reverse transcriptase would evolve as retroviruses would combine with tRNA bonded with amino acid [38]. Eventually, protein synthesis evolved after DNA synthesis providing a faster evolution and nowadays RNA plays a role in translation and synthesizing proteins. Another possibility is that life originated through the process of abiogenesis as the Miller-Urey experiment was conducted. In this experiment, artificial lighting stimulated the formation of organic substances such as proteins from inorganic molecules [42]. However, it is possible that life originated in space before earth existed.
According to panspermia theory, the first gene was formed in the solar system and had genetic instructions for evolution and metamorphosis on Mars and other planets. Life, water, and other ingredients were transported by asteroids, comets or meteorites to Earth and other planets [39]. A large meteorite known as Murchison meteorite struck the earth on 28th September 1969 in Murchison. This meteorite is composed of 92 amino acids and nucleobases that serve as building blocks for nucleic acids and proteins. When it's important to mention that carbon, N_2, and O_2 were among the first elements in the universe that interacted with H2 forming organic compounds that make up 96% of the human body. Also, other abundant elements such as sulfur (S) are required for creating stars in the universe and serve as building blocks for life to exist [43] [44].
Recently, there was evidence of life and water discovered in dried lake beds of Gale Crater and other regions of Mars. There is evidence of parallel evolution as these species evolve similarly from the same ancestor and it is possible that they are repeatedly transferred between Earth, Mars, and other planets. Sometimes these species can even transfer into another galaxy if these galaxies collide. It is possible for some organisms to survive in space as their silent genes can activate [39]. A Russian experiment was done to prove whether organisms can survive in space. The experiment was successful as bacteria, fungi, and plants enhanced their adaptive mechanisms and survived outside the walls of International Space Station (ISS) after 7 to 13 months. There were no alternations in morphology and physiology and these organisms developed normally. Another piece of evidence was found that *Caenorhabditis elegans* survived a speed of 660-1050 km (about 652.44 mi)/h while the space shuttle was destroyed as this nematode did not show any alternations in morphology and

physiology as it was able to adapt [31]. It is still unknown whether life exists on all planets given the fact that some planets may provide harsh conditions that might be impossible for life to exist. However, some organisms such as tardigrades may survive in almost any conditions [45] and many scientists from National Aeronautics and Space Administration (NASA) are working on discovering life on Venus, Neptune, and Jupiter as well as other parts of the universe [46],

4.2. How did viruses evolve?

It is also uncertain whether viruses evolved before cells or after and it is possible that these viruses may have multiple origins [47]. There is no fossil record of viruses as they are too small and fragile to be preserved on a rock. But many scientists were able to find their preserved fossils in host's genome that they infected as the genome of virus may integrated in host's genome [48]. If the host's cells are not damaged and happen in cell that becomes egg or sperm, then offspring may inherit the viral genome. Also, there is a slower rate of mutation in the host's cell compared to viruses, which makes the viral genome preserved for a longer time [49]. By studying integrated viral genomes of all organisms, the age of viruses can be determined. It is possible that they evolved during Hadean econ and play a role in evolution of organisms [50].

Currently, there are three theories in which the virus has evolved. One way is that viruses originated from broken pieces of genome inside the cells and were able to move between the cells. This theory is called Progressive, or another term is Escape Hypothesis. Retroviruses such as Human Immunodeficiency Virus (HIV) belong to this category as they have single-stranded RNA (ssRNA) that is converted into double-stranded DNA (dsDNA) through reverse transcriptase. A dsDNA goes to nucleus and with help of integrase, it is inserted into host cell's genome. This is possible as retrotransposons are like retroviruses, move within genome via RNA intermediate and may become a virus. Another theory is that viruses formed when there was a mutualistic relationship between two unicellular organisms and this theory is called Reduction/Regressive theory. This is based on the discovery of giant viruses that are similar in size and composition of bacteria and depend less on the host's cells [47]. These viruses are also called virophages as they can infect other viruses and may have unnecessary genes e.g., nucleocytoplasmic large DNA viruses (NCLDV) have stretches of DNA that are required for cellular rather than viral metabolism. These genes might be leftovers suggesting that back then viruses were more complex and free-living as they did not depend on their host. However, when they formed a symbiotic relationship with another organism, they became smaller and more dependent [51]. The last theory is based on how viruses came from pieces of RNA molecules before the cells existed. This theory is known as Virus-First theory and was proposed by Koonin and Martin [52].

