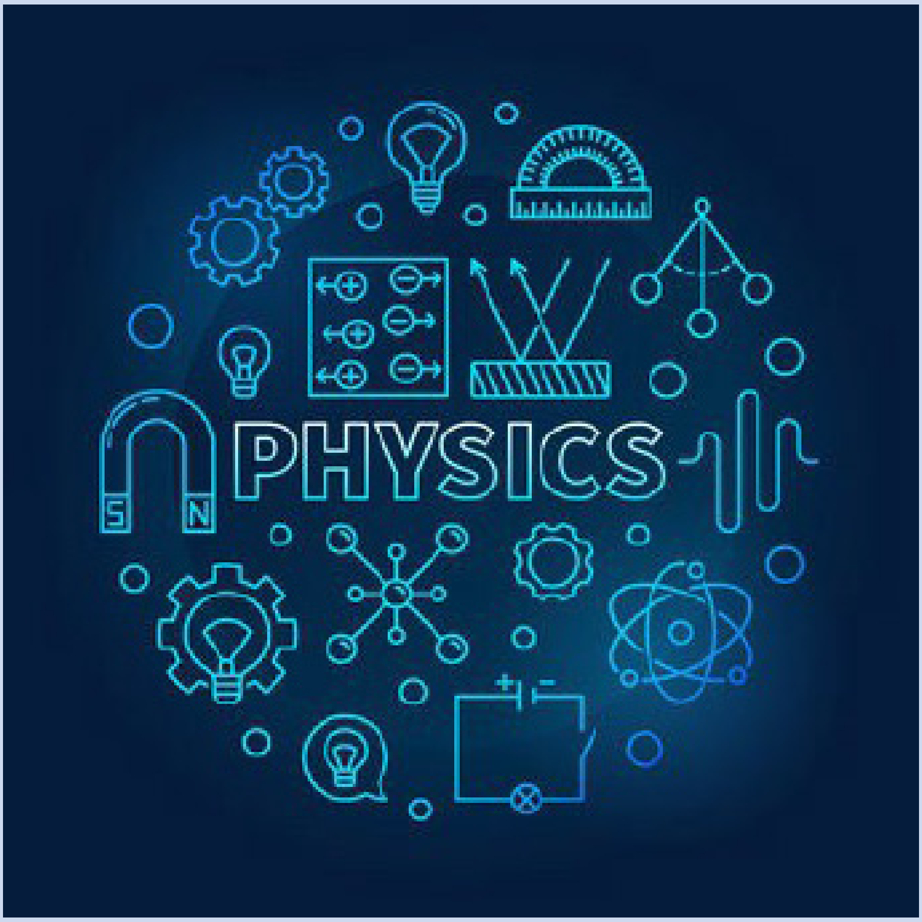
Physics A Level Essays 2024



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Contents

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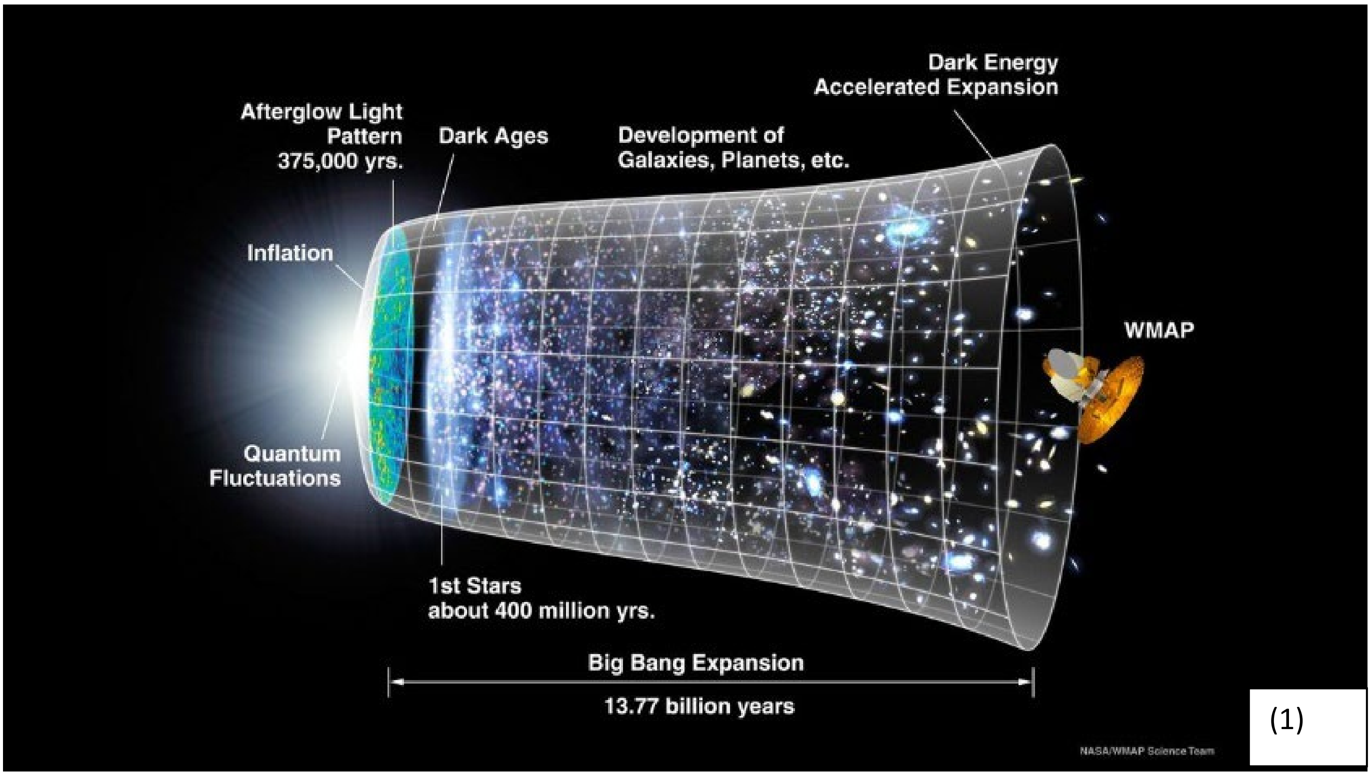
The Origin of the Universe to the End of the Universe

Introduction

The Universe is ever-growing. It is always expanding and is now bigger than our minds can comprehend. However, everything started from somewhere, and this is where the Big Bang Theory comes into play. We will look into the theory behind the beginning of the universe and the possible theories of how the universe might end.

The Origin of the Universe

The very start of the observable universe that we know today started from a concept known as cosmic inflation.



(1)

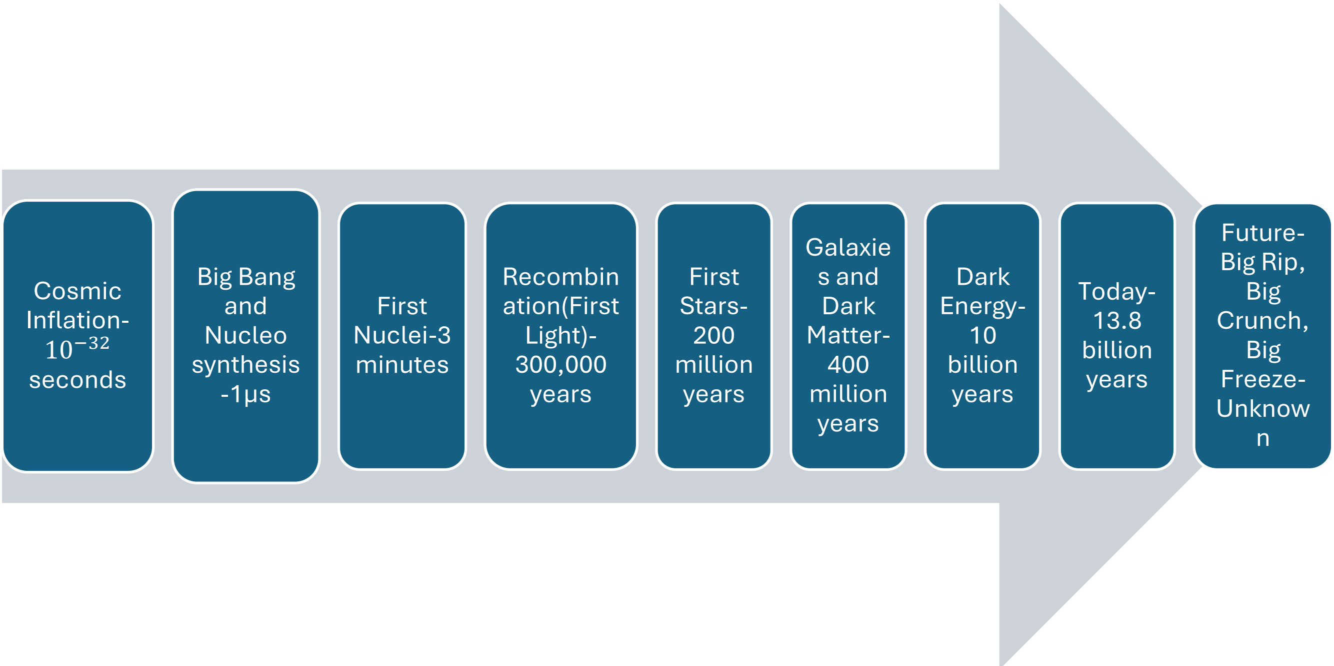
Cosmic Inflation

Cosmic inflation is when the universe expands faster than the speed of light for a fraction of a second (2).

Big Bang (13.8 billion years ago)

After cosmic inflation, energy was transferred to matter and light which caused the big bang (2). This theory was proposed by Georges Lemaitre in the 1920s who emphasised that the universe began from a single primordial atom (3). Furthermore, this atom was thought to be less than a million billionth billionth the size of a single atom (3).

This primordial atom is so dense and energetic so that all four fundamental forces such as gravity, electromagnetism and the strong and weak nuclear forces are combined into a single force (3). This was later supported by Edwin Hubble who interpreted the distant stars and galaxies receding from Earth in every direction (4). This led to Edwin conclude that the current matter and energy in the universe were once condensed as a tiny hot mass. Then a huge explosion occurred which sent matter and energy expanding in all directions (4). This huge explosion is known as the Big Bang. This theory was then confirmed by Arno Penzias and Robert Wilson in the 1960s with the discovery of cosmic microwave radiation for which they received a nobel prize (3).



-(2)

Nucleosynthesis

A fraction of a second after the Big Bang, the universe was hot and contained elementary particles known as quarks and leptons (5). This led to the creation of protons and neutrons and electrons, atomic nuclei, atoms, stars, galaxies, clusters of galaxies and superclusters (5). Within a few minutes, the earliest elements were formed such as hydrogen, helium and traces of lithium and beryllium due to collision of protons and neutrons (2). The vast majority of electrons were freely floating as they are not attached to the nuclei (2). This created the fog that scattered the light and hence the cosmos appeared opaque (2).

Recombination (380,000 years after the big bang)

At this point of time, the universe has cooled down to the point where atomic nuclei can capture electrons (2). This led to:

1. The cosmic fog cleared due to lack of free floating electrons, so that light could travel over great distances (2).
2. The first atoms formed gave off its own light known as cosmic microwave background radiation which is still detectable today, hence being the oldest observable light in the universe (2).
3.

Dark Ages (200 million years after Recombination)

This is the period where the universe remained dark due to the absorbing effects of the hydrogen atoms (2). At this time, there were no stars to shine and the cosmos consisted of a sea of hydrogen atoms, helium, and trace amounts of heavier elements (2).

Appearance of First Stars (Several hundred million years after Dark Ages)

First stars were created as nuclear fusion occurred at the centre of clumps of gas which was hot (2). These clumps grew more massive and the center became hot where the nuclear fusion occurred (2).

Reionization (1 billion years after the big bang)

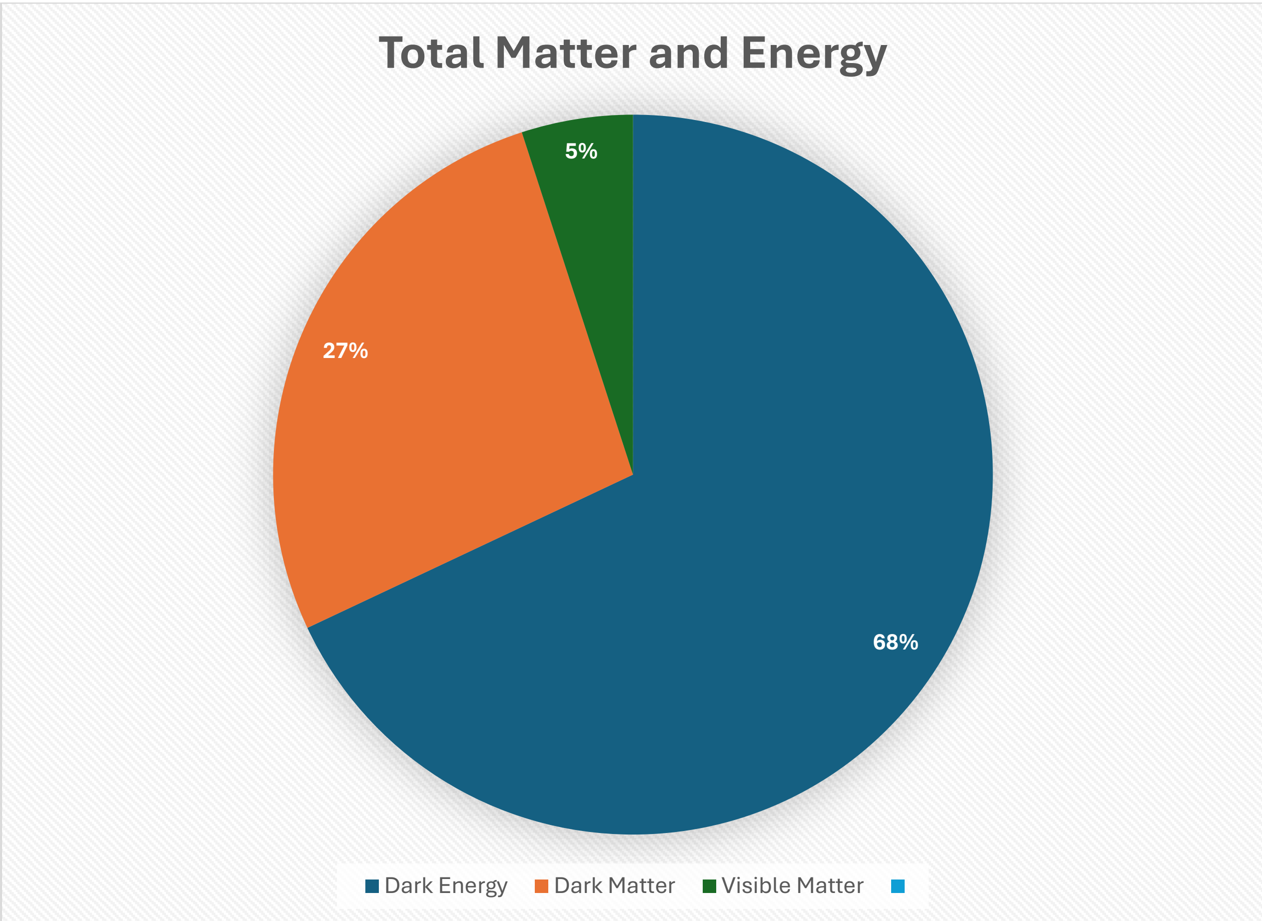
As more and more stars are being formed, the clumps of gas starts to decrease (2). The ultraviolet light emitted from the stars ionise the hydrogen atoms in the gas into protons and electrons (2). Eventually, the universe becomes transparent which allows light to travel as we see today (2).

The End of the Universe

There are various theories that we think are linked to the End of the Universe:

1. Earlier, scientists thought that the universe's current expansion was slowing down (2).
2. In 1998, scientists discovered that certain supernovae explosions were fainter than predicted. This led to them concluding that the universe is continuing to expand (2). They also think that this could be driven by a mysterious substance called dark matter. This expansion has been observed by the data collected by the James Webb Space Telescope (3).

Dark energy is thought to make up 68 percent of the universe's total matter and energy (3). Dark matter makes up another 27 percent (3).



There are three theories that propose the end of the universe which is known as the big crunch, big freeze and the big rip (6).

