THE IDEA SPACE

BONUS CHAPTERS

CLÉMENT DECROP

THE IDEA SPACE

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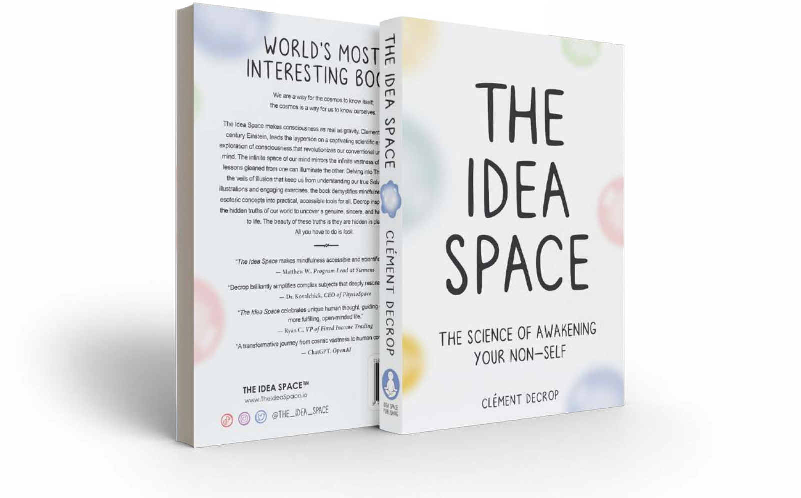
Clément Decrop

Idea Space Publishing

THE IDEA SPACE

THE SCIENCE OF AWAKENING YOUR NON-SELF



We are a way for the cosmos to know itself;
the cosmos is a way for us to know ourselves.

The Idea Space makes consciousness as real as gravity. Clement Decrop leads the reader on a captivating scientific exploration of consciousness that revolutionizes our conventional understanding of the mind. The infinite space of our mind mirrors the infinite vastness of the universe, and lessons gleaned from one can illuminate the other. Delving into *The Idea Space* lifts the veils of illusion that keep us from understanding our true Selves. Packed with illustrations and engaging exercises, the book demystifies mindfulness by transforming esoteric concepts into practical, accessible tools for all. Decrop inspires those seeking the hidden truths of our world to uncover a genuine, sincere, and harmonious purpose to life. The beauty of these truths is they are hidden in plain sight. All you have to do is *look*.

"A transformative journey from cosmic vastness to human consciousness."
— ChatGPT, *OpenAI*

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Bonus Chapter 0

PRIMER

These Bonus Chapters serve as a complement to the book, *The Idea Space: The Science of Awakening Your Non-Self.* The main text focuses on providing an overall analysis of the concept of an "idea space", and how an idea space relates to the universe at large. Some technical points that didn't fit within the book are further highlighted in an appendix, labeled supplemental material.

In a sense, these Bonus Chapters are a continuation of the book. They distill complex physics topics into an accessible format, covering themes like the cosmic calendar, the Big Bang, star formation, black holes, and galaxy formation. They are crafted to be read as stand-alone assets, offering a deeper exploration of the universe for the curious reader.

If you haven't read *The Idea Space* yet, then this chapter serves as a primer to the topics covered in the Bonus Chapters. The approach taken here is meant to be pedagogical. This methodology is different than the book, which asserts a more introspective, contemplative tone, while bridging the gap between the humanities and exact sciences.

THE SUNSET CONJECTURE

The heart of *The Idea Space* lies in a concept called the *Sunset Conjecture*, which is two-fold: (a) everyone lives at the center of their own observable universe, and (b) at the center of your observable universe lies your idea space (figure 1). Your observable universe is a giant sphere centered on you, where everything you see is in the past.