Also, it is not clear whether viruses should be classified as living or nonliving organisms. Because all known viruses are unable to play a role in metabolic reactions, form adenosine triphosphate (ATP), do not contain ribosome and depend on host's cell for replication. However, some scientists suggest that they are living organisms that belong to a different category known as capsid-encoding organisms. In this category, there are three types of viruses which infect each of the 3 domains (viruses of archaea, viruses of eukaryotes, and viruses of bacteria) while bacteria, archaea and eukaryote are part of ribosome-encoding organisms [47].

4.3. How did Earth's oxygen levels rise and what are the consequences?

During Archean Econ, Bacteria used H_2 and CO_2 to produce acetate while Archaea used hydrogen, carbon dioxide and acetate for methanogenesis. At that time hydrogen was the main fuel for metabolism[53]. Sun was 20 to 30% less bright than today and its atmosphere had mostly CH_4 and nitrogen (N_2). At that time, the earth was anoxic, and O2 existed in some compounds such as water[29]. 3.5 billion years ago, photosynthesis evolved from bacteria as they obtained energy from the sun. Most of these bacteria have one photosystem that uses hydrogen sulfide (H_2S) to react with CO_2 producing glucose, water, and S 0.7 to 1.3 billion years later, cyanobacteria evolved from anoxygenic phototrophic bacteria and caused a notable change to the atmosphere [54]. These bacteria developed a second photosystem that uses water (H_2O) instead of H_2S, releasing oxygen instead of S [55]. This leads to an increase of O_2 levels on earth starting to interact with CH4, iron sulfide (FeS), iron disulfide (FeS_2) and other molecules [56].This led to an increase of subaerial volcanism (CO_2, H2O and sulfur dioxide (SO_2)) while submarine volcanism was decreasing[28]. Even though O_2 was toxic for most anaerobic organisms, some of these organisms found ways to adapt and survive and the continents of the earth began to stabilize.

During Proterozoic Econ, the GOE started as the levels of O_2 were increasing in the atmosphere and the ocean while the levels of CH_4 were decreasing. However, at that time there was lower levels of O_2 than today's atmosphere[57]. Studies show that the deep ocean was rich in iron (Fe) or sulfide (S^{2-}) as it had extraordinarily little O_2. Using Proterozoic rock, it is found that there was loss of manganese (Mn) from paleosol, and limited terrestrial of manganese being oxidized[29]. O_2 would react with ultraviolet (UV) light in which it was split into two atoms and one of atoms reacts with O_2 molecules forming ozone (O_3) layer which prevents UV radiation coming out of the sun. The O_3 layer is present in the stratosphere and allowed organisms to eventually become terrestrial[58].

4.4. How did eukaryotes evolve from prokaryotes?

Due to increase of oxygen levels, eukaryotes evolved 2 billion years ago as H_2-dependent Archaea and α-proteobacteria formed symbiotic relationship in which there was H_2 transfer between them [59]. Also, it is possible for eukaryotes to evolve earlier as there might be fossils that resemble algae with age of 3.7 billion years as well as fossils that resemble multiple species of fungi. However, this is uncertain as the fossil record is not identified [31]. Even though it is not exactly clear when did eukaryotes evolve, there is proof that many eukaryotes and prokaryotes evolved through the process of endosymbiosis as the last common eukaryotic ancestor (LECA) had mitochondria formed through endosymbiosis [60].