The Big Crunch

The Big Crunch was first proposed by Alexander Friedmann in 1922 through his Friedmann equations (6).

$$H^2 - \frac{8\pi G\rho}{3} = \frac{kc^2}{S^2}$$

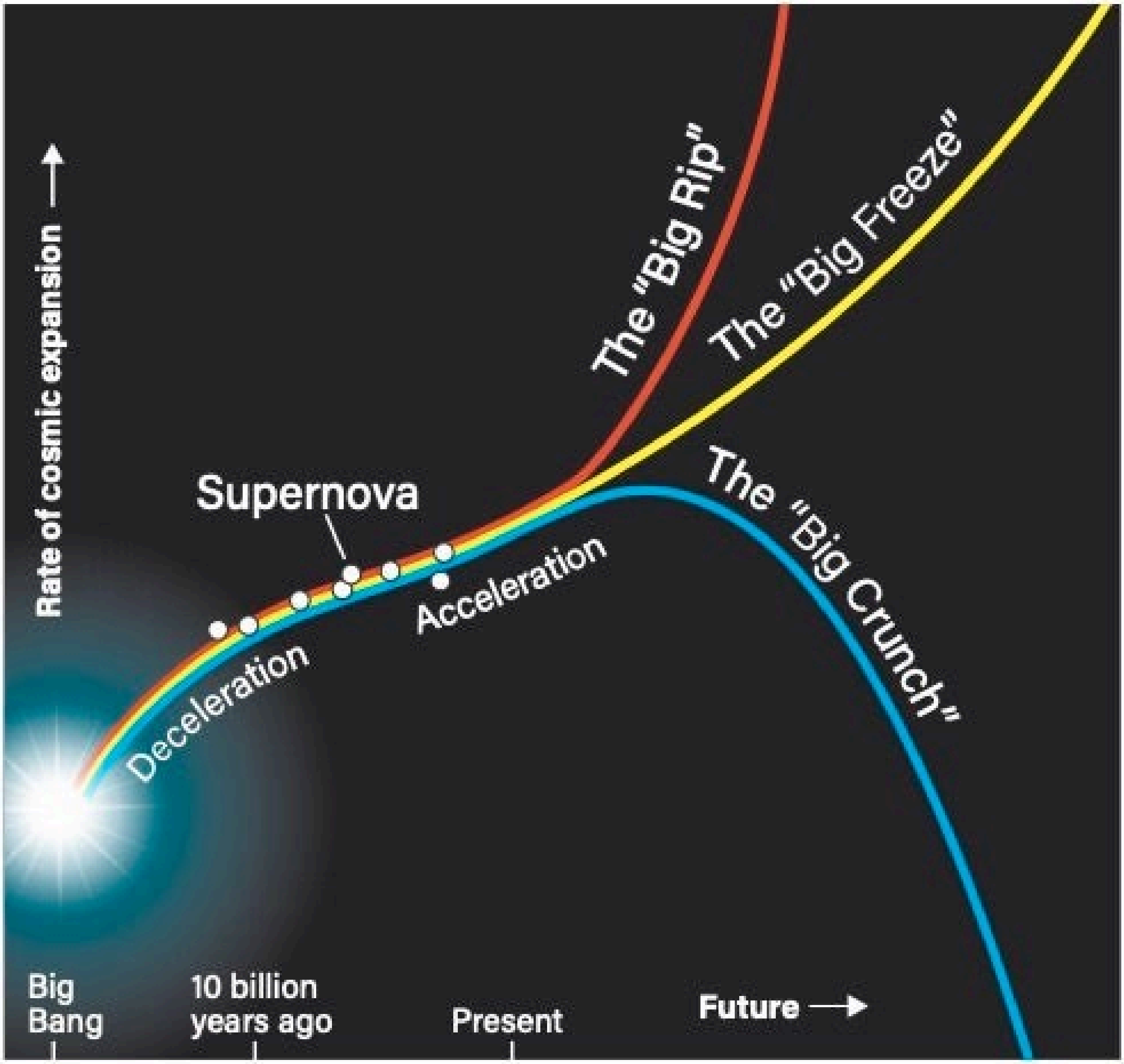
$$(expansion) - (density) = (curvature)$$

-(7)

The density of the universe determines whether the universe will expand, or contract as shown through the equation (6). Furthermore, if there is enough matter in the universe then the gravity will stop the expansion and cause it to crash back inwards (6).

The Big Freeze

The Big Freeze is thought to happen as the universe expands via dark energy where at some point the closest galaxies will be too far to see which is 100 trillion years from now (6). Then another 100 trillion years later, star formation will stop as there will be no more gas clumps due to the gas thinning out as the universe expands (6). The remaining material will be locked up by white dwarfs and black holes (6). And then a few years later, the last objects in the universe, supermassive black holes, will finish evaporating via Hawking radiation (6). This will cause the universe to become dark.



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<u>The Big Rip</u>

In 2003, the Big Rip theory was first proposed by Marcelo Disconzi and his hypothesis is based on dark energy and the cosmological viscosity (8). This led him to conclude that for the Big Rip to occur, dark energy must win a battle against gravity to a point where individual atoms rip apart (8).

Conclusion

In conclusion, I find that the Big Bang Theory is the most believable theory because there is more evidence from scientist like Edwin Hubble. When looking at the theories for the end of the universe, I find that the Big Freeze Theory is more plausible as it is evident that the universe will never stop expanding and I believe that the gas will thin out which will prevent anymore stars being made and the remaining stars will be absorbed and the universe will freeze.

I find that the universe has interesting theories and may not be the end to how many more theories are to come. In the future, I believe that more theories will come up and overthrow the existing theories that we have today. This could be because of the technological advances as time goes on which can improve the understanding that we have of the universe. We will know a lot more to possibly make these theories obsolete.

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Alex Turner

Interplanetary and Interstellar Travel

On the 20th of June 1944, from the Peenemunde Army Research Centre, an A-4 test rocket was launched above the Karman line and became the first man-made object to reach outer space and the first sub-orbital spaceflight [(1)]. Later, Sputnik 1 was launched into orbit in 1957 as the first satellite to orbit the Earth [(2)] and, in 1969, humanity had successfully reached the moon [(3)]. In the present day, thousands of satellites and spacecrafts have been sent into space and remain there now. Currently, the farthest unmanned spacecraft from Earth, Voyager 1, has travelled over 15 billion miles into space [(4)]. While we are currently not capable of transporting humans this far, our technology is rapidly developing and large corporations, such as NASA, are looking to make it possible to form colonies on Mars. This report will explore the present capabilities of space travel and different ideas on what it may look like in the future.

Technology and Becoming Multi Planetary:


How SpaceX's massive Starship rocket might unlock the solar system- and beyond [(19)]

SpaceX's Starship is a potential representation of what interplanetary travel requires and what it could look like. It is designed to transport crew and cargo anywhere as far as Mars and beyond. In addition, it is the world's most powerful launch vehicle and can be refuelled in low-Earth orbit, making it highly effective at travelling vast distances throughout space [(5)]. Alongside Starship, SpaceX has been making lots of test flights for reusable rockets such as the Falcon 9, which has currently had over 300 launches and landings [(6)]. If more spacecrafts like this are made within the next few years, it is likely that we will see more frequent developments about space travel. Furthermore, SpaceX and NASA are not the only companies aiming for Mars: Relativity Space and Impulse Space have also been targeting it. Although it was delayed by two years, they have made plans to send their Terran R rocket to Mars in 2026 and make their first commercial lander mission [(7)].

Another big competitor in the space industry is Blue Origin, owned by Jeff Bezos. Over the years, it has become more recognised and is gradually increasing its influence to rival that of SpaceX [(8)]. Despite not yet being as significant on a large scale, Blue Origin aims to contribute with its own unique innovations such as Blue Alchemist [9] to enhance our technological capabilities. Its main ambition is to bring people and industries into space along with utilising the resources of space to benefit Earth [10].

While humanity's journey to become multiplanetary has been long and laborious, these large corporations are making life in space increasingly promising within the coming decades.

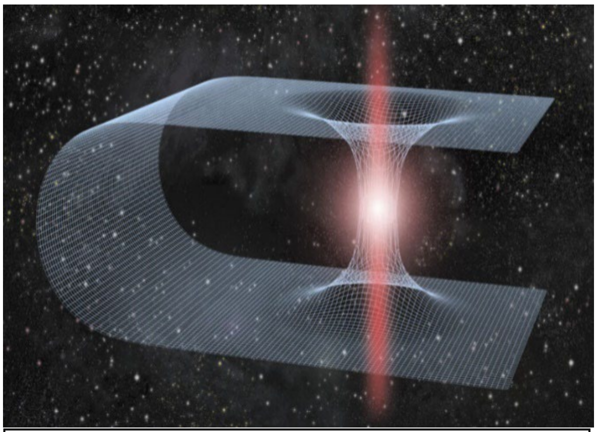
Going Interstellar

Interstellar travel is something that has been depicted in countless different media. Unlike moving to Mars, going outside of our solar system is a near impossible feat to accomplish within one lifetime from the present day and we are highly unlikely to make it so far without using unmanned spacecraft. This is due to the sheer scale of space and the high level of technological advancements needed to traverse such long distances. There are also factors such as time dilation [11], which would complicate the realism of going so far away from Earth, particularly communication. However, there are numerous theories on how humanity could make it to the stars in the distant future, no matter how unlikely they are to happen or how long they would take.

An artist's impression of a Generation Ship, Article from Strange Horizon [20]

One such theory is that of generation ships [12], immensely large vessels capable of holding vast quantities of people and resources to be transferred to another solar system or habitable planet. Their journeys involve hundreds or thousands of years of travel and requires complete self-sustainability. Although they do not rely on Faster Than Light speeds, there are several ways in which they are unrealistic. Staying in space for long durations can negatively affect the human body in different ways [13] and high levels of technology would be required to recreate many of the conditions of Earth on the vessel. In addition, the nearest exoplanet in the habitable zone of a red dwarf star, Proxima Centauri b [14], is approximately 4 light years away from Earth. Due its gargantuan size, a generation ship could not come anywhere close to the speed of light as it would require unfathomable quantities of energy to be propelled that fast. This means that travelling this distance would take at least several tens of thousands of years, in which hundreds of generations of humans would pass before reaching their destination.

The idea of generation ships is not completely unrealistic since it does not break the laws of physics, but there are too many factors such as the effects of space travel on humans and the logistics of a tremendously long journey which make it a highly unlikely possibility.



Could ripples in spacetime point to wormholes? [21]

Another theory on how we would move across the stars is by traversing wormholes [15], a structure resembling a tunnel connecting two points in the universe. These structures are hypothetical, and their existence is not confirmed, but there are indications that they could exist. Based around Albert Einstein's Theory of General Relativity [16], wormholes can be explained as a connected black hole and white hole [17], creating a bridge between two areas of spacetime as one side which pulls in matter and another which releases it. As a method of moving around the cosmos, they would be ideal for travelling thousands of light years in a substantially shorter period. However, even if we discovered that they do exist, they would most likely be located at unreachable distances away from Earth. It would also be highly unsafe to travel into a wormhole as it shares the qualities of a black hole, which simultaneously stretches and compresses anything in proximity of it (known as spaghettification) [18].

Wormholes are only theoretical, meaning that we will probably never see them. On the contrary, they are based on the same principles that proved the existence of black holes. So, there may be a time when we find that they are real, but the chances of being able to use them are slim.

<u>Conclusion:</u>

Space travel is something that humanity is only just beginning to scratch the surface of, and we have yet to set foot on the surface of Mars. Despite that, we can expect to see drastic changes as technology becomes more advanced and as more effort is focused on getting to Mars. Furthermore, although it is likely that we may never reach outside of our solar system, there is still so much about the universe that we do not know and all it could take is one discovery to change everything.

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<u>Was Bohr the main reason for Einstein's success in quantum mechanics?</u> **By Archie Hamblin**

Bohr and Einstein both competed and supported one another's discoveries when it came to quantum mechanics in the early 20th century[1]. This all originated from Bohr's model of the atom, which by 1912 the atomic pieces were ready to be put together. In 1912 Bohr had moved to Manchester and had started work on the structure of the atom with Rutherford (Gribbin, 1984)[2]. Einstein had introduced the ideas of photons and the explanation for the photoelectric effect in which he proposed the existence of discrete energy packets during the transmission of light as Bohr was navigating England and Europe also stated by Gribbin in his novel. However, one problem with making influential discoveries is the fact that some scientists may not back you and agree with your ideas especially because of the time these discoveries were made in and the beliefs at the time. Bohr's ideas were the most heavily accepted before the start of the first world war because of his expansion to his work with Rutherford, as Rutherford's work with the Gold Leaf experiment and the firing of alpha particles was revolutionary in terms of finding the protons/positively charged nucleus in the atomic model which are well known and taught in schools to this day. In June 1922 Bohr visited the University of Gottingen in Germany to give lectures on quantum theory and atomic structures. These lectures were a large turning point in this argument, and this is something I will go into further detail about later. 1923 was the most important year for Einstein as his idea on the photoelectric effect was finally accepted, this paper was originally released in 1905, and the rest of his ideas were summarised in his autobiographical notes in 1949[3]. Both scientists are described and talked about as being revolutionary in Quantum Mechanics, of which I will go into further detail next.

Ehrenfest, P. (1925) *Niels Bohr (left) with Albert Einstein (right)*. Paul Ehrenfest's home in Leiden.[3]

By 1925 Bohr was debating quantum theory, during this process he proposed that electrons circle the nucleus following the classical laws but subject to limitations, such as the orbits they can occupy and the energy they lose as radiation when they jump from one orbit to another[4]. Einstein was debating quantum theory with Bohr, and they formed a team, this helped Bohr clarify the concept, but it was a theory Einstein never quite accepted. This Bohr-Einstein fusion created a scientific breakthrough and evolution better than no other, the confusion it created for Einstein relayed a wave of knowledge over Bohr making them a fantastic pairing.

Where did it all begin?

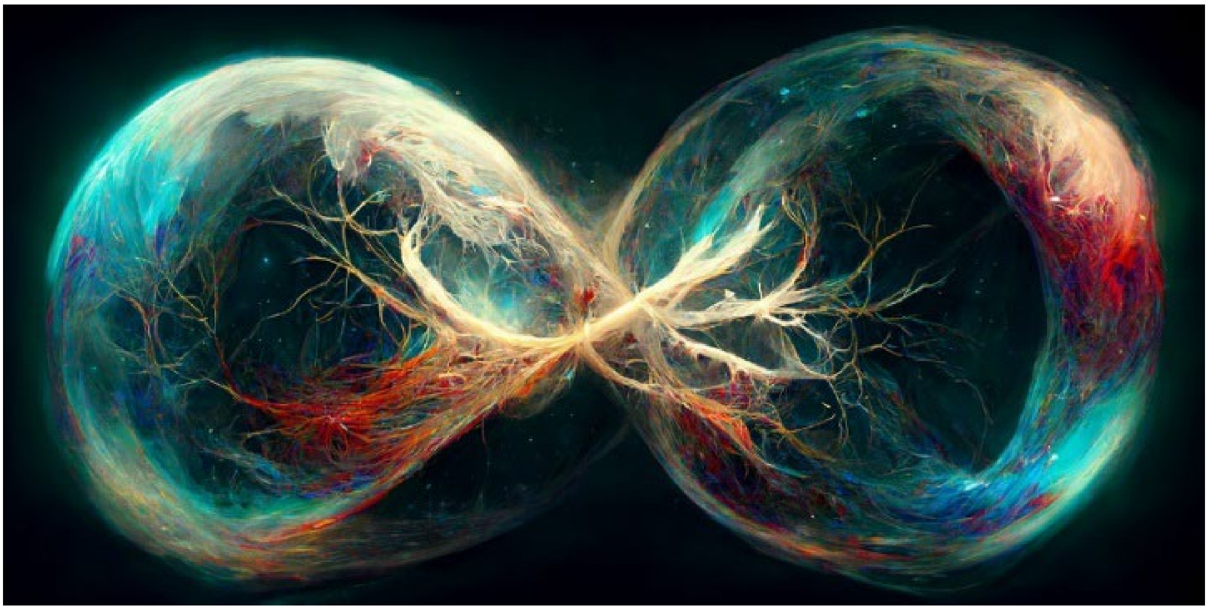
For Bohr it all began in 1885 in Copenhagen, Denmark when he was born[5]. Bohr's father was a professor of physiology at the University of Copenhagen and was nominated for the Nobel Prize twice. In 1912 the Wedding Bells rang for Bohr, and they had 6 children together in a happy marriage. A year later he published his model of the atom which was a positively charged nucleus made up of positively charged protons and neutrally charged neutrons orbited by a set number of shells containing negatively charged electrons. This idea took 9 years to be properly accepted and then in 1922 Bohr was awarded a Nobel Prize just like his father in previous years. Bohr went on to organise the Atoms for Peace Conference in Geneva in 1955. In addition to his major contributions to theoretical physics, Bohr was an excellent administrator. The institute he headed is now named for him, and he helped found CERN, Europe's great particle accelerator and research station[6]. During my time in Geneva at the museum of modern science I learnt that Bohr was so influential in the creation of CERN and the evolution of the structural integrity of the atom, also showing that multiple strands of science can all overlap to allow for more discoveries to be made. Moreover, in 1957 Niels Bohr receives the Atoms for Peace award, concreting his ability to move the scientific world forward with or without assistance from other credited scientists.

Hertzog, S.J. (2024) *The Large Hadron Collider*. Geneva.[7]

Albert Einstein's journey started and finished in a very different matter. His journey first began in Ulm, Germany in 1879, from there he moved all around Europe, first to Munich then Milan and eventually settled in Switzerland, more specifically the Polytechnic school in Zurich[8]. In 1917 he became the director of the Kaiser Wilhelm Institute of Physics in Berlin which is the beginning of his controversial antics. 10 years later he begins his debates with Niels Bohr, and this is where the two first meet. However, a year later he is diagnosed with a heart condition. As the Nazi rule was encapsulating Germany and Eastern Europe, Einstein got away as soon as possible and in 1933 he fled to Princeton in America to continue to be a spearhead in the quantum science world. From there Einstein expanded on his work on nuclear warfare and worked with Oppenheimer. Oppenheimer directed the Institute for Advanced Study from 1947 to 1969, and Einstein was a faculty member there from 1933 to his death in 1955[9]. At the prestigious 1927 Solvay Conference Bohr and Einstein began their dispute, by most accounts of this public debate, Bohr was the victor[10].

Quantum Entanglement and Realism

Quantum Entanglement can be defined as a bizarre counterintuitive phenomenon that explains how two subatomic particles can be intimately linked to each other even if separated by billions of light-years of space[11].



Ferrie, C. (2022) *Quantum Entanglement.*[12]

Albert Einstein famously dismissed the idea of Quantum Entanglement as a 'spooky action at distance'. Entanglement is better understood as information, but that's admittedly bland[13]. Einstein really revolutionised how the quantum world was perceived within his time in the scientific world, along with Bohr these two changed the way theoretical and practical science work together to discover new methods to their madness. Einstein, Podolsky and Rosen introduced the concept of entanglement in 1935 to demonstrate that quantum mechanics is not a complete theory, this includes a discussion of what is reality and what is a complete physical theory[14]. Einstein and Bohr's debate over quantum entanglement taught us that uncertainty is inherent to our universe and the world we can physically see acts completely differently to the microscopic world, therefore creating a clear divide between the Quantum world and the physical world[15].

Realism is another of the strands of quantum mechanics discussed by Einstein and Bohr. This is the idea that nature exists independently of a man's mind and abides by the "consciousness causes collapse" theory[16]. The fact that quantum mechanics is built up from a collection of theories proves that the scientists are only making assumptions, doing so by putting their best ideas forward. However, the assumptions are built around fact and are reviewed by respected scientists making them acceptable.

Bohr and Einstein once again differed in opinions on this matter, Bohr evidently misunderstood Einstein's argument about the quantum mechanical violation of relativistic causality and instead he focused more on the consistency of quantum indeterminacy[17]. In my opinion I think that the reason why these two differed so much was because of a lack of understanding of where the other was coming from, they were more clued in and focused on separate strands of quantum mechanics which led to a clear path of misunderstanding.

Who has the answer?

In conclusion, Bohr and Einstein were the arrowheads of the quantum world into the modern bullseye, opening doors and passageways for the present. Textbooks say that Bohr's side won and that the Solvay Conference was the indefinite turning point of the argument between the two, but the discussions and disagreements were the real reason for any sort of improvement in the world of quantum mechanics[18]. Einstein's famous quote "God does not play dice" can be interpreted in many ways, one of which is that God does not take risks/gamble unlike the scientists like Einstein and Bohr for example. Overall Bohr took the bigger risks and sacrifices leading to his 'victory' in the debate over quantum mechanics. That brings an end to the quantum journey and battle between Einstein and Bohr between the early to mid-1900s, the winner of the battle is an open discussion, many believe it's Bohr and so do the textbooks but there are many reasons to be on Einstein's side too, both were great scientists in their own right and deserve all the credit they receive, the two working together was a scientific fusion like no other.

Albert Einstein and Niels Bohr attend the Solway conference in 1920 in Brussels, Belgium. *Photo courtesy Wikipedia.*[19]

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Evan Kidley

How can the field of physics influence palaeontology?

Introduction

X-rays have had a major influence on the world, whether for medical usage or for historical research[1]. For the field of dinosaurs, and other history-based fields, this has allowed us to perform CT-Scans. This has developed our perception of dinosaur behaviour, reconstruction and even hunting patterns. How have CT scans allowed for a wider knowledge of our dinosaurs? CT scans allow for a reconstruction of bones or most importantly, skulls of fossils which may lack the proper needed bones for a valid or clear analysis. What is CT-scans, and how do they work? What are the benefits, and lastly, what are the disadvantages to our CT scans.

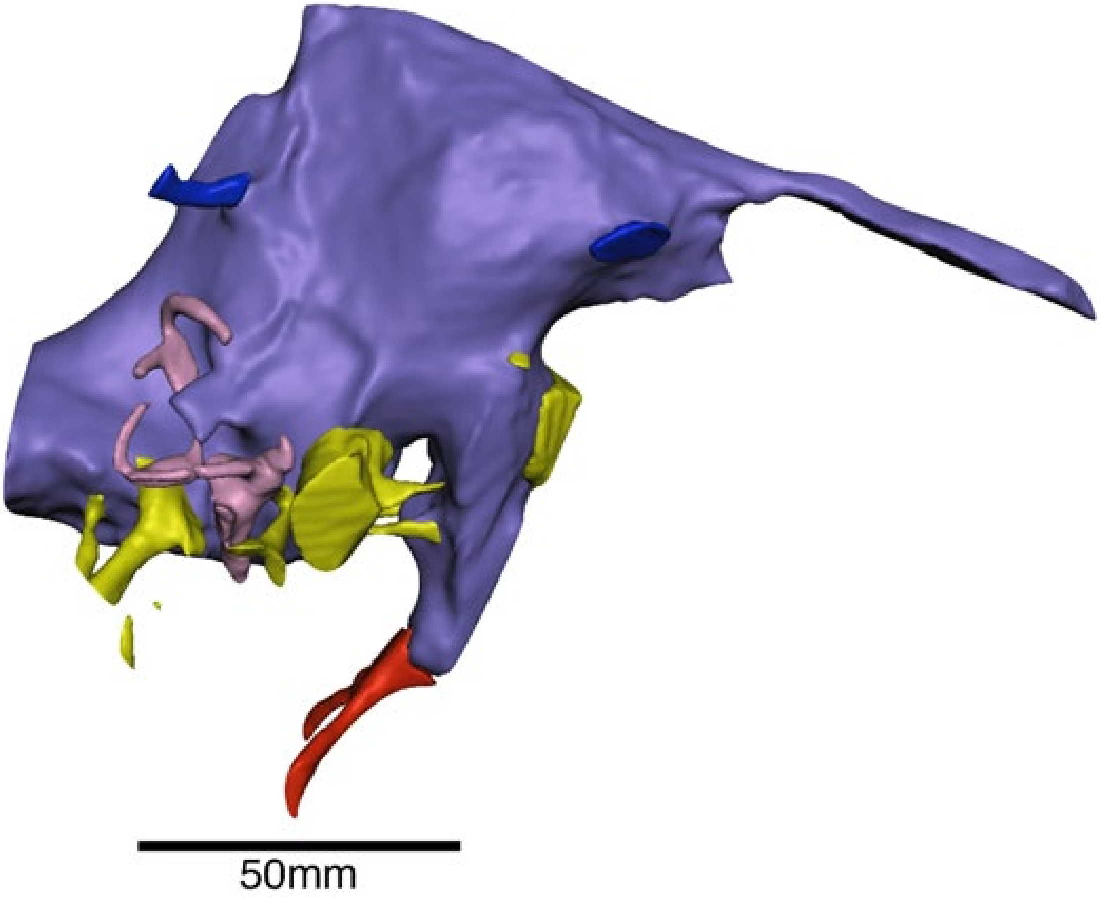

Figure A: Image of a cranial scan of a Spinosaurus 2

[1] https://www.cambridge.org/core/journals/the-paleontological-society-papers/article/abs/fossil-secrets-revealed-xray-ct-scanning-and-applications-in-paleontology/3109CE435D7ACDC29DDCC2E938A30436 Accessed (19/08/24)

[2] https://www.news9live.com/science/ct-scanning-reveals-brains-of-oldest-spinosaurs-known-au941-2052811, Accessed (19/08/24)

What are CT scans, and x rays? And what can we do with them?

CT scans stand for "computed tomography," where a type of wave called x rays are fired towards objects or patients. As the waves are rotated around the object or patient, it will produce several cross-sectional areas/slices. These produce tomographic images, which can then be built towards making 3D images. Unlike normal x rays which are limited by their 2D imaging and use of an x ray tube; CT scans use an X-ray motor source that travels in a circular motion called a "gantry". These slices continue until desired image if shown[3]. For example, we take a section of fossil after applied acid to remove any unwanted rock, added with plaster and then scanned, these machines are obviously adapted towards more paleontological usage[4]. After the scan, we can use the computing system to stack the images and have our result of a more detailed, comprised image of our fossil. These allow for us to understand higher details on dinosaurs which could not be originally identified by eye or other computing systems. This brings us to a field known as virtual palaeontology. These scans do not need to be just for vertebrae life, as they can also be used towards plants as well! I will explain the benefits of the plant scans, but the scans allow to study "extraordinary detail preserved in fossilized plant seeds" allowing for reconstruction of "histories of how plant groups evolved and spread over time." Of course, these were not the only ways we reproduced fossils, as palaeontologist during the 20th century have taken photos each time, they cut a slice from a fossil and use the photos to reproduce wax models. However, these were later outdated by machines, and I will discuss the consequence of these methods. [5] These flexible scans are shown to be useful, but there becomes discussion on whether these scans are worth using for fossils.

[3] Computed Tomography (CT) (nih.gov), Accessed (19/08/24)

[4] Fossils Get a CT Scan | Smithsonian Ocean, Accessed (19/08/24)

[5] https://www.sciencenews.org/article/3-d-scans-reveal-secrets-extinct-creatures Accessed (19/08/24)

Why do we use CT-scans for fossils?

Safer approaches for the fossils

Using scans when understanding our fossils can be a far safer method when analyzing the specimens. After scanning the fossils, we can determine what compartments of the fossil are calcium carbonate. In that case, we can safely remove the rock with a specific acid. [6] This preserves the fossil without any unnecessary damage to the fossil. The scans also allow for analysis of harder to reach and observe sections of the fossil, such as cranial parts. Preserving the fossil for other scientists to peer review and even provide latest ideas and hypothesizes on the dinosaur, as the scanning can provide safer methods for the specimen. Creating a wider range of accuracy opposed to 20th century methods, leading to destroyed specimens.

The crucialness of accuracy within palaeontology and palaeobotany.

Being as accurate as possible is incredibly important when understanding specimens. As minute details such as teeth or skin structure can lead to completely different reconstructions of the animal. Scans allow a greater depth of understanding the biology of dinosaurs such as teeth from dinosaurs in the Jurassic. [7] Along with these higher accuracies bring further benefits to our world, as we can utilize micropalaeontology and these higher resolution photos to bring positivise to our future. Using scans on prehistoric plants allow scientists to study the stomata of these plants. [8] Studying the stomata shows how the rate of gas exchange in their prehistoric atmosphere, and hints towards previous climates. Allowing climatologists to create a further detailed board of how the Earth climate has changed and being able to track what our next cycles may include on Earth's climate.

Furthermore, having collections of how a species has adapted its body through scanning its remains allows palaeontologists to predict and fill in gaps when creating specimens from new fossils, as most fossils are left as small pieces and fragments. These create bigger pictures for the trajectory of evolution and predict how and what our present-day animals may evolve and change, and even on how our animals will adapt and evolve according to climate changes.[9] Overall, these scans are essential and vital when palaeontologists need to be as accurate and precise as possible, as studying these specimens on a closer, deeper scale given through the image slicing from the CT-scans can give a bigger picture on how our world has responded to climate changes and next temperature cycles.

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[6] https://museum.wales/articles/1026/Fossils-in-stone-acid-preparation-of-fossils/#:~:text=It's%20not%20easy%20to%20remove,pens%20similar%20to%20engraving%20devices. Accessed (19/08/24)

[7] https://www.birmingham.ac.uk/news/2023/x-ray-ct-scanner-will-reveal-secrets-of-ancient-specimens Accessed (19/08/24)

[8] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5462064/#:~:text=Fossil%20plant%20stomata%20reveal%20insights,with%20the%20exception%20of%20liverworts Accessed (19/08/24)

[9]

Examples of these scans being effective was during the Megalosaurus scan, where through over 3,000 scans showed an important detail of the jaw which would not been able to see through the eye. Where the scans reveal hidden teeth, below the right of the present teeth. [10] With this, palaeontologists were able to decipher that the animal was polyphyodonty. Where, typically carnivorous or predatory animals, will undergo constant teeth replacement. [11] Giving us the first evidence of these dinosaurs evolving with replacement teeth, and greater knowledge of dinosaurs generally.

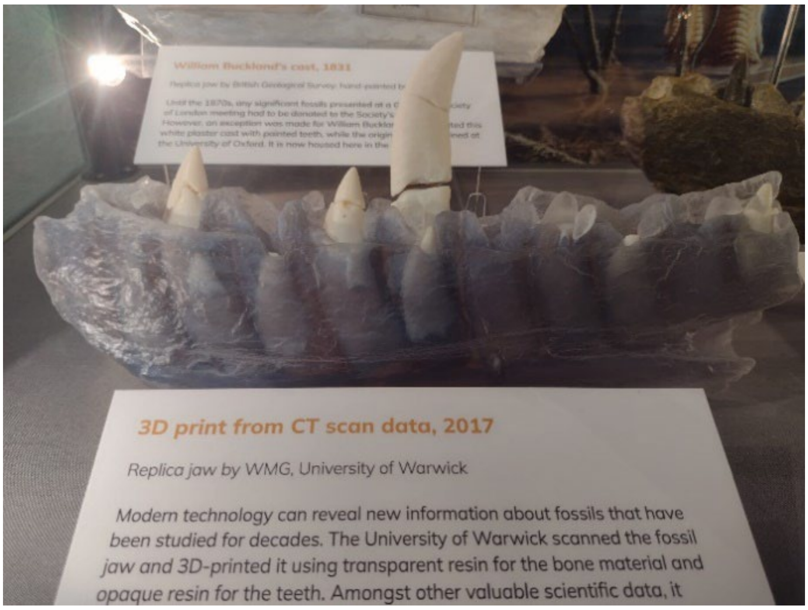

Figure B: Oxford Museum photo of Megalosaurus Jaw (Own Photo)

Potential downsides of relying on CT scans

CT scans are beneficial for quantitative data, but there are some risks and challenges when facing the use of these scans. Firstly, CT scans require substantial amounts of money to use per hour and require a large space of time when booking these scans. [12] This means any unplanned interruptions or delays that may occur, may delay projects further and cause any disruptions towards other planned projects ahead of time with the tested specimen. Additionally, the costs too can further add delay or even a deterrence towards examining the fossil due to some museums not having the funds. According to the article as well, the similar densities of the matrix surrounding the specimen will cause disruptions in analysing such as calcium carbonate present in both limestone and certain bones or shells. This may lead to inaccurate readings of the animal and create uncertainty when analysing, leading to some questions around the fossil to be left unanswered for heavy amounts of time and further gaps in understanding the animal.

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[10] Victorians Missed Key Dental Detail in 1st Dinosaur Ever Named | Live Science Accessed (19/08/24)
[11] Polyphyodont Definition & Meaning | Merriam-Webster Medical Accessed (19/08/24)
[12]] Investigating CT Scans as a Palaeontology Research Tool (palaeo-electronica.org) Accessed (19/08/24)

So, where does computed tomography place in the palaeontology?

With varied success depending on the exact matrix and geology of certain specimens, the scans have created a broad range of beneficial new techniques and have been widely used and popularised by geologists and other prehistoric and historic fields. Allowing new flows of data and hidden key concepts and data found within fossils, and with museums and other companies purchasing and regulating them themselves; its created faster methods of analysing specimens. Allowing scientists to discover these hidden details such as plant stomates, teeth rotations or cranial scans of dinosaurs create a better understanding of our own present life. Creating predictions of future climates and even possibly understanding trajectories of evolution, whether past, present, or future. They have provided us with larger range of knowledge and overall, have a significant impact on historic and prehistoric research.

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Harley Symington

The Creation and Development of Nuclear Weaponry: Origins of The First "Nuke"

The United Kingdom began the world's first research on nuclear weaponry which was codenamed Tube Alloys in 1941(1). Initially the UK did not want to collaborate with the US on further research into the potential of nuclear weapons due to Britain having doubts of secrecy and that the US would be a liability. However, the irony of the situation is that Britain had already been infiltrated by Soviet spies such as Klaus Fuchs and Guy Burgess. Despite this in 1942 the United States in collaboration with the United Kingdom initiated the Manhattan Project, the following year the design of a powerful weapon using nuclear fission began, which also saw the aid of Canada.