It is quite common for cells to engulf other cells and either of these cells can go in two directions: either endosymbiosis or phagocytosis to be completely digested [25]. Cells may undergo endosymbiosis, due to certain environmental conditions and energy-saving measures. In this way cells live inside another cell for mutual benefits and undergo regression, losing genes required to live independently and for certain metabolic reactions [51]. For instance, a layer of peptidoglycan is found between two plasma membranes of cyanobacteria and can maintain the structure with low osmolarity. But once it is engulfed by another cell, it uses cytoplasm that provides similar osmolarity. Eventually, the genes for peptidoglycan layer become useless and are lost [25]. Also, there are studies done that prove that some organisms undergo endosymbiosis several times. In primary endosymbiosis, the eukaryotes will engulf a prokaryote usually a bacterium such cyanobacteria. For example, red and green algae are generated through primary endosymbiosis involving cyanobacteria. Secondary endosymbiosis occurs when a eukaryotic cell engulfs a cell that has already undergone primary endosymbiosis e.g., brown algae. Tertiary endosymbiosis may occur but rarely e.g., dinoflagellate [61] [62].

It is known that eukaryotic cells are chimeras which have components of the eukaryotic cell (the nucleus) and organelles that prokaryotes (chloroplasts, mitochondria). It is found that not only eukaryotes have nuclear genomes but have plastid (present only in plants and some algae) and mitochondrial genes. Lynn Margulis suggested that mitochondria and chloroplasts were once an ancient bacterium that evolved to become an organelle through endosymbiosis [63]. 2 billion years ago, mitochondria were formed as α-proteobacteria placed into a protocell while 1.5 billion years ago, chloroplast was a cyanobacteria that formed a symbiotic relationship with eukaryotic cells. This theory seems true as chloroplast and mitochondria share properties with prokaryotes in the sense that they all have circular DNA, undergo binary fission, have usually no introns, have double membrane and have 70S ribosomes. Not only did α-proteobacteria become mitochondria; DNA was separated from nuclear envelope forming the nucleus as this was caused by assembly of membrane vesicles that are made of bacterial lipids which led to separation of nucleus and cytoplasm [59].

Organisms kept evolving as their nucleus would interact with other organelles and may replace organelle genes. There are two ways in which genes in the nucleus replace organelle genes. One way is that nuclear genes replace organelle genes inducing the new function of organelle whereas organelle gene is lost with no damage. Another way is that a protein called transit peptide transfers genes from an organelle to nucleus. For instance, a plant called *Arabidopsis thaliana* has 10% nuclear genes that were transferred from chloroplasts. An endosymbiont's DNA can be fused into the host genome, as damaged or aged organelles may accidentally release some parts of DNA into the host cytoplasm that may be transferred into the host's nuclear DNA [25]. At the same time, when chloroplast evolved and started to play a role in photosynthesis, unicellular eukaryotes started to adhere to one another to avoid being eaten by predators. Eventually tissues were formed as each group of cells performing a different function as well as organs that perform a certain function [64].

4.5. The origin of sexual reproduction

As mentioned earlier, reproduction is one of the main goals and initially organisms were reproducing asexually producing genetically identical offsprings. It is possible that the LECA was unisexual and was inheriting organelles such plastids uniparentally [65]. The question is how did sexual reproduction evolve and is it more beneficial than asexual reproduction? Germline cells are differentiated from somatic cells leading to the evolution of sexual reproduction in which offspring with different genetic variants are produced [66]. Asexual reproduction can create an offspring with different genetic variant if the offspring carries mutated genes. Even though it takes more time to reproduce sexually, these organisms have a higher chance of surviving and adapting to new environmental conditions. Also, the disease cannot affect the entire population of these organisms with different genomes [67].

However, there are still many organisms such as bacteria that reproduce asexually. Most animals reproduce sexually and have separate sex as they are motile that is maintained by neurons and sensory organs and can choose a partner to mate with [65]. Most animals would choose an attractive partner as they subconsciously see that they have good genes to ensure a better chance of producing healthier offspring [68]. Most plants and fungi are mostly asexual and immobile. They may reproduce sexually but not in the same way as animals as they are mostly immobile. Fungi have multi sexual systems and have different mating types that are encoded of alleles of the mating-type (MAT) locus. Some plants such as angiosperms reproduce sexually through pollination. They may reproduce through self-fertilization which is considered to be sexual reproduction as the genes are sorted and redistributed. There is no known terrestrial organism that is motile using neuromuscular system and autotroph, but it is possible to discover it in the future.