The main figurehead behind the Manhattan Project was J Robert Oppenheimer (born Julius Robert Oppenheimer in New York City, New York on April 22nd, 1904 (2). He was a respected physicist who obtained a doctorate in physics from the university of Ohio, Germany. Oppenheimer joined the Manhattan Project in 1942 and was given the responsibility of creating the first nuclear weapons at the project's Los Alamos Laboratory in New Mexico where he looked for a method to separate naturally occurring uranium from uranium-235 and to figure out how much uranium was needed to construct a nuclear bomb, where he was appointed director in 1943. His scientific knowledge and leadership were crucial to the project's accomplishment. He witnessed the first test of the atomic bomb, Trinity, on July 16, 1945.

That same year, in October, Oppenheimer resigned. He took over as director of the Institute for Advanced Study in 1947 (4). He also oversaw the Atomic Energy Commission's General Advisory Committee from 1947 to 1952, during which time it voted against the hydrogen bomb's development in October 1949. The Atomic Energy Commission (AEC) temporarily revoked Oppenheimer's security clearance on December 23, 1953, citing "interests of national security" as explanation. Oppenheimer faced accusations of long-standing ties to the Communist Party during the height of anti-communist sentiment in the United States. His views on the creation of the hydrogen bomb were also mentioned, stating that Oppenheimer remained opposed to it even after President Truman gave permission for a programme to proceed. Furthermore, they asserted that his resistance had slowed the project's advancement (5). On April the 12th 1954 a panel of the Atomic Energy Commission's personal security board starts the 19-day hearings, refusing to reinstate Oppenheimer's security clearance and terminating his government service. Then in May 1954, the May issue of bulletin discusses the Oppenheimer case which in summary talks about how The Bulletin highlights the ethical and procedural flaws in the AEC's decision, emphasizing that Oppenheimer's opposition to the hydrogen bomb was based on technical and military considerations rather than any political affiliations.

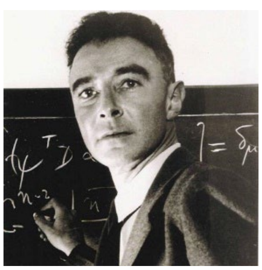

Figure 1Julius Robert Oppenheimer (3)

The issue also goes over the impacts of Oppenheimer's work on his personal life and how after seeing the testing of the hydrogen bomb, and how he never wanted it to be created saying" now I have become death, destroyer of worlds" (6). On December 2nd, 1963, Oppenheimer received the Enrico Fermi award in the White House and a reward of $50,000 from President Lyndon, however despite this his security clearance remained suspended. On the 8th of February 1967 Julius Robert Oppenheimer would sadly pass away at age 62 of throat cancer at 8 o'clock in his home (6).

Early Cold War and the Arms Race:

Just six months after the United Nations General Assembly's formation, the United States initiated its first post-war nuclear tests, known as Operation Crossroads (7). Conducted at Bikini Atoll in the Pacific, these tests were to evaluate the impact of nuclear explosions on naval vessels. A total of ninety-five ships, including captured German and Japanese vessels from World War II, were subjected to these tests. The operation involved detonating two plutonium implosion-type bombs: one exploded above the fleet and the other underwater.

Meanwhile, the Soviet Union was developing its own atomic weapons behind closed doors. During World War II, Soviet efforts were hampered by a scarcity of uranium, but new deposits found in Eastern Europe provided a reliable supply (7). This allowed the Soviets to establish a domestic source for uranium. Despite American experts' predictions that the Soviet Union would not develop nuclear weapons until the mid-1950s, the Soviets successfully detonated their first bomb, "First Lightning" also known as "RDS-1" on August 29, 1949, in Kazakhstan. This bomb was a replica of "Fat Man," one of the bombs the United States had dropped on Japan in 1945 and had a yield of 22 kilotons.

Then on the 24th of September 1951 the Soviets began their second round of nuclear weapons testing and development on a bomb nicknamed "RDS-2" which was a part of the Soviet effort to refine and improve the design efficacy of their nuclear weapons, The RDS-2 had an approximated yield of 38 kilotons which is significantly larger than the previous RDS-1 The new and improved bomb was tested on September 24th, 1951, at the Semipalatinsk Test Site in Kazakhstan (8), the primary nuclear testing ground for the Soviet Union. The testing and development of the RDS-2 was a part of a much greater vision that the Soviets had which was to build a devastating nuclear weapons arsenal.

August 12th, 1953, the Russians tested their first ever thermo-nuclear weapon nicknamed RDS-6s (Joe-4), at Semipalatinsk which had an approximate yield of 400 kilotons (9). The bomb had a unique design which we know to be the 'layer cake.' 10% of the bombs yield was from the fission of uranium-235, 20% from fusion and 70% from the fission of the uranium-238 layers (9).

Then only a short couple of years later in 1955, the Soviets began testing the RDS-37 two-stage hydrogen bomb (10). This was also the world's first air-dropped fusion bomb test. ""The device was deliberately detonated high in the air to avoid local fallout." The height of the burst was 1,550 m (5,090 ft) above the ground but despite this, a building 60km (about 37.28 mi) collapsed killing a young girl and a group of 42 civilians were reported to have sustained injuries. The measured energy yield of the bomb is equal to 1.6 megatons of TNT (10).

Figure 2 RDS-220 (11)

On October 30th, 1961, the Soviets began the test of the Tsar Bomba also known as the RDS-220. It is the largest Hydrogen bomb ever detonated with a yield of 50 megatons. The bomb was a three-stage hydrogen bomb meaning it uses a nuclear fission-type bomb as the first stage which then will compress the thermonuclear second stage The energy produced from this explosion is then directed to compress the much larger thermonuclear third stage (12). Tsar Bomba was dropped during the test by a Soviet Tu-95V long-range bomber flown by Major Andrei Durnovstev. A Tu-16 observation plane, which oversaw gathering air samples and recording the tests, flew alongside the bomber. To reduce heat damage to the planes' surfaces, white reflecting paint was used (12). Tsar Bomba was or 27 metric tonnes, in weight. It had a diameter of 6.9 feet and a length of 26 feet. The Tu-95V was a huge aircraft, thus its fuselage fuel tanks, and bomb bay doors were removed. The bomber and observation planes had more time to fly around 30 miles away from ground zero before detonating since Tsar Bomba was tied to a parachute that weighed close to 1,800 pounds (12).

Nuclear weapons in the modern day:

On January the 20th 2001 George W bush was inaugurated as the president of the United States, he set out to place a more restrictive nuclear policy stance. Eventually, his administration announced they were withdrawing from the Anti-Ballistic Missile (ABM) Treaty which has been the foundation of U.S.-Soviet/Russian arms control since 1972 (13). What the treaty entailed was that both the United States and Union of Soviet Socialist Republics (USSR) were hindered from the development and use of nuclear weapons. But considering Bush left the treaty the US now had more freedom with experimenting and permitted use of nuclear weaponry with Bush saying, "I have concluded the ABM Treaty hinders our government's ability to develop ways to protect our people from future terrorist or rogue-state missile attacks" (13).

In 2003 North Korea decided to leave the Nuclear Nonproliferation Treaty (NPT) as this prevented them from creating any nuclear weaponry and blamed the United States aggression for its decision (14). George Bush spoke to China's president Jiang Zemin and stated his newfound concerns of North Korea threatening to start World War Three.

Beginning in August 2003 and lasting several negotiations, the Six Party Talks signaled a reversal of Washington's nonengagement strategy with Pyongyang (14). The agreement reached in September 2005 required Pyongyang to give up its pursuit of nuclear weapons. In his 2002 State of the Union speech, former president George W Bush had previously referred to North Korea as part of the "Axis of Evil" (14).

Figure 3 North Korean nuclear missile (17)

Later that year, the CIA concluded that Pyongyang was carrying out uranium enrichment program in violation of a 1994 normalisation deal. After acknowledging its activities, North Korea withdrew from the Nuclear Non-proliferation Treaty (NPT), resumed its enrichment of plutonium, and compelled the inspectors of the International Atomic Energy Agency (IAEA) to leave.

Then in 2010, tensions on the Koren Peninsula significantly escalated due to two major incidents involving North and South Korea (15). In March of that year the South Korean warship Cheonan was sunk, resulting in 46 sailor deaths. A widespread investigation, led by South Korea concluded that a North Korean torpedo caused the sinking (15). Despite this North Korea denied their involvement in the scenario, but the event heightened military and political tensions between the two Koreas. Subsequently in November 2010, North Korea fired artillery shells at Yeonpyeong Island, a south Korean island near the disputed maritime border, killing four people, including two civilians which was one of the most serious military confrontations since the Korean war (15). These events resulted in heightened military alertness, increased U.S.-South Korea military cooperation, and strong international condemnation of North Korea's actions. The year marked a peak in hostilities, further straining the already volatile relationship between the two Koreas.

As of recent Vladimir Putin has been making outrageous and violent threats towards not only the Ukrainian population but the rest of the world. His threat of using tactical nuclear weapons has been a particular focus of concern. Tactical nuclear weapons are lower-yield warheads designed for battlefield use, as opposed to strategic nuclear weapons, which are designed to cause widespread destruction (16). Russia possesses a considerable number of tactical nuclear weapons, and their use in a regional conflict like Ukraine could theoretically alter the battlefield dynamics without provoking full-scale global nuclear retaliation. However, even a limited use of tactical nuclear weapons would be unprecedented and could lead to unpredictable and severe consequences, including a potential wider nuclear war.

Conclusion:

In future the development of nuclear weapons is likely to be spearheaded by technological advancements and evolving international norms with these advances, there is the potential for more precise and catastrophic nuclear devices, designed for tactical use. Artificial intelligence along with cyber warfare will modernise the nuclear command and control systems and raise security concerns. The global community has the potential of seeing renewed efforts in nuclear disarmament and non-proliferation due to things such as international treaties, diplomacy and awareness of the consequences of nuclear warfare. Advanced missile defense systems pose new challenges with technology increasing their range and precision posing a threat to all.

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Dark matter identity crisis: exploring different candidates for dark matter

Isabelle Horlick

What we know about dark matter so far:

To this day, dark matter is a mystery to physicists about what it is made up of; developing theories in particle physics could be the answer to this. But what do we already know about dark matter? Currently, dark matter is estimated to make up 27% of matter whilst dark energy makes up about 68% of our universe[i]. Dark matter has also been found to interact in one field only, gravity. This knowledge has been key to developing theories and observing dark matter's behaviour, since many different research groups have used gravitational lensing to find where light has been bent, to determine where dark matter is located[ii]. Because of this, there has been further progression in dark matter findings like the Bullet cluster. The Bullet Cluster was a collision of 2 large galaxies (also known as 'galaxy cluster 1E 0657-56') '3.8 billion light years away from Earth' – which was detected by 'Chandra in X-rays' – proving dark matter does not interact with itself. This property of dark matter was made apparent when the dark matter particles did not slow down in the impact of the collision, which contrasts how the hot gas from the collision behaved[iii]. These are just a few discoveries that contribute to the science community's understanding of dark matter, causing debates if these particles could be a part of the standard model or derive from other sources that have already been discovered. This essay will debate the plausibility of different particles and celestial objects being candidates for dark matter.

MACHOS:

MACHOS (massive compact halo objects) are likely not to be a source for dark matter, although argued white dwarfs could still contribute to a small percentage for dark matter emissions. Dr Katherine Freese discusses in her article about dark matter that most substellar objects have been ruled out as a likely source for dark matter due to a 'combination of theories and Hipparchos parallax data' – which includes bodies like Brown dwarfs. These revelations do not give much hope in MACHOS being the primary source of dark matter, however that is not to discredit the chance that white dwarfs could make up a small quantity of dark matter's population. Freese explains white dwarfs cannot produce all dark matter particles, because if they did, enough infra-red radiation would be produced to swallow TeV gamma rays. Unfortunately, this cannot be the case, because VERITAS (the Very Energetic Radiation Imaging Telescope) have detected gamma ray emissions from dwarf planets. Furthermore, Freese comments of the insignificant contribution MACHOS would have to the energy density of galaxies if they were less massive than $0.1M_{\odot}$[iv].

Despite the possibility of white dwarfs contributing to a small quantity of the output of dark matter in galaxies, they cannot contribute to all the dark matter estimated in the universe. Therefore, making other candidates more likely to identify with dark matter detections.

Sterile Neutrinos:

Whilst standard neutrinos are not a viable candidate[v], sterile neutrinos could potentially be an answer to what dark matter is[vi].

According to Ethan Siegel, normal neutrinos were first put forward as a possible candidate for a few reasons: they rarely interact with normal matter; do not emit or absorb light, so it cannot be detected by a telescope; they interact with weak forces, which suggest there is a surplus quantity of neutrinos, that were emitted during the earlier stages of the Big Bang; and they could have a non-zero mass[vii]. This would have been a great explanation to what dark matter actually is, however, standard neutrinos were ruled out as a possible candidate, due to normal neutrinos being considered 'hot particles', meaning they travel close to the speed of light. Since dark matter does not have enough energy to travel at this velocity, it cannot be considered a standard neutrino[viii].

Despite normal neutrinos no longer being considered a plausible answer to what dark matter is, sterile neutrinos with heavy masses are still a viable option – according to Basudeb Dasgupta and Joachim Kopp. Reasons why sterile neutrinos could be dark matter are because of some of their properties such as: being able to remain stable, noninteracting with other particles and can have a velocity slow enough to be considered cold dark matter. Kopp and Dasgupta go on to explain that the image (on the left) shows the regions where sterile neutrino dark matter can produce an acceptable abundance, all coloured regions are where sterile neutrinos dark matter cannot be produced in an abundance. The graph shows it is possible for sterile neutrinos to be dark matter[ix].

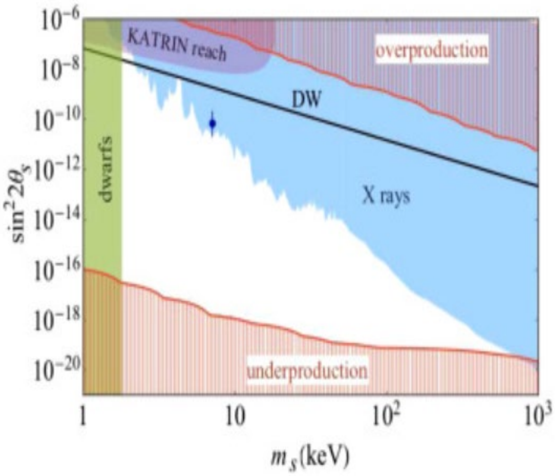

Figure1 Regions of sterile neutrino masses[x]

Freese also talks about potential evidence for sterile neutrinos being dark matter, since 3.5 keV lines have been detected using X-rays in clusters of galaxies. These detections are consistent with dark matter origins, therefore indicating dark matter and sterile neutrinos could be the same concept, because they share the same location. However, Freese argues that the interpretation of this data could be wrong, since some scientists say the X-ray line cannot be seen from the dwarf galaxy named Draco, causing a controversy in the credibility of the previous conclusion tying sterile neutrinos and dark matter together. Whether this data is valid is still argued, however this does not take away from other detections supporting the sterile neutrino dark matter theory. What does give this theory flaws are their models. Freese points out that most sterile neutrino models depict dark matter as warm dark matter – which contradicts the fact most dark matter in the universe is cold – therefore making it unlikely for dark matter to be the same as sterile neutrinos[xi].

Although there have been detections of sterile neutrinos in dark matter origins, most models between the two particles do not line up – like the velocities. There are models that do show sterile neutrinos to be cold dark matter, however the majority work better being depicted as warm dark matter, meaning sterile neutrinos are not the strongest candidate.

Axions:

Axions are a hypothetical elementary particle that was theorised in 1978 by Frank Wilczek and Steven Weinberg that was originally used to explain the strong CP problem in quantum chromodynamic, but what if axions could explain other strange mysteries such as dark matter[xii]? The theory of axion dark matter emerged, stating that dark matter are waves in an axion field according to Francesca Chandra-Day, John Ellis, and David J.E. Marsh (authors). The article explains that oscillations of the axion field, caused by spontaneous symmetry breaking, is why axions are a viable candidate for dark matter[xiii]. Spontaneous symmetry breaking is when a physical system in a symmetrical state spontaneously turns into an a-symmetric state[xiv]. Considering other particle candidates were not proving to be viable, thinking of dark matter as a wave could lead to promising results. Chandra-Day, Ellis, and Marsh claim there were two scenarios of dark matter forming through the axion field. First, the initial fluctuation in the axion field occurred before the Big Bang, meaning all the spatial gradient is removed leaving only the initial value of the field and its mass; if this is the case, the axion field and dark matter density can then be determined by a simple wave equation with the expansion of the universe acting as friction. The second outcome would occur if the initial value happened during the Big Bang. In this case, topological defects occur meaning axions can decay into dark matter. In either scenario, dark matter has the right conditions to form, and when the axion number density becomes diluted due to the expansion of the universe, axion cold dark matter forms.

Even though axion's existence has not been confirmed yet, it does not mean they couldn't be a candidate for dark matter; sterile neutrinos are also only hypothetical yet their credibility for being a dark matter candidate is not questioned because of it[xv]. The axion field also explains how cold dark matter forms, unlike the other candidates, making axions the most plausible out of the three. In this model dark matter is presented as waves, which also explains why it does not interact with other forms of matter. These reasons make axions the strongest candidate out if the three.

Conclusion:

Axions can explain how an abundance of cold dark matter can be produced, explain why dark matter does not interact with other particles, and explains how it can form whether it was before or during the Big Bang. Sterile neutrinos and MACHOS both have flaws in their theories. Therefore, axions are most likely to be dark matter out of the three candidates discussed.

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[i] We have no idea by Jorge Cham and Daniel Whiteson. Published in 2017 by John Murray. Page number: 8
[ii] Through the wormhole with Morgan Freeman, season 5 episode 10, Discovery +, release date 2014.
[iii] Bullet Cluster https://chandra.harvard.edu/graphics/resources/handouts/lithos/bullet_lithos.pdf published date: 21.8.06, accessed date: 26.3.24.
[iv] Status of Dark matter Status of Dark Matter in the Universe - Katherine Freese (caltech.edu) section 4.1, author: Dr Katherine Freese, published in 2017, accessed date: 26.3.24
[v] Are neutrons dark matter Ask Astro: Are neutrinos dark matter? (astronomy.com) author: Kaliroe Pappas, published: 20.9.22, last updated: 18.5.23, accessed date: 21.5.24
[vi] Status of dark matter in the universe Status of Dark Matter in the Universe - Katherine Freese (caltech.edu) section 7, author: Dr Katherine Freese, published in 2017, accessed date: 26.3.24
[vii] How much of dark matter could be neutrinos How Much Of The Dark Matter Could Neutrinos Be? (forbes.com) author: Ethan Siegel, published date: 7.3.19, accessed date: 21.5.24
[viii] Are neutrons dark matter Ask Astro: Are neutrinos dark matter? (astronomy.com) author: Kaliroe Pappas, published: 20.9.22, last updated: 18.5.23, accessed date: 21.5.24
[ix] Sterile neutrinos Sterile neutrinos - ScienceDirect section: abstract, authors: Basudeb Dasgupta and Joachim Kopp, published date: 15.9.21, accessed date: 4.9.24
[x] https://www.sciencedirect.com/science/article/pii/S0370157321002696#sec6 section: 6, authors: Basudeb Dasgupta and Joachim Kopp, published date: 15.9.21, accessed date: 4.9.24
[xi] 5 things we know about dark matter (and 5 things we don't) 5 Things We Know About Dark Matter (And 5 We Don't) (forbes.com) author: Ethean Siegel, published date: 13.3.20, accessed date: 4.9.24
[xii] Axion Axion - Wikipedia accessed date: 8.7.24
[xiii] Axion dark matter: What is it and why now? 2105.01406 (arxiv.org) authors: Francesca Chandra-Day, John Ellis, and David J.E. Marsh, published date: 18.10.22, accessed date: 2.9.24
[xiv] Spontaneous symmetry breaking Spontaneous symmetry breaking - Wikipedia accessed date: 4.9.24
[xv] Can sterile neutrinos exist? Can Sterile Neutrinos Exist? | Scientific American author: Clara Moskowitz, published date: 4.11.21, accessed date:4.9.24

Kai Drake-Law

Is Earth the only hospitable place for life in our solar system?

Introduction

As of today, we know of only one place in the whole universe that harbours life, the Earth. But just how rare are life forms in reality? Since we are the only forms of life known, we only have one source to look at to imagine what conditions life needs to flourish. However, as we have looked out to the cosmos using instruments such as the Hubble telescope, we have discovered a truly remarkable detail. Our solar system is completely unique compared to every other star system that we have observed. Whilst our solar system has 8 distinct planets, other star systems tend to contain only '2 planets or even 2 stars'[1]. Most of these star systems contain an exoplanet like a super Earth that can grow to around 10 times the size of our home planet. In addition, these super Earths are usually tidally locked to their star (only one side of the planet faces the star) or are so close to their star that the temperature is far too harsh for the question of life to even be asked[2]. This discovery reinforces the idea that we really are alone in the universe.

Our solar system really is something special since each of the planets plays a vital role in keeping material in check and keeping a strong balance in orbits. For example, Jupiter (also known as the godfather[3]) is the largest planet in our solar system. This gas giant has such a strong gravitational field, that is keeps the whole asteroid belt in a strict orbit as well as its own '95 moons'[4]. As of now Earth is the only one of the four terrestrial planets to be hospitable to life as we know it. But why is this, and could it have been different? Thanks to the past 60 years of space exploration, we can now confidently answer these questions. Of the four rocky planets, we understand that three of them have (excluding Mercury) had the potential to harbour life at a point in the solar systems history. Mars for example, is a rocky world frozen in time which provides the evidence of ancient lakes and oceans that once flourished[5]. We understand that our twin planet would have become an Earth-like planet if not for unfortunate circumstances.

Space exploration has taken us to the far reaches of our solar system as well. Our findings have been just as remarkable as the inner four planets. Space craft missions such as Cassini and Voyager one and two have discovered that conditions for life can

[1] Paul S 2023: Of 4 types of planetary systems, ours is rarest.
[2] Paul S 2023: Of 4 types of planetary systems, ours is rarest.
[3] Andrew C & Brian C 2019: The Planets page 125.
[4] Andrew C & Brian C 2019: The Planets page 125.
[5] Andrew C & Brian C 2019: The Planets pages 103-104.

be found in the most unexpected regions of space and that these places do not have to be in the form of a planet either. We have found worlds with thick atmospheres and liquid oceans and lakes in the freezing temperatures of our solar system. For example, the moon Titan is orbiting around Saturn with an atmosphere thicker than our own as well as liquid flowing is lakes[6]. Even in the asteroid belt, we have found failed worlds stripped of their materials and atmospheres due to the chaotic nature that once existed in the early solar system.

All these findings have proved one thing to us, that we are truly lucky to have our home planet remain in stable conditions for the time that it has. Out of every potential Earth only our own planet came out on top. Although life outside of our home seems abstract, it is never out of the question. As our own sun ages, it will grow into a red giant and destroy most of the terrestrial planets as well as all life on Earth. However, maybe some of these frozen worlds will be given their own time in the light and could host life forms.

Over this report, I will cover the remarkable past of our solar system as well as what could be. In addition, I will cover the question of whether life could truly exist beyond our haven.

What are the most basic conditions for life to exist?

Hydrothermal vents

In regard for sources of life, we only have our own planet to look at and compare. No matter where we look on Earth, we see life wherever liquid water is present. Water is as important as it is because it acts as a solvent which can dissolve various substances for chemical reactions. These reactions allow complex chemistry to happen in animals and plants enabling features such as temperature control and photosynthesis[7]. Due to this we understand that life must at least have a soluble liquid to evolve. As a result, we have explored our oceans to find where life could have originated from, which has led us to the discovery of hydrothermal vents. Hydrothermal vents are geysers on the ocean floor which spew out toxic minerals from the Earths' crust[8]. Although the minerals are toxic, life manages to thrive with hundreds of species around these vents. The reason for this is that bacteria can covert toxic vent minerals into usable forms of energy such as carbohydrates through a process called chemosynthesis[9]. Chemosynthesis is a process used by microbials in which carbon dioxide and water are reacted to create carbohydrates[10]. The fascinating part about life forms around hydrothermal vents is that there is an absence of sunlight due to the depth of the geysers. This tells us that photosynthesis is not used at all meaning that it is possible for life to exist without the

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[6] Andrew C & Brian C 2019: The Planets pages 229-232.
[7] Angela M 2024: Deep Sea hydrothermal vents.
[8] Angela M 2024: Deep Sea hydrothermal vents.
[9] Angela M 2024: Deep Sea hydrothermal vents.
[10] Angela M 2024: Deep Sea hydrothermal vents.

suns' energy. If life can exist without a sun, then could it be possible to find life underneath the surface of other planetary bodies?

Earth's protective shield

All animal forms of life on Earth need to maintain certain temperatures as well as a constant cycle of aerobic respiration to survive. Whilst our planet lies within the goldilocks zone of our sun, our atmosphere is what really keeps us alive. The goldilocks zone is the distance a planet must orbit from its host star to maintain liquid water[11]. The flow of oxygen that we breathe, and density of air is maintained globally in our atmosphere which protects us from harmful radiation emitted from our sun. The atmosphere has an ozone layer which protects us from UV (Ultraviolet) radiation on the surface, preventing life from experiencing issues like cancer or DNA mutations. However, our atmosphere is always facing the threat of solar wind ripping it apart. Solar wind is charged particles emitted from the sun which move at velocities of up to 800 kilometres an hour[12]. Due to these speeds solar wind can react with molecules in the atmosphere and eject them into space. Despite this huge threat, our atmosphere is protected by an invisible shield known as the magnetic field which is generated by a dynamo within the Earths' core[13]. The Earths' core contains a flow of molten iron which rises and cools before returning to the centre[14]. This process enables our magnetic field which saves our atmosphere from solar wind by deflecting the charged particles though stretching and distorting the field on the right side[15]. We can see the magnetic field working at the Earths' poles where auroras can be seen in the atmosphere.

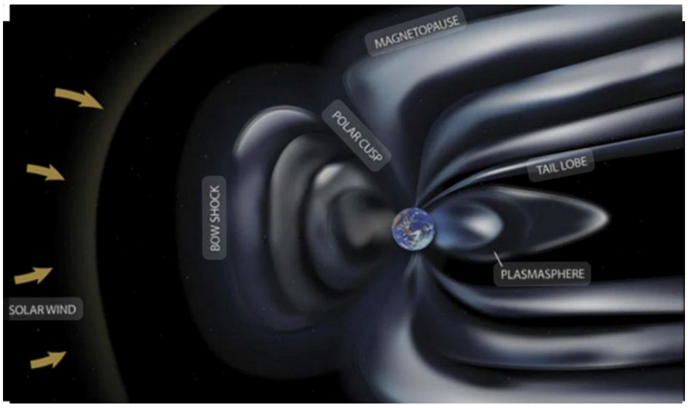

Figure 1 - Earth's magnetic field

Earth's magnetic field[16]

[11] NASA 2024: What is the habitable zone or goldilocks zone.
[12] Andrew C & Brian C 2019: The Planets page 114-115.
[13] Andrew C & Brian C 2019: The Planets page 114-115.
[14] Andrew C & Brian C 2019: The Planets page 114-115.
[15] Andrew C & Brian C 2019: The Planets page 114-115.
[16] NASA 2024: Earth's Magnetic Field

From our own planet, we can clearly see that life needs to have a constant source of liquid water to exist as microbes but also needs a stable atmosphere with a strong magnetic field to sustain long term evolution. Now let us look at some other potential candidates for life within our solar system.

The sister planet Mars

Frozen in time

Our sister planet Mars has been geologically inactive for over three billion years, meaning that the surface has remained nearly identical since then[17]. Mars' state could be vital to understanding how life begins on terrestrial planets since the landscape and minerals from the past could show us whether life starts within the sea or through other ways. But why is Mars in its current state? Unfortunately, like most bodies in the early solar system, Mars was affected by Jupiter's' rampage, stripping the planet of its mass. This resulted in Mars having a diameter equivalent to half of the Earth's resulting in Mars having significantly less material than it could have had[18]. Due to this loss of mass, Mars had a much smaller core with less iron resulting in a weak magnetic field that was neutralised. As previously seen, the magnetic field is responsible for protecting a planet's atmosphere from the sun's harsh solar winds. Once Mars lost its magnetic field, its fate was sealed as the atmosphere slowly deteriorated over a period of a billion years. This caused the Martian oceans to freeze, killing off the planet's hopes of becoming a stable water world.

Past paradise

Despite the desolate landscape we see today, Mars first started out as a water world that was very geologically active. The Martian volcanoes scattered across the surface are an indicator of this. Mars even has the largest volcano in the solar system, Olympus Mons which has a diameter of 600km[19]! These volcanoes would have created land similar to what we see on Earth. In addition, Mars has channels, valleys, and gullies all over the surface with some channels reaching a depth of 2000km and a width of 100km which suggests that liquid water once flowed, caving out pathways through erosion[20]. One of Mars' largest lakes is known as the Eridania sea which has a volume of 210,000 kilometres cubed[21]. Thanks to the work of the MRO's (Mars Reconnaissance Orbiter) CRISM spectrometer (Compact Reconnaissance Imaging Spectrometer for Mars) we have been able to analyse the contents of the Eridania sea[22]. In the deepest areas of the

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[17] Cassie F 2023: Volcanic Activity on Mars Upends our Understanding of the Red Planet's Interior
[18] Cassie F 2023: Volcanic Activity on Mars Upends our Understanding of the Red Planet's Interior
[19] Charles Q 2023: Mars: Everything you need to know about the Red Planet.
[20] Charles Q 2023: Mars: Everything you need to know about the Red Planet.
[21] Andrew C & Brian C 2019: The Planets page 143-152.
[22] AGU 2007: Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on Mars Reconnaissance Orbiter (MRO).

Eridania Basin it was found that magnesium and iron-rich clay minerals were in abundance which are materials usually found on the seafloor of Earth[23]. The fact that these materials are similar to what we find on our own planet could imply that Mars experienced similar conditions within its seas to our own planet today. Higher up the basin walls, chlorides were found which are indicative of evaporation of shallow waters[24]. The chlorides originate from volcanic activity which is similar to hydrothermal vents on Earth[25]. If Mars did have hydrothermal vents, then it is quite possible that life could have existed.

Figure 2 - Perseverance on Mars

(Perseverance on Mars)[26]

<u>Hidden lakes</u>

Despite the freezing Martian temperatures, it appears that there is still liquid water on Mars in small pockets such as lakes. The first discovery of water on Mars was from MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding)[27] which is a piece of equipment that uses synthetic aperture techniques and a secondary receiving antenna to isolate subsurface reflections[28]. MARSIS was used at the south pole of Mars where it detected echoes from beneath the southern polar cap of Mars that were evidence that there was liquid water was beneath the ice[29]. These echoes gave a general map of the lake which roughly 20 km across and buried a mile beneath the ice cap[30]. Since Mars is as cold as it is, the water must be rather salty or else the water

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[23] Andrew C & Brian C 2019: The Planets page 143-152.
[24] European Space agency 2019: ASPERA-3: Analyser of Space Plasmas and Energetic Atoms.
[25] Andrew C & Brian C 2019: The Planets page 143-152.
[26] NASA 2024: Perseverance on Mars.
[27] Megan B 2018: Mars liquid water beneath ice cap.
[28] Megan B 2018: Mars liquid water beneath ice cap.
[29] Eisman 2024: Venus.
[30] Eisman 2024: Venus.

would be frozen[31]. However, despite the saltiness, if life exists in this lake, then it would be protected from radiation thanks to the thick layer of ice above which would prevent any DNA mutations. We know that life can exist in underground lakes since scientists on Earth have drilled through deep glaciers and found microbial life thriving[32]. In addition, from Antarctica we have found that there are 400 underground lakes, so it is possible that the Martian southern pole also contains multiple lakes as well[33]. If this is the case, then perhaps life has had an exceedingly lengthy period of time to thrive on Mars.

Venus

Planet of hell

Although Venus has similarities to the Earth such as gravity and diameter, its conditions are something truly horrifying. Venus has a thick atmosphere with a density of 5.2 g/cm3 which is 93 times denser than the Earth's atmosphere[34]. This density is mainly accounted for by the astounding 95.5% of carbon dioxide within the atmosphere[35]. Carbon dioxide is a greenhouse gas, so it traps heat from the sun within the atmosphere which has resulted in Venus reaching surface temperatures of 465 degrees (this is so hot that lead can melt on the surface!)[36]. Since the surface temperature is so hot, no liquids can flow on Venus meaning that it is impossible for even microbes to live on the surface. On top of the hot temperature, Venus has a surface pressure of 92 bars or 1,350 psi which would crush you within seconds (the Earth is only one bar!)[37]. Despite all this, we now know that Venus was a water world for a brief period of time.

Moment in the sun

From analysis of Venus' atmosphere, it has been found that there is a high percentage of water vapour (0.002%) which implies that water once flowed on Venus and evaporated into the atmosphere[38]. The best evidence we have so far to prove that Venus was once a wet world is that Venus has a far smaller ratio of D/H (Deuterium/ Hydrogen) than Earth which suggests that Venus has lost more water over its lifetime than Earth[39]. So, if Venus was once a water world, what lead to its fate?

Unfortunately, when Venus reached its Earth-like conditions our sun was still growing. As the sun grew brighter, its energy output increased which caused lots of water vapour

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[31] Eisman 2024: Venus.
[32] Eisman 2024: Venus.
[33] Eisman 2024: Venus.