4.6. The origin of 4 eukaryotic kingdoms

It is possible that the first protists existed and eventually fungi and animals evolved from unicellular organisms that are like choanoflagellates while plants evolved from green algae [65]. Around 600 million years ago, there were simple animals like worms and jellyfish that appeared in the ocean [8]. However, a major event which is known as the Cambrian explosion happened 540 million years ago causing formation of various animals in the ocean. At that time, all organisms had 11 cell types which did not have any eyes, or brain. There are several probable causes of the Cambrian explosion [31]. One reason is due to higher levels of oxygen which lead to higher metabolic rate and more complex body structure. This might have caused alterations in ocean chemistry leading to formation of harder body parts such as teeth and skeleton. The second reason is because mass extinction and new species were formed. The third reason was mutation as there may have been alternations in the "Genetic tool kit" gene [69]. On the other hand, a Cambrian explosion might have occurred on Mars, or another planet and these species were delivered to Earth. Because there are fossils of acritarchs, algae, lichens, stromatolites, and many others found in Martian meteorite and life evolved in similar pattern like in Earth but at a higher speed. Lichens are eukaryotes that play role in oxygenic photosynthesis indicating that there was GOE and Cambrian explosion on Mars, billion years earlier. Another proposal is that multicellular eukaryotes were transferred into Earth's Ocean over 600 million years and caused a Cambrian explosion. At that time, most organisms lived beneath the ocean, but eventually they started to colonize the mainland [31].

When they settled on the mainland, they had to deal with new environmental changes including UV radiation, soil salinity, drought, and bigger temperature variations [65]. Plants evolved from a green alga and with fungi, they colonized the mainland 470 million years ago. To deal with these changes, they became immobile and developed strong cell walls [32]. Also, fungi lost their light-sensory organs and flagellate forms [65]. 430 million years ago, vascular plants appeared with xylem allowing transport of water and nutrients. At that time, 7 types of arthropods settled the mainland and played a role in soil development, decomposition, and recycling of nutrients. The 7 types of arthropods include: myriapods(centipedes), arachnids (mites, spiders, and scorpions), hexapods, and 4 types of crustaceans. They all developed wider and thicker legs than aquatic ones, to increase their musculature and overcome effects of gravity. Arachnids, insects, and insects developed tracheal system while scorpions and spiders developed "book lungs" (tissues membrane organized like page of book). 410 million years ago, a secondary xylem appeared allowing production and maintenance of trees. Mycorrhizae eases recovery and assimilation of soil nutrients leading to creation of first known forests. Eventually bigger vascular plants evolved turning into trees/shrubs and the root systems were increasing leading to pedogenesis and landscape stabilization. Also, there is more contact surface as vascular plants

would generate more acids than algae or lichens.380 million years ago, tetrapods and the rest of the vertebrates colonized the mainland. The question is how did the tetrapods evolve and what major impact it will have later?
Starting from the Devonian period which is known as "Age of Fish", fish evolved to:

- Cartilaginous vertebrates (e.g., sharks)
- Bony vertebrates (ray-finned fish and lobe-finned fish (e.g., tetrapod))
- Armored and jawless vertebrates (disappeared at the end of the period)

420 million years ago, in lobe-finned fish, lungs evolved providing the ability to breathe O2. Due to changes in the regulation of certain development genes, fingers were generated instead of fin rays. These tetrapods had more than 5 fingers in each limb that had 3 segments (arm, forearm, and hand). Some tetrapods evolved into amphibians including toads and frogs that lived both in water and land. 365 million years, gymnosperms originated and played a role in pedogenesis. This led to reducing levels of CO2 and the planet started cooling globally. During the Carboniferous and Permian era, ice caps were formed in southern Pangea, a supercontinent that was formed 335 million years ago. Also, the atmospheric ocean was recirculated, and precipitation was elevated [31], [70]. Also, the change of atmosphere was caused by large volcanism in Siberia in which a lot of species have become extinct. Most of these organisms that survived would go from the Southern part to Northern part and begin to diversify [8].