[34] Aeronormie 2024: Venus's atmosphere
[35] Amanda B 2023: Temperatures Across Our Solar System
[36] Kate H 2023: What would it be like to stand on the surface of Venus?
[37] Andrew C & Brian C 2019: The Planets pages 49-55
[38] Amanda B 2023: Temperatures Across Our Solar System
[39] Andrew C & Brian C 2019: The Planets pages 49-55

to be released into the atmosphere resulting in it thickening[40]. Then, due to the greenhouse effect, Venus began to increase in temperature, sealing the planets fate as a stable water world. However, this process took longer than what you might expect, so it is estimated that Venus could have maintained its oceans for 2 billion years and perhaps only lost them 700 million years ago[41]. It is entirely possible that life evolved in this time, but we would have no way of knowing since landing spacecraft on Venus is near impossible due to the harsh conditions. Although it has been found that not all of Venus is hellish.

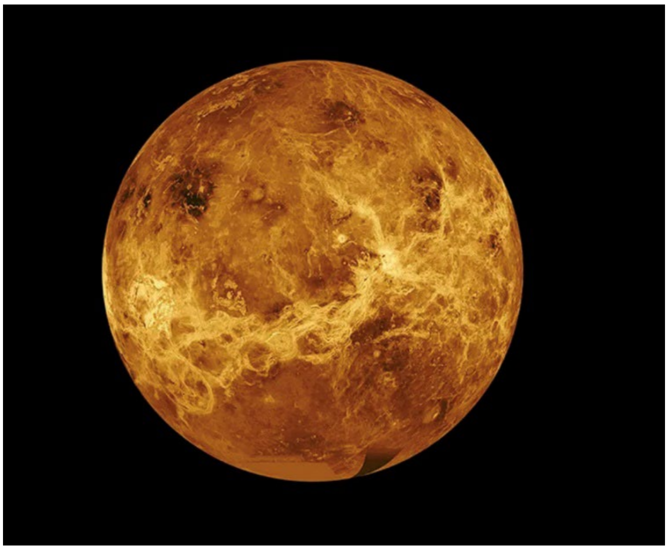

Figure 3 - Venus

(Venus)[42]

<u>Life in the clouds?</u>

After further analysis of Venus' atmosphere, it has been found that between the altitudes 48km and 60km, the atmospheric pressure and temperature are similar to the surface of Earth[43]. At these altitudes, the atmosphere is thin enough so that there is plenty of sunlight to act as a power source for life which means that small microorganisms could potentially survive in the atmosphere[44]. Although the conditions are Earth-like, the atmosphere still contains lots of sulphur dioxide which reacts to create high concentrations of sulfuric acid[45]. In order to see if life could withstand these conditions, a group of scientists lead by Max eager and Massachusetts conducted an

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[40] Andrew C & Brian C 2019: The Planets pages 49-55
[41] Andrew C & Brian C 2019: The Planets pages 49-55
[42] NASA 2024: Venus
[43] Lewis D 2024: Life on hellish planet Venus? There may be hope yet, hidden in the chemistry of its acidic atmosphere.
[44] Lewis D 2024: Life on hellish planet Venus? There may be hope yet, hidden in the chemistry of its acidic atmosphere.
[45] Lewis D 2024: Life on hellish planet Venus? There may be hope yet, hidden in the chemistry of its acidic atmosphere.

experiment called the 'Acid test' in which 20 different amino acids used by terrestrial life are dissolved within concentrated sulfuric acid and left at room temperature for several weeks[46]. The team checked the samples after a month and discovered that 19 out of the 20 amino acids were still unreactive or only chemically modified in their side chain (This happens naturally with water)[47]. Although amino acids are not actual life forms, they make up DNA and RNA, meaning that technically simple life forms could exist within Venus' atmosphere[48].

Ceres

Structure and location of Ceres

Ceres is a protoplanet that lies within the asteroid belt between Mars and Jupiter. Ceres takes up 'one third of the asteroid belts mass.' It is unusual that Ceres takes up such a substantial percentage of the asteroid belt. Ceres has a diameter of 946km[49]. NASA's Dawn mission has allowed up to take a closer look at Ceres and uncover its strange past. Dawn could only peer 62 miles into the interior of Ceres[50]. Of this discovered region, Dawn found that Ceres has a 40-kilometer-thick crust which consists of ice, salts, and hydrated minerals[51]. These compounds are intriguing since they tell us that the body contains water close to the surface. In addition, the salts give the indication that liquid water once flowed upon the surface of Ceres because salts form when water reacts with other elements such as calcium. The second layer of ceres is dominated by hydrated rocks such as clay[52] which indicates that the planet is still moist. This was confirmed by Dawn as between the two layers, it was found that a layer of briny liquid was flowing[53]. The fact that a form of liquid can be maintained on Ceres is significant because it shows us that the object is still geologically active.

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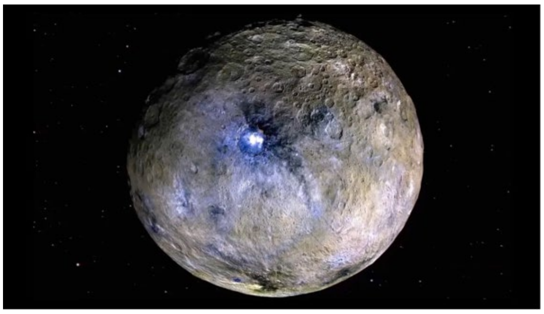
[46] Lewis D 2024: Life on hellish planet Venus? There may be hope yet, hidden in the chemistry of its acidic atmosphere.
[47] Lewis D 2024: Life on hellish planet Venus? There may be hope yet, hidden in the chemistry of its acidic atmosphere.
[48] Lewis D 2024: Life on hellish planet Venus? There may be hope yet, hidden in the chemistry of its acidic atmosphere.
[49] Edward F 2024: Ceres, Location, Size, Water, and facts
[50] NASA 2024: Ceres' Internal Structure (Artist's Concept)
[51] NASA 2024: Ceres' Internal Structure (Artist's Concept)
[52] NASA 2024: Ceres' Internal Structure (Artist's Concept)
[53] Michael G 2020: Dwarf planet closest to Earth is geologically alive.



An image of dwarf planet Ceres captured by NASA's Dawn mission.
(Image credit: NASA)

Figure 4 - Dwarf planet Ceres

(Dwarf planet Ceres)[54]

Living frozen planet

Across the surface of Ceres, cryovolcanoes have been discovered. These volcanos are shaped by ice which tells us that the surface has changed over time. This point further backs up that Ceres is geologically active. Furthermore, the fact that the volcanoes are made of ice indicates that liquid water once flowed upon the surface. But how could water have been in a liquid state?

To answer that we must look into the past of our solar system. During the early solar system, chaos was everywhere due to 3600 mini planets bouncing around the inner solar system[55]. This caused a lot of collisions which prevented planets from maintaining stable orbits. Ceres is the only object in the asteroid belt that contains a thin atmosphere of evaporating water and ammonia ice[56]. Due to these more unusual chemicals, we know that Ceres must have formed in the outer solar system where temperatures were much lower. However, as the largest planet Jupiter formed, it cleared a large area of the solar system, resulting in debris being projected towards the sun including Ceres[57]. This caused Ceres to be bombarded with asteroids which would have warmed the surface enough to allow liquid water to flow, eventually leaving Ceres with a beautiful salt ocean covering the rocky surface. The constant bombardment also provided Ceres with an abundance of minerals which could have helped support the development of life[58].

The end of a water world

Unfortunately, due to Jupiter clearing Ceres' path of material, the protoplanet could not grow any larger and without a suitable atmosphere, liquid water cannot be sustained. Another planet known as Mars used its gravity which pushed Ceres into a stable orbit in

[54] NASA 2016: Dwarf planet Ceres.
[55] Teresa P 2022: Jupiter's massive gravity kicked strange Ceres into the asteroid belt.
[56] Teresa P 2022: Jupiter's massive gravity kicked strange Ceres into the asteroid belt.
[57] Andrew C & Brian C 2019: The Planets pages 103-104.
[58] Andrew C & Brian C 2019: The Planets pages 103-104.

the asteroid belt where it remains today[59]. Although it is unlikely that life could have developed within this period, it could be possible that microbial life managed to begin

The ice moon Enceladus

Saturn's' hidden jewel

Enceladus is a small moon about the size of Iceland (diameter of 504.2km[60]) which orbits Saturn. In addition, Enceladus is the most reflective object in the solar system which gave the first indication that the moon was made from ice[61]. Enceladus has a surface temperature of –201 degrees and has a volume of 67.1km3[62]. Cassini was a spacecraft sent to observe Saturn and some of its moons and observed Enceladus for the first and last time in human history. Cassini discovered geysers all across the surface of Enceladus that were emitting giant plumes of water vapour and ice, indicating that the ice moon was very geologically active[63]. It was measured that 200kg of material was being released every second from these geysers and the material was being used to replenish Saturn's rings[64]. But how could a moon 9.5 AUs away from the sun contain liquid water?

Tug of war

Since Saturn is as massive as it is, its gravitational force has a considerable influence over any orbiting bodies. Due to this, Enceladus experiences a strong pull towards Saturn which is countered every few rotations by a larger moon called Dione which pulls Enceladus back into its orbit[65]. However, because of multiple gravitational forces acting on Enceladus, its structure is stretched and squeezed, warming the moons interior resulting in the ice melting[66]. This effect allowed the moon to host a deep, salty ocean which is protected from the harsh conditions of space by the thick ice barrier on the surface.

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[59] Andrew C & Brian C 2019: The Planets pages 103-104.
[60] Britannica 2024: Enceladus
[61] Andrew C & Brian C 2019: The Planets pages 233-236.
[62] The Planetary Society 2024: Enceladus, Saturn's moon with a hidden ocean.
[63] Andrew C & Brian C 2019: The Planets pages 233-236.
[64] Andrew C & Brian C 2019: The Planets pages 233-236.
[65] Andrew C & Brian C 2019: The Planets pages 233-236.
[66] Andrew C & Brian C 2019: The Planets pages 233-236.

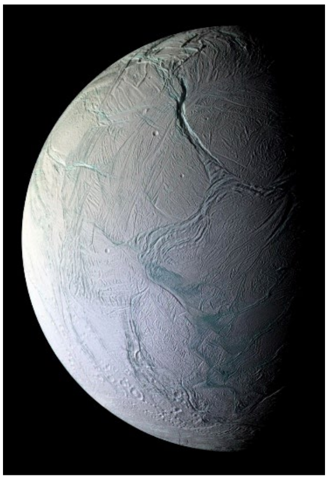

Figure 5 - Enceladus

(Enceladus)[67]

<u>Enceladus' ocean</u>

Before Cassini ran out of fuel, it was sent through one of the plumes to analyse the erupting material. As Cassini analysed the material, it found complex organic compounds and silica particles which are often found in hydrothermal vents, implying that Enceladus may already have all the ingredients for life to exist in microbial form[68]. However, since Cassini's flyby, we have never returned to the moon due to its distance; as a result, we have turned to simulations using the data we know so far. The most accurate simulation so far took place in 2022 where the results predicted that the ocean was slightly alkali, ranging from a PH of 7.95 - 9.05[69]. These PH predictions are quite close to oceans on Earth (8.10), which could play a key factor in the development of life within oceans[70]. Assuming the PH predictions are accurate, Enceladus could be perhaps the perfect vessel for life to develop given its constant geothermal energy and protection from space. The simulation also looked into concentrations in the ocean and predicted that the concentration levels of carbon dioxide and hydrogen could be sufficient to support hydrogenotrophic methanogens (microorganisms that consume carbon dioxide and hydrogen)[71]. Given Enceladus' position in the solar system, it still has a good two billion years to exist before the sun expands and melts the moon which could allow enough time for life to evolve in a much more secluded manor.

[67] NASA 2024: Enceladus.
[68] Aaron A 2024: Details of Enceladus subsurface ocean
[69] Aaron A 2024: Details of Enceladus subsurface ocean
[70] National Oceanic and Atmospheric Administration 2024: Ocean acidification
[71] Aaron A 2024: Details of Enceladus subsurface ocean

<u>Saturn's largest moon – Titan</u>

Titan sticks out compared to Saturn's other moons due to is planet-like features. For example, Titan is the only moon in our solar system known to have clouds with a dense atmosphere as well as liquid flowing on its surface[72]. Finding liquid on another body is extraordinary, especially given Titan's distance from our sun (Titan is roughly 1.4 billion km from the sun)[73]. Considering that both Enceladus and Titan contain a form of liquid, maybe it is more common to find life-like conditions away from a star or even orbiting another planet instead. We could definitely assume that Titan is more of a planet as it is larger than Mercury which is a planet[74].

<u>Conditions on Titan</u>

Titan orbits Saturn at a mean distance of 1,2221,850km which takes the moon around 15.94 Earth days to complete a full revolution[75]. However, Titan's rotation is synchronous which means that one face always faces Saturn (We can see this effect with our own moon at night)[76]. As a result, one side of the moon would receive more sunlight than the other for a period which would warm one side whilst freezing the other. Titan has a diameter of 5,150km, giving it enough mass to build a spherical structure. For comparison, Titan is only 120km smaller than Ganymede (Jupiter's largest moon), so its size is quite significant[77]. Titan has a low density of 1.8gcm3, similar to terrestrial planets meaning the moon is made from rocky and icy materials[78]. Voyager one travelled past Titan where it detected infrared and radio data, revealing that most molecules within the atmosphere had a mean molecular weight of 28.6 atomic mass units[79]. This value is significant because it indicates that the atmosphere is made up of mostly nitrogen, like the Earth today (78.084%)[80]. Voyager also found from ultraviolet light absorption, that Titan contained molecules such as hydrogen and carbon-bearing-molecules. These carbon molecules are carbon monoxide, carbon dioxide and organic compounds like ethane and propane[81]. Carbon is a vital element for life as it is found everywhere in animals and plants, so an abundance of carbon could make Titan suitable for life[82]. Titan has a similar surface pressure to the Earth at 1.5 bars which is 50% higher than sea-level pressure on Earth[83]. Despite these positives for life, Titan is still a very cold place with a surface temperature of 94K (-179 degrees)

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[72] William B 2024: Titan.
[73] NASA 2024: Dragonfly's Journey to Titan.
[74] William B 2024: Titan.
[75] William B 2024: Titan.
[76] William B 2024: Titan.
[77] William B 2024: Titan.
[78] William B 2024: Titan.
[79] William B 2024: Titan.
[80] NASA 2024: Moons of Jupiter
[81] William B 2024: Titan.
[82] National Geography 2024: The Carbon Cycle.
[83] Andrew C & Brian C 2019: The Planets pages 229-232.

which would kill life as we know it[84]. The troposphere 42km in the atmosphere is even colder at 71K (-202 degrees) so the whole moon is still too cold to harbour surface life[85]. Cassini travelled over the south pole of Titan, where it found a large outburst of methane clouds, indicating the moon frequently endures methane rain which is poisonous to complex organisms on Earth[86].

Stable features

After prolonged periods of observation, scientists discovered that Titan experiences seasons much like Earth which each last for seven years. During these seasons, the atmosphere experiences changes such as the concentration of hydrogen cyanide[87]. Hydrogen cyanide is an important compound to life because it is the building block for amino acids and vinyl cyanide which is suspected to form cell membrane[88].

Huygens is a spacecraft used to analyse the surface of Titan in detail. The spacecraft made measurements where it found that the abundance of methane was not a flammable gas but instead a liquid that flowed on the surface in lakes[89]. One of these lakes has been named Ontario Lacus which contains one oof the rarest sights we have ever seen. Ontario Lacus is a 15,000km2 lake made up of hydrocarbons with an eroded shoreline providing evidence that the moon has similar processes to the Earth[90]. Since Ontario Lacus, 40 lakes of liquid methane have been discovered, with the largest body being Kraken Mare which covers an area of 400,000km2, has a depth of 160 metres and contains hydrogen cyanide[91].

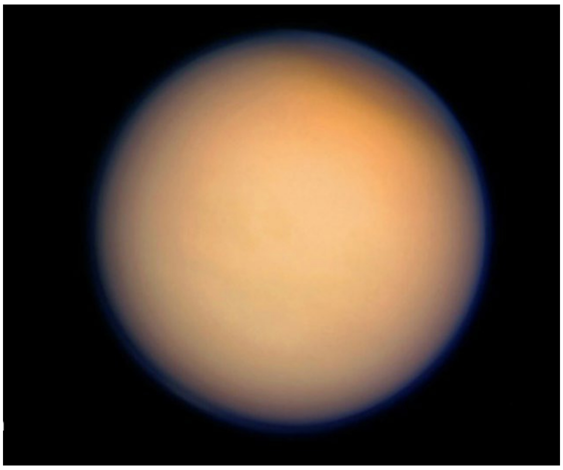

Figure 6 - Titan

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[84] Andrew C & Brian C 2019: The Planets pages 229-232.
[85] Andrew C & Brian C 2019: The Planets pages 229-232.
[86] William B 2024: Titan.
[87] European Space Agency 2024: Monitoring seasonal changes on Titan.
[88] Andrew C & Brian C 2019: The Planets pages 229-232.
[89] Andrew C & Brian C 2019: The Planets pages 229-232.
[90] Andrew C & Brian C 2019: The Planets pages 229-232.
[91] Andrew C & Brian C 2019: The Planets pages 229-232.