4.7. The age of reptiles

320 million years ago, amniotes evolved from tetrapods that eventually diversified into two groups: synapsids and diapsids [71]. 290 million years ago, all reptiles except for turtles evolved from diapsids [72], and 60 million years later some of these reptiles evolved into dinosaurs and they dominated the Earth for 166 million years 25 million years later, mammals evolved from synapsids and were ridiculously small that consumed mostly insects. They were active during the nighttime and had to stay away from dinosaurs as even small baby dinosaurs would eat them. Dinosaurs were classified into two groups: Saurischian and Ornithischian (e.g., theropods) and whether they were bipedal or quadrupedal [11]. Most well-known reptiles and amphibians are cold-blooded/ectothermic in which they maintain their temperature depending on the external environment. Synapsids are classified as warm-blooded/endothermic as they generate heat internally and can maintain a constant temperature. Endothermy has evolved from ectothermy as volume density of mitochondria elevated which caused microscopic metabolisms to accumulate and overall metabolic rates increased [73]. It is not clear whether dinosaurs were ectothermic or endothermic. It is possible that they were not either ectothermic or endothermic, but instead they were mesothermic as they generate enough heat to keep themselves warm but cannot maintain a constant temperature [74]. Or separate groups of dinosaurs evolved different metabolisms. It is known that birds were endothermic which means that theropods were endothermic as birds evolved from theropods 150 million years ago [75], [76]. For reproduction, dinosaurs and birds laid hard-shelled eggs that were made of calcite and had small pores allowing the embryo to grow and breathe properly while other reptiles like crocodiles laid off soft-shelled eggs [8].
During the “Age of reptiles,” the continental drift caused the supercontinent Pangea split into two continents: Laurasia (Northern Part-North America, Europe, and Asia) and Gondwana (Southern part-Antarctica, Asia, Australia, Africa, and South America). This happened around 190 million years ago and 100 million years later, India was headed toward the Indian ocean while Australia and Antarctica were still connected (they separated 50 million years later). South America and Africa were separated, and the North and South Atlantic oceans were made [77], [78]. At the same time, an active volcanism caused a hotter and wetter climate leading to higher sea levels and there was no ice formed in polar caps. This was another massive extinction of 3/4 of organisms known as Cretaceous-Tertiary extinction which happened 65 million years ago. This is when dinosaurs extinct as there was high volcanism in India and at the same time a large asteroid land in Chicxulub, Mexico [8], [79].

4.8. The age of mammals

After dinosaurs became extinct, angiosperms and mammals started to dominate on Earth. Angiosperms that evolved from gymnosperms 130 million years ago, triggered diverse groups of insects to evolve [80]. Because they used color, scent or in some cases both to allure insects e.g., insects consumed nectar from angiosperms and evolved into a more complex organism such a bee. Also [69], they grow and decompose faster as they take out more N2 and phosphate (P) creating better soil conditions [14]. Mammals became bigger and were classified into 4 groups:

1. Multituberculates (extinct around 30 million years ago)
2. Monotremes/metatherians (lay off leathery eggshell and do not possess teeth e.g., echidnas)
3. Marsupials (have a pouch in which a premature offspring stays inside after it is born and continues to grow, e.g., koala and kangaroo)
4. Placentals/eutherians (have placenta connected to fetus to permit exchange of fluid and nutrients e.g., aquatic mammals like whales, carnivorous mammals like cats, primates) [81]