(Picture of Titan)[92]

Bright future

Scientists have stated that all the ingredients for life are currently present on Titan, meaning that life could possibly develop in the future[93]. In a few billion years, the sun will expand into a red giant, providing more energy to the outer solar system including Titan[94]. Titan will begin to warm making it impossible for methane to remain in liquid form, evaporating the lakes. However, Huygens found that Titan's mountains are made from ice water, meaning that once the sun expands it will provide enough heat to melt the ice resulting in an ocean of liquid water replacing the methane lakes[95]. The period for Titan to become a water world will be short because, once the sun becomes a red giant, it will begin to die, creating a white dwarf[96]. Despite this, perhaps our solar system could see another body host life in our sun's last breaths.

Conclusion

Even though we have found multiple planetary bodies which could support life either now or in the future, it is important to remember that we still do not fully understand our own origins. Therefore, our ideas of what life is could be completely wrong, so whatever side of the argument you agree with could be correct, but we just do not know at this point in time.

However, I think that life will develop outside of Earth with the strongest candidate for me being Enceladus. Since Enceladus' Ocean is completely shut off from the elements, it has been given a strong stability which would allow life to grow without being wiped out constantly. On its own, Enceladus would be a rogue planet which is a planet ejected from its host star with a frozen layer of ice protecting an ocean. This means that Enceladus could harbour life even after the sun becomes a white dwarf (although due to a lack of geothermal energy Enceladus would need to remain in orbit around Saturn).

The main issue I can see regarding life is that the early solar system was constantly changing, preventing planets from growing or stabilising as a water world. As a result, life was never given the opportunity to evolve anywhere apart from Earth. We are extremely lucky that the Earth has a strong magnetic field, remained in the goldilocks zone, and had the right materials needed for life to exist.

[92] Phys.org 2024: Picture of Titan.
[93] Andrew C & Brian C 2019: The Planets pages 229-232.
[94] Andrew C & Brian C 2019: The Planets pages 229-232.
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Physics in Formula One

Laura Zbiciak

Introduction

Formula One is often considered to be the pinnacle of motorsport and physics plays a fundamental role in the sport as designing a fast, efficient, reliable and safe car requires a great understanding of the science. Forces are one of the key components of not only physics, but of racing too, this can be clearly seen through the aerodynamic design of modern F1 cars, which relies heavily on the shape of the sidepods, the front and rear wing and the diffusers, as well as on other features of the bodywork of the car that create a perfect balance between sufficient downforce and minimal drag, enabling high speeds to be achieved. However, forces must also be considered when it comes to the safety of the drivers as they experience G-forces throughout the duration of the whole Grand Prix weekend, reaching up to approximately 5g[1] at the apex of a corner, and during crashes, where they experience much more intense forces, with 254g[2] being the highest in F1 history. Other areas of physics are also closely linked to F1 as energy, electricity, and materials are also a major part of the sport. Therefore, physics is an inherent aspect of Formula One.

Aerodynamics

In a sport where speed is an essential contributor to success, aerodynamics plays a major role as an effective design reduces drag and increases downforce, enabling the car to travel at higher velocities.

DRS

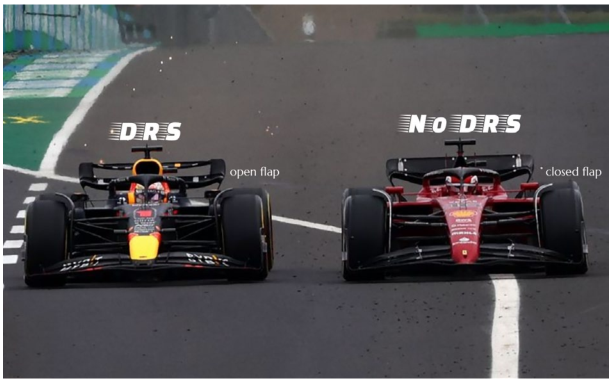

Figure 1 - DRS rear wing comparison

A reduction in drag is essential as it minimises the magnitude of the resistive force the engine has to work against, the higher the speed of the car, the higher the drag; so, in 2011[3] a new system was introduced to temporarily reduce drag in order to facilitate more overtaking during a race. DRS (Drag Reduction System) is a device that is activated by a driver pressing a button on their steering wheel (when they are within a second of the rival ahead), causing their rear wing to "open using an actuator controlling a flap in the middle of it"[4] and enabling them to drive quicker than the car in front. However, there are some limitations, for example, the drivers can only activate their DRS in the zones of the circuit that are outlined by the FIA and in extremely rainy conditions it is prohibited to use the device. But, there are also various other benefits to drag reduction as it increases the efficiency of the engine and power unit as less power is required to be exerted due to the decrease in air resistance, thus consequently improving fuel efficiency, cooling and decreasing costs (as less engines will have to be used throughout the season), which are all important aspects of modern racing

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Downforce

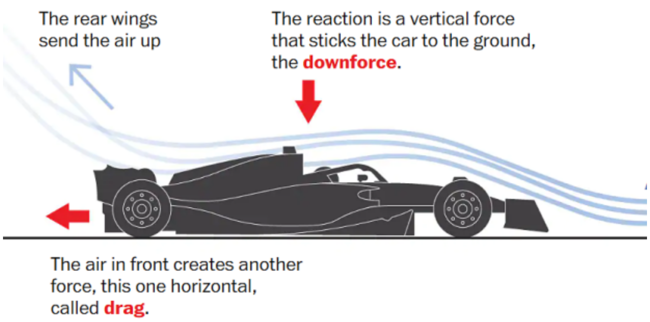

Figure 2 - airflow around the car

"'Downforce' is a vertical, downward aerodynamic force created by the air moving over the car's bodywork that pushes the car down into the track"[5]. When greater downforce is generated, the drivers can take corners at higher speeds, due to the increased traction with the asphalt, without losing control of their vehicle. For example, at tracks such as the Las Vegas Strip Circuit, drivers enter turn 17 at 315kph (87.5 m s^{-1}), and at the fastest circuit on the F1 calendar (Autodromo Nazionale di Monza) the average speed is 265kph (73.6 m s^{-1}), and the top speed is 362kph[6] (100.6 m s^{-1}), thus making high downforce essential for better grip and accuracy when turning and steering. In F1, downforce is generated by the floor, rear wing and front wing of the car and at around 150kph the car generates approximately as much downforce as it weighs[7] (so around 7798.95N as the minimum mass of an F1 car is 795kg[8]), however, at maximum speed this value can triple, or even quadruple, which is why according to the Mercedes AMG Petronas Formula One Team "downforce is undoubtedly the most important in terms of car performance"[9] as it really impacts the speeds the cars can reach.

Key components in generating downforce:

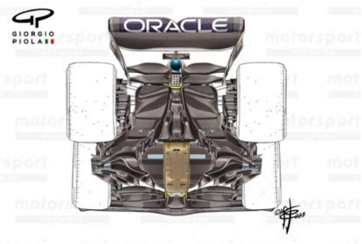

Figure 3 - floorboard of the car

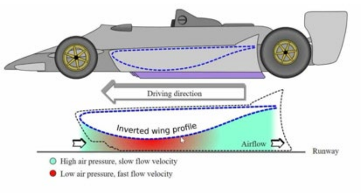

Figure 4 - Venturi effect

- **The floor:** the undercarriage design of the car can be exploited to create the Ground Effect, which is a very specific exploit of the Venturi Effect in the floor of the car[10]; the Venturi Effect is the "reduction in fluid pressure that results when a moving fluid speeds up when travelling through a constricted section of a pipe"[11]. So, this results in a pressure difference being created above and below the car and as the air tries to enter the low-pressure area, the car is pushed down, and massive amounts of downforce are applied to the vehicle, enabling it to move at a higher velocity. Although the implementation of the new regulations in 2022, which allowed the return of the ground effect, is mainly positive since it facilitates closer competition, the major downside is that it created a new problem: porpoising, which is essentially the car bouncing on its suspension: previously leading to intense back pain for some drivers, such as Lewis Hamilton.

- **The Diffuser:** a diffuser is the "flared opening at the rear of the floor and is the part of the car responsible for generating the most downforce from the underside of the vehicle"[12]. It has to be designed carefully so that there is no

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separation of airflow as it exits the underneath area of the car since this would affect the successfulness of the whole floor.

- **The Front and Rear Wings:** both wings are adjustable so teams can change the size and angle of both the front and rear wing elements to provide different levels of downforce in order to optimise their performance on different tracks. For example, on a high-speed circuit with long straights, the wings are smaller and nearly flat, allowing air to travel through them with less resistance, whereas, on a circuit which has more corners, the surface area of the wings is larger, and they are angled against the airflow, thus enabling more grip. The front wing is the first point of contact the car has with the air and the "tips" of the front wing create a vortex that aids to improve the quality of the airflow all around the car and feed the diffuser, as well as work to reduce the negative drag created by the front tyres[13]. The rear wing is mainly responsible for the function of the DRS.

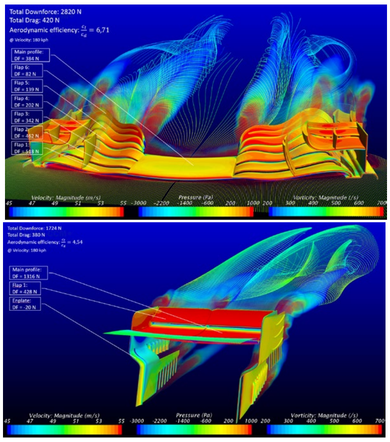

Figure 5 - front and rear wing aerodynamics

Therefore, overall, it is crucial for engineers to balance the downforce as optimally as possible in order to ensure that the car is both stable and fast.

Dirty Air

Figure 6 - dirty air versus slipstream

In F1, 'dirty air' is when a car that is closely following another car drives through its roiling wake[14], which causes the aerodynamic features of the car to work less effectively in the turbulent air, thus consequently reducing the downforce that is being generated. On the other hand, a slipstream is the opposite as it is a pocket of low-density air, which causes the driver that is following the car ahead to experience less drag and therefore to drive quicker. The difference between the two is that dirty air occurs in the corners, where downforce may arguably be more important as more stability is necessary, whereas a slipstream occurs in the straight parts of the track. Unlike dirty air, a slipstream is beneficial as it is a partial vacuum created by the car ahead punching a hole in the air which enables a higher speed to be sustained by the car behind, providing it with leverage to overtake or to have a faster lap time in qualifying, therefore, teams often exploit this effect during qualifying by ordering their drivers to stay close together on track (mainly on the straights) to take advantage of this.

Energy & Electricity

With the development of the hybrid era in F1, the importance of energy conservation increased as over time the power units have become more reliable on the electrical components due to new regulations. The motor

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generator unit-heat (MGU-H) and the motor generator unit-kinetic (MGU-K)[15], which are a part of the energy recovery system, generate 120kW[16] of power, however after the 2026 engine changes the new engines will have an almost 50/50 split[17] between the internal combustion engine and the electrical power. These changes mean the MGU-K is is expected to provide up to 350kW and so the MGU-H will be dropped.

ERS

The energy recovery system (ERS) generates "electrical energy from two sources: kinetic energy recovered from brake usage, and thermal energy from the car's exhaust"[18], and converts it into additional power, providing up to 180hp[19] that can be deployed strategically to enhance performance during the race. ERS enables drivers to accelerate quicker, allowing them to close gaps to competitors and to pull away from them, as well as to achieve a higher top speed and thus to overtake quicker; it also makes the cars "more efficient and environmentally friendly"[20].

The Power Unit

A formula 1 power unit consists of: "the internal combustion engine (ICE), motor generator unit-heat (MGU-H), motor generator unit-kinetic (MGU-K), turbocharger, energy store (ES), control electronics (CE) and exhaust"[21], and generates 1000hp from just 1.6 litres[22]. The V6 engine is an internal combustion engine with six cylinders shaped in a V formation and has a compact and lightweight design compared to other engines, making it ideal for F1 cars in which weight is extremely important and also supports the FIA's goal of being more environmentally friendly with its lower fuel consumption (compared to the V10s that were previously used).

Materials

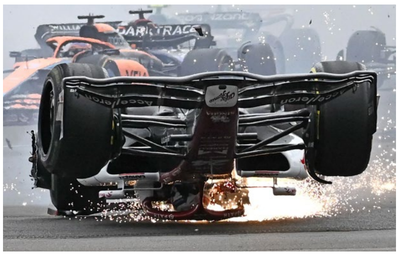

Figure 7 - Zhou Guanyu crash – Silverstone 2022

Figure 9 - Max Verstappen and Lewis Hamilton crash – Monza 2021

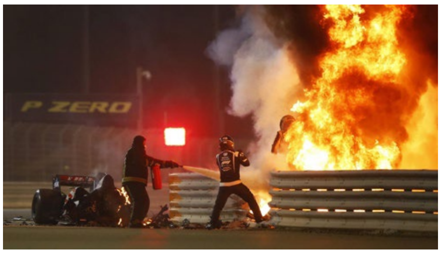

Figure 8 - Romain Grosjean crash - Bahrain 2020

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The materials which are used to build F1 cars are also a significant part of the design process. The weight and durability are key areas to look at since it is essential for the various components of the car to be lightweight but to also withstand the different forces when driving and in a crash. The materials that are used all have different purposes as some (carbon fibre) are meant to shatter into small pieces to absorb excess kinetic energy and to decelerate the car, meanwhile others are used in the monocoque to protect the driver when the surrounding components in the crumple zones deform to absorb even more impact and reduce the risk of injury.

Figure 10 - wreckage of RB16B after the collision caused by Lewis Hamilton – Silverstone 2021

The Halo

The Halo is a "three-pronged tubular titanium structure that surrounds the cockpit of a Formula 1 car"[23], it shields the driver from objects and debris that could land on their head and absorbs the impact during an accident. It can withstand a vertical load of 12 tonnes[24], whilst only having a mass of 7kg[25], thus providing extra protection for the driver's head by preventing damage from above but also from the side by inhibiting the helmet from coming into contact with the barriers.

The Race Suits & Helmets

The race suits are made from a fireproof material called Nomex, which can withstand a temperature of 600-800 degrees Celsius for over 11 seconds[26], which provides the drivers with enough time to exit the burning vehicle and enables them to survive the accident. The suit has a small mass of around 750g[27], and the helmet has a mass of 1.5kg[28], making them comfortable to wear but also allowing excess weight to be saved. The helmets are an essential part of the safety gear as they prevent direct impact to the driver's head; they are made of carbon fibre and Kevlar and must prevent the deceleration of the driver's head being above 275G when impacted at 9.5m s^{-1} [29] .

The Tyres

Since 2011[30], Pirelli has been the sole manufacturer of the tyres used in F1, each car has four tyres, with the rear being larger (40.5cm in width) and the front being smaller (30.5cm in width), but all four have the diameter of 67cm[31]. Intermediate tyres, which are 'the most versatile of the rain tyres'[32] 'can be used on a wet track with no standing water, as well as a drying surface'[33], and can 'evacuate 30 litres of water per second at 300kph'[34], are

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5cm wider and full wets (which are ‘the most effective for heavy rain’[35] and can evacuate ‘85 litres of water per second at 300kph’[36]) are 10cm wider than the slicks. Excluding the wheel rims, the front tyre has a mass of 9.5kg and the rear has a mass of 11.5kg[37]; slick tyres are split into six different compounds, ranging from C0 to C5, with the C5 being the softest. The C5 tyres are designed for the ‘slowest circuits with low wear and degradation where the maximum mechanical grip is required from the rubber’[38] (especially on street circuits where the asphalt is smoother), whereas the C0 tyres are the hardest in the range and are designed for the circuits that ‘take the most energy out of the tyres’ and so they provide the maximum resistance to heat and extreme forces in order to be capable of running very long stints[39].

Figure 12 - Pirelli wet and intermediate tyres

Figure 11 - Pirelli tyre compounds (hards, mediums, and hards)

Figure 13 - Red Bull Racing pitstop – Qatar 2023

Moreover, the rear tyres are wider due to the power of the engine and torque being delivered through the rear wheel, so a larger contact patch creates more grip and stability, therefore the cars have better grip under acceleration; the front tyres however, are slimmer as they are used for steering and thus having a slim tyre facilitates turning and allows greater speed when cornering due to the smaller contact patch[40]. F1 tyres are composed of ‘10% natural rubber’ [41] (the rest is synthetic), and are filled with nitrogen as it behaves predictably even when the temperature varies[42]; they play a crucial role in the performance of the car as well as in strategy as there is one mandatory pit stop per race, where the tyre compound must be changed and each compound lasts a different number of laps at different tracks. The actual action of changing the tyres takes 2-3 seconds, with 1.80 seconds[43] being the fastest and involves around 20 crew members so coordination is key. Each driver is allocated with 8 sets of softs, 3 sets of mediums, and 2 sets of hards per race weekend[44] (plus a varying

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number of sets of intermediates and wets depending on the weather), therefore each team conducts calculations and simulations do decide on their tyre strategy throughout the weekend.

Conclusion

Overall, physics are considered at every level of the design process of the car as without an understanding of physics there would be no successful engineering and thus the sport would simply not exist. Furthermore, due to the continuous development in the understanding of physics and due to the incredible work of engineers such as Adrian Newey, the complex designs of the cars will continue to evolve and improve, especially the aerodynamics of the car with the introduction of active aerodynamics ("moveable front and rear wings to allow for closer racing"[45]) in the 2026 regulations, as well as the development of a more sustainable engine design due to further refinements in green technology. As the sport progresses, the manufacturing process of the cars will likely undergo improvements as well as the composition of the fuel and tyres as more research is continuously being conducted, therefore, F1 will continue being an ever-developing sport in order to maintain its prestige and the title of being the pinnacle of motorsport.

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Length Contraction: How speed can make things seem smaller

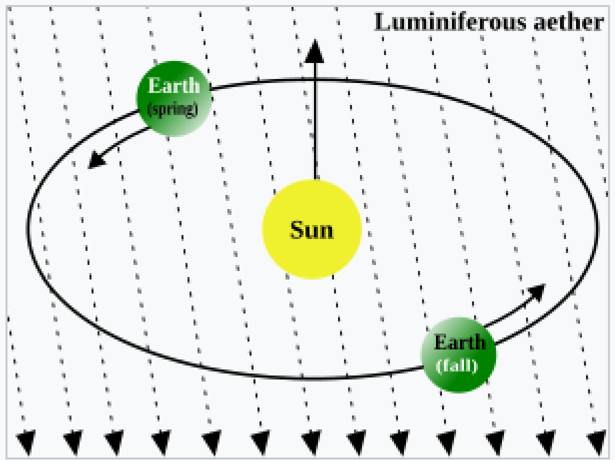
Luca Dobos

Length contraction is a fundamental concept in Einstein's theory of special relativity which describes how lengths appear to change for observers in relative motion (1). According to Einstein's theory of special relativity, as an object moves closer to the speed of light, its length in the direction of motion appears to shorten. This phenomenon is a consequence of the effects of space contraction and time dilation.

The Origin of Length Contraction:

The idea of length contraction has its roots in the attempts to explain the 'null' results of the Michelson-Morley experiment.

The **Michelson-Morley** experiment, conducted in 1887, by Albert A. Michelson and Edward W. Morley aimed to detect the presence of a hypothetical medium called 'aether', which at a time was a medium which light was presumed to travel through. (2) This idea was crafted due to physicists at the time, like Michelson, believing that it was necessary for the propagation of light waves, much like how air is for sound waves. This 'aether' was a theoretical substance that was proposed in the 19th century – proposed by Hendrik Lorentz and George FitzGerald - and was a concept widely accepted in the scientific community prior to modern theories of electromagnetism and relativity.



A depiction of the concept of the "aether wind"

(4)

What did the experiment tell us?

The main objective was to measure the relative speed of light in different directions, while expecting there to see some variation in the Earth's motion through 'aether'. (3)

The experiment uses equipment like an interferometer, which equally splits a ray of light into perpendicular directions to one another. These rays are then reflected and interfere, creating a pattern.

The interferometer is then rotated to test different orientations relative to the supposed 'aether', if aether existed light that travelled parallel to the motion through aether would move faster than the light travelling perpendicular to it, which would change the interference pattern.

The 'Null' results:

The experiment found no significant difference in the speed of light; despite the way the interferometer was facing. This null result told us that the speed of light is constant in all directions and that aether does in fact, not exist. This was considered as a null result. (5) A null result in scientific experiments refers to the outcome where the expected effect was not observed. It tells us that the experiment was not able to give us an anticipated result, leading to the conclusion that the hypothesised phenomenon, in this case aether, does not exist.

This conclusion was critical in the development of modern physics, as it essentially paved the way for Einstein's theory of relativity. Supporting the idea that the speed of light is never changing and led to the understanding that space and time are not related.

The aftermath of the disproval of the aether theory:

Following the conclusion of the Michelson-Morley experiment, it gave physicists a new gage on how space and time relate to one another, and with this, Albert Einstein was able to formulate his theory of relativity based on the two hypotheses that came from the experiment: (6) That 'the laws of physics are all the same in all inertial frames of reference'. An inertial frame of reference is a perspective in which an object is at rest or moving at a constant velocity. There will be no change in speed or direction. Lastly, 'the speed of light in a vacuum is constant for all observers, regardless of their motion or the motion of the light source'. The speed of light is approximately 3x10^8 m/s, in everyday life the speed of an object depends on the motion of the observer and the object itself. For example, if you are in a car moving at 60 km/hr and another car at 50km/hr in the same direction, you perceive the other car's speed as 10km/hr relative to you.

What Albert Einstein said was, no matter how fast you are moving or in what direction the speed of light will always be 3x10^8 m/s. Therefore, his idea of where the speed of light in a vacuum is always the same regardless of the observer's motion. While it seems counterintuitive as it goes against common experience of relative motion, this is how things are.

Length Contraction:

Length contraction was first mathematically described by Hendrik Lorentz, the **Lorentz transformations**, which are a set of equations that relate the space and time coordinates of two moving systems moving at constant velocity relative to one another. The general formula for length contraction is given by:

$$L = L_0\sqrt{1 - \frac{v^2}{c^2}}$$

(7)

L = Contracted length

L_0= The actual object length

V = Velocity of the object

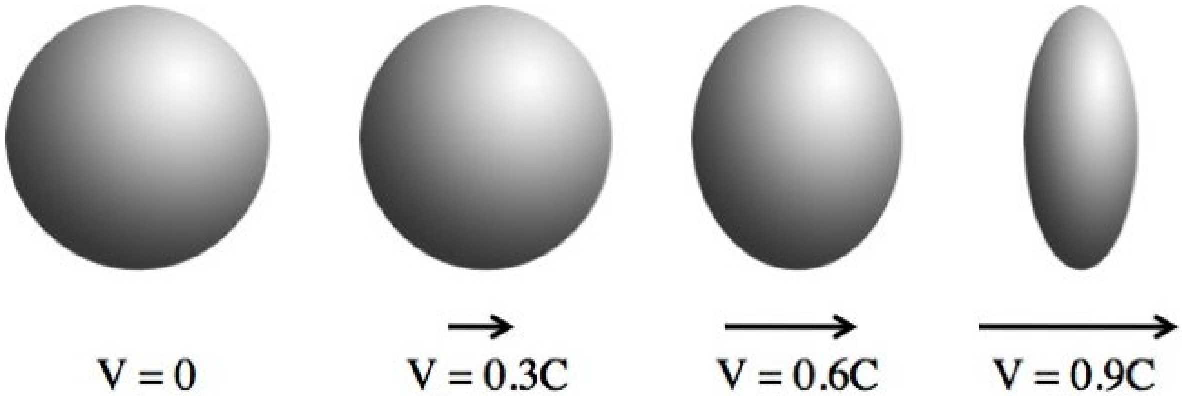
C = Speed of light

An example of this would be, if a spaceship is travelling at 80% of the speed of light and its actual length is 100 meters. The contracted length observed would be 60 meters.

Length contraction is closely related to the relativity of simultaneity (8), which tells us that evens occur at the same time in one frame of reference may not be simultaneous in another. This affects the measurement of lengths along the direction of motion.

The First Discovery

Today, there are many ways to prove that length contraction exists in our universe, while the average person may never get to experience it, physicists can make this possible in a variety of ways with the first observation being the observation of muons. (9) Mouns are elementary particles similar to electrons but with a much greater mass – about 207 times more. They belong to the second generation of leptons and have a negative electric charge. Muons are created in the Earth's upper atmosphere when cosmic rays collide with nuclei in the atmosphere. This collision produces a large number of particles, among of which are pions, which decay into muons and neutrinos. Muons have an incredibly short life span, at approximately 2.2 microseconds (2.2x10^-6 seconds). Given their short lifespan, muons should theoretically be able to decay into electrons and neutrinos very long before even reaching the Earth's surface. Their short lifetime of 2.2 microseconds gives them roughly a few hundred meters of travel in the atmosphere. Yet, a few muons can be detected at the Earth's surface, how can this be possible? With the travel being almost 10 kilometres from the atmosphere to the ground?



(10) '*A visualised diagram of the change in length of a sphere as it approaches the speed of light'*

The Paradox:

The solution to this lies in the fundamentals of relativity, time dilation and length contraction. According to special relativity, time passes slower for objects moving closer to the speed of light. In this case, since muons travel at such high speed, their internal 'clocks' run slower than those compared to observers from on Earth. The term internal clocks refer to any mechanism for measuring the passing of time. For the muons, their passage of time can be thought of as its decay. Therefore explaining this strange phenomenon, as from our perspective, the muons' lifetime is extended.

Einstein's final deduction:

Following the contradiction of the concept of 'aether', the conclusion of the Michelson-Morely experiment, the mathematical explanation of length contraction by Hendrik Lorentz and the observations concluded from muons, Einstein was able to publish one of his most famous papers, that fundamentally expanded our understanding space, time, and motion, in 1905 named '**On the Electrodynamics of Moving Bodies'** (11). Overall, Einstein was able to address other physicists' inconsistencies, such as the work of Maxwell's electrodynamics, pushing at the need for a better framework.

This paper was published in the journal 'Annalen der Physik' (12) was part of his annus mirabilis (''miraculous year''), in which he published four seminal papers that laid the foundation for modern physics. This served as a piece of monumental work that resolved many gaps and holes in physics at the time and set the stage for numerous advancements in our time today.

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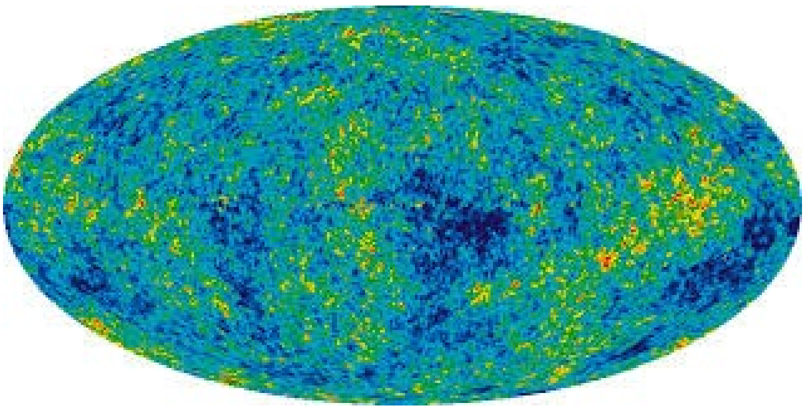
Singularities and the Beginning of the Universe

By: Vova Vickers

As the universe keeps expanding, so does humanity's' curiosity. A century ago, it was discovered that objects further away from earth were moving away faster [*pbs.org, Hubble proves that universe is expanding, 1929,]* and today the question is – how it all began? What caused the universe to expand, how and when this happened? According to Hawking's singularity hypothesis, the universe began its existence from a single point, which had infinite density and temperature, which is known as ***initial singularity***, like ones found at the centre of Black Holes. In this write-up I want to describe another hypothesis of how universe began, and to do it I will use Penrose-Hawking's singularity theorems and link it to General Relativity theorem which states that all the mass in the universe before the Big Bang event was concentrated in one point, called **singularity** [*Curiel, Erik (2021)*]Penrose-Hawking singularity theorem is an attempt to describe the formation of singularities as a result of gravitational impact and is considered as a possibility that our universe began expanding **as a result of singularity collapse**. These theories have a lot in common and they both describe the singularity as a point in space which has an infinite curvature and so much energy, that spacetime stops being a manifold [*Einstein, Albert, 1915, General Relativity Theorem, 1915,*].

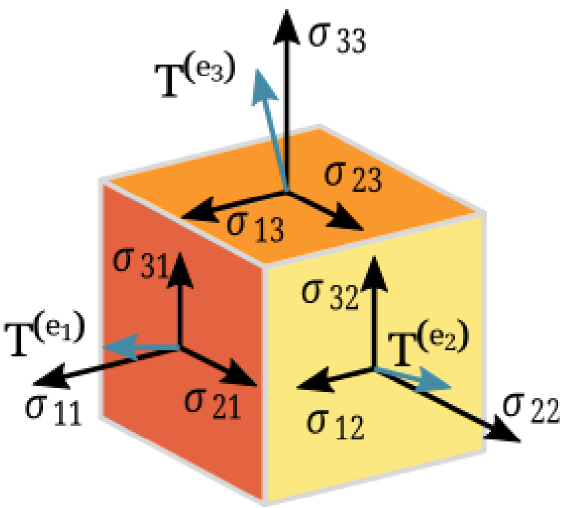
The expansion of the universe and the introduction of Hubble-Lemaitre Law [*Wikipedia.org*, *Hubble-Lemaitre Law, 2013*] have encouraged the appearance of Big Bang theory, suggesting that all matter has appeared to concentrate in one spot, before being spread out due to massive energy release. What was interesting about this event, is that all mass was spread evenly across the universe, which is impossible in something as chaotic as explosion.



Source: *https://www.wtamu.edu/*

spread of matter across known universe.

This is when the known physics stops working with singularities. If all the mass were centred at a specific point in space, that point could be considered the origin and the point of beginning of universe. However, general relativity has introduced the principle of General Covariance, suggesting that coordinates cannot be linked to the manifold because they were introduced to describe it. Instead, tensors were introduced.



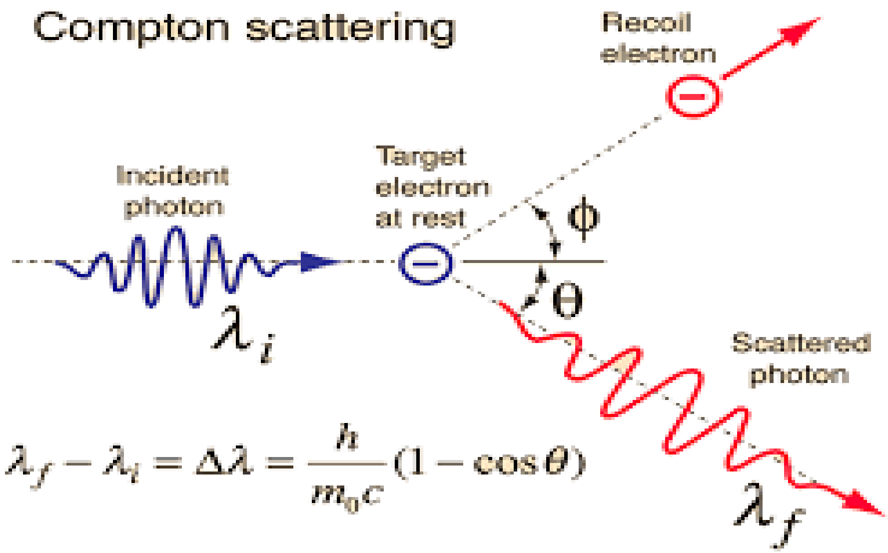
For any unit vector , the product is a vector, denoted , that quantifies the force per area along the plane perpendicular to . This image shows, for cube faces perpendicular to , the corresponding stress vectors.

Source: wikipedia.org/wiki/Tensor *Tensors in vector geometry.*

Tensors are mathematical objects that describe physical properties like scalars and vectors, but they can take form of both – scalar is zero rank tensor, and vector is first rank tensor.

Introduction of tensors has massively simplified Einstein's field equations and has also included singularities in them, as it was problematic to express an object with zero volume in dimensions of space. It has also solved the problem of the unusually uniform expansion of the universe, because now each dimension had a separate vector that was not linked to any coordinate. [*Cambridge, Department of Materials Science & Metallurgy , 2004]*

Another problem of defining the singularity comes from the known laws of quantum mechanics. The assumption that singularity has infinitely small size stands against the fact that no object or particle can inhabit a space smaller than its Compton Wavelength. This property of particle is defined as the wavelength of a photon whose energy is the same as the rest energy of that particle. [Zebrowski, Ernest (2000)]



From this equation, assuming wavelength is zero, the mass of the singularity must be infinite, which breaks theoretical maths and therefore is considered impossible. ($\Theta < 90$)

http://hyperphysics.phy-astr.gsu.edu/ – *Compton Scattering,*

Conclusion:

Identifying those problems at the right time helped to modify physics laws to how they look today. One of the recent modifications of Penrose-Hawking theorem now suggests that singularities need to be re-defined. Instead of previous definition, latest version states that singularity has geodesics that cannot be extended in a smooth manner.

Today, singularities still stay a mystery, fundamental physics laws contradict the presence of singularities. However, every discovery moves humanity closer to the day when we will be able to not just understand their nature but use it in our favour.

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