Mammals are the only vertebrates that have a single bone in their lower jaw that's attached to their skull while the other vertebrates have the jaw with more than one bone separately [82]. Like birds, they are warm-blooded and evolved to have hair to retain heat from the cold and constant body temperature. Their red blood cells do not have a nucleus while other vertebrates have nucleus [83], [84]. They evolved to have checks and heterodont teeth to chew and break down the food [85]. Also, the secondary palate has evolved to allow mammals to breathe at the same time while they are eating [86]. The question is how did humans evolve as they are also mammals?
Humans belong to a group called primates that evolved 55 million years ago. These organisms evolved to hold their body upright, had their claws formed into flattened nails, evolved to have stereoscopic vision, and had their thumb separated from their fingers and big toes separated from other toes and would carry one offspring during pregnancy. They evolved into two groups:

1. Prosimians (active at night, e.g., lemurs and most of them are extinct)
2. Anthropoids (active during the day and evolved from prosimians e.g., monkeys, apes, and humans)

Old World monkeys would reside in Africa and Asia, and some of them evolved into apes (25 million years ago) and some of them into New World monkeys at the same time as South America and Africa separated. This happened 40 million years ago, and these monkeys would reside in South America and evolve separately for many years [87]. Around this period (20/30 million years ago), C4 plants evolved from C3 plants to minimize photorespiration in hotter conditions as rubisco grabs O_2 instead of CO_2. These plants use less CO_2 and H2O thereby utilize more nutrients and more efficient photosynthesis [14]. Apes had a larger brain and did not have a tail but could move through trees. But they mostly spent their time on the ground in Africa and were diversified into two groups:

1. Lesser apes (e.g., gibbons)
2. Greater apes (e.g., gorillas, humans)

The question is how did humans exactly evolve from greater apes? It is found that humans and chimpanzees share a common ancestor that lived 6 million years ago. These species that diverged from this common ancestor were more related to humans than chimpanzees and were bipedal. Today all these species except for humans are extinct. It is not exactly clear how did humans evolved but Australopithecus ("southern ape") might have evolved from this common ancestor that lived 4 million years ago, and some of these species evolved into *Homo erectus* 2.2 million years later. *H. erectus* evolved to have a nose with nostrils facing downward allowing the frigid air to be heated before entering the lungs as they had to adapt to colder weather [87]. Artifacts found with fossils of *H. erectus* indicate that they would hunt, make fire, and have a home base. It is possible that modern humans evolved from *H.erectus* in Africa and went to Asia and Europe 1.5 million years ago [88]. Homo sapiens such as *Homo neanderthalens* evolved from H. erectus about 500,000 years ago. Some of these species survived until 30,000–10,000 years ago, overlapping with modern humans.
Another approach to study human evolution is to examine mitochondrial DNA (mtDNA) and Y chromosome. Every newborn offspring receives mtDNA from their parents and mutations in mtDNA can give approximate timeline of genetic divergence suggesting that a common ancestor lived in Africa 160,000 years ago. Y chromosome is found in men and rarely in women and passed down to their son suggesting that a common ancestor live in Africa 140,000 years ago [87], [89].

4.9. How does evolution precede more complexity?

What is important to mention is that as mammals keep evolving, their brain gets larger [90] and possesses more energy rate density as neurons obtain energy 10 times faster than any other tissue to maintain their consciousness and structure [14]. The number of network connections increases out of proportion to the size of the brain within the neocortex. For example, humans have 3 times larger brains than chimpanzees [91]. There are several factors why humans evolved to have a bigger brain than apes. One reason is that Homo species started cooking food in which hot food promoted faster chewing and digestion, letting their body absorbs more nutrients. The second reason is that they started to have more free time and use it to create social relationships and organize for each person to do a task. In this way, humans can sense the environment better and increase the chance for successful reproduction [14].
At the beginning of human evolution, humans were hunter-gathers that would feed off on animals but became agriculturist as they started to domesticate animals and plants as they grow crops and build communities [92]. Industrialists learned how to use more energy to power shops and homes, leading communication, and production and transportation of goods. This caused a huge requirement of fossil fuels and waterpower which will eventually run out. However, many scientists are inventing new substances that can replace fossil fuels and that are more environmentally friendly [93], [94]. Technologists started to manufacture and design electronic devices such as computers and cell phones requiring more energy than industrialist [95]. This led to an increase of human population up to 8 billion as they manage to control dangerous illnesses and produce more food [96].
However, even though humans might be considered unique as they invented a lot of things, increased their lifespan, and discovered many things, they do not possess the most energy rate density. It was found that birds possess the most energy rate density as they function in 3-dimensional (3D) environments while most animals function in 2-Dimensional (2D) ground level. Their lung sacs, wing aerofoils, and pectoral muscles permit birds to obtain oxygen while flying. It requires more energy for birds to work against gravity and have the fastest metabolic rates. Also, insects possess more energy rate density as they also function in 3D environment [97].

6. Conclusion

Overall, it is not clear how life originated but there is evidence of life on mars and possibly on other parts of the universe. It is possible that life originated in the solar system and was deposited on Earth, Mars, and other planets. In the future, there might be more evidence of whether there is life on other planets as scientists from NASA are doing research on Neptune, Venus, and Jupiter. It is not clear whether viruses should be classified as living or nonliving organisms and whether viruses evolved before cells. It is possible that they may have different origins and that archaea and bacteria emerged from LUCA but there is no fossil record. The atmosphere of the young earth was anoxic but slowly became oxic as cyanobacteria produced oxygen as a waste product.
Unicellular eukaryotes evolved due to symbiosis between archaea and α-proteobacteria becoming a mitochondrion while at the same time nucleus was formed. Eventually, chloroplasts evolved in plants and some algae and at the same time these eukaryotes gathered to form multicellular organisms and started to reproduce sexually. It is not clear where the Cambrian explosion occurred, but it happened 542 million years ago leading to more diverse animal groups.
Eventually, most organisms became terrestrial and eventually plants as well as other organisms formed the first known forests. These organisms keep evolving and becoming more complex. Amniotes evolved from tetrapods and some of them evolved into reptiles and into mammals. Mammals and birds are warm-blooded and more complex than most vertebrates as they require more energy rate density and higher metabolic reactions. As mammals keep evolving, their brain gets bigger, but they do not possess the most energy rate density. Birds obtain the most energy rate density as they operate in 3D environment. Life and the universe are becoming more complex as entropy increases and organisms keep evolving. However, the universe could come to an end as maximum entropy is reached, and no work no longer needed to be done. When this happens, stars and galaxies will no longer exist to support life and planets.
What it is important to mention is that the evolution of life is studied by studying fossils and genomes. However, as mentioned earlier not everything is discovered as some fossils might have been destroyed and only 18% of the ocean is explored.

Even all seven continents are not completely explored as there was not much research done in Antarctica and not mention how little the universe is discovered. More discoveries might be made in the future, possibly giving an unfamiliar perspective of evolution and classification of organisms. However, time will tell what will happen in the future.

7. Abbreviations and acronyms

LUCA Last universal common ancestor
LECA Last eukaryotic common ancestor
NASA National Aeronautics and Space Administration
GOE Great Oxidation Event
ATP Adenosine triphosphate
O3 Ozone
CO2 Carbon dioxide
CH4 Methane
Si Silicon
Ni Nickel
Mn Manganese
MAT Mating-type
He Helium
H2O Water
SO2 Sulfur Dioxide
Fe Iron
S- Sulfide
FeS Iron Sulfide
FeS2 Iron Disulfide
H2S Hydrogen disulfide
RNA Ribonucleic acid
DNA Deoxyribonucleic acid
ssRNA single-stranded RNA
dsDNA double-stranded DNA
ISS International space station
HIV Human Immunodeficiency Virus
ATP Adenosine triphosphate
NCLDV Nucleocytoplasmic large DNA viruses
N2 Nitrogen
H2 Hydrogen
UV Ultraviolet
mtDNA Mitochondrial DNA
2D 2-Dimensional
3D 3-Dimensional
S Sulfur
P Phosphate

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