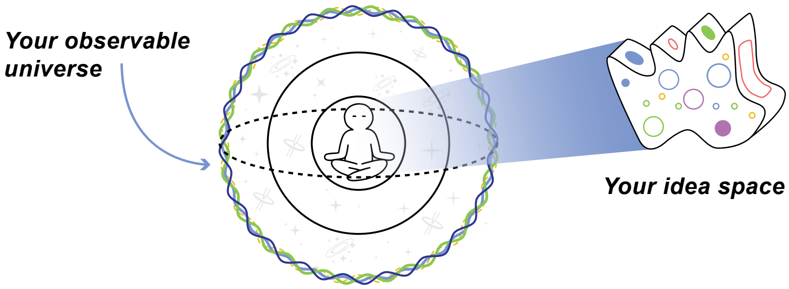
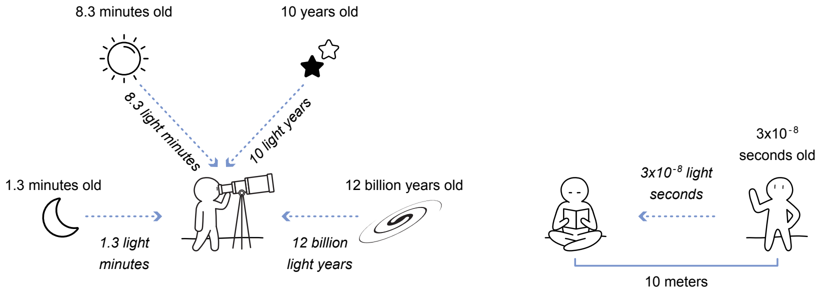


Figure 1. The Sunset Conjecture.

The reason everything you see is in the past is because it takes time for light to travel from point A to point B, even at 186,000 miles per second (figure 2). For instance, light you're seeing from the sun took eight light minutes to reach you. So, *right now*, you're seeing how the Sun *was* eight minutes ago—not what it actually looks like now. So, if the Sun exploded, which it won't, then you wouldn't know about it for another eight minutes.



(a) When we see light, we are seeing the past

(b) Even at close distances, we're seeing the past

Figure 2. Everything you see is in the past.

Overall, the Sunset Conjecture explains why the sun can simultaneously set on two people. This is best illustrated through a short story:

> *Picture yourself on the beach. You had a fantastic day of doing nothing but reading, drinking piña coladas, and talking with friends. At the end of the day, you decide to take a walk on the beach to watch the sunset. You say to your friends, "I must be special. It seems as if the sun's golden rays are reflecting right off the water directly toward me." Your friend responds, "No, you idiot. The golden rays are pointing directly toward me." Clearly, you are both right (figure 3).*

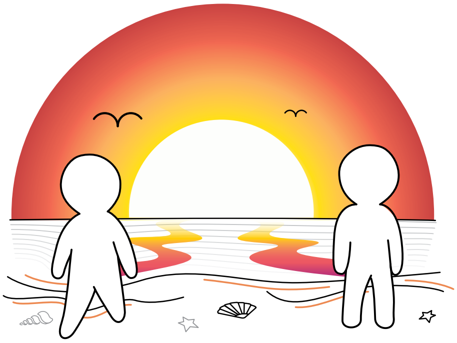


Figure 3. The sun sets on two people simultaneously.

Simply put, the Sunset Conjecture shows us that everyone's perspective of the observable universe is unique—from a small butterfly 10 meters away to the edge of our observable universe, the Big Bang.

YOUR IDEA SPACE

Everyone experiences their own unique perspective of the universe, which amalgamates as their *idea space.*

Your idea space is a scientific model for your mind that's congruent with modern physics. An idea space consists of your thoughts, emotions, sensations, perceptions, and the empty set, ∅, or nothing. Thoughts contain words, pictures, memories, daydreams, songs, etc. Emotions involve feelings of pleasant, unpleasant, neutral, and everything in between. Sensations include the classic five: touch, sight, sound, taste, and smell. Perception is one's ability to recognize something. For instance, a pen is a pen. A computer is a computer. Together with the empty set, ∅, or nothing, these elements make up your idea space (figure 4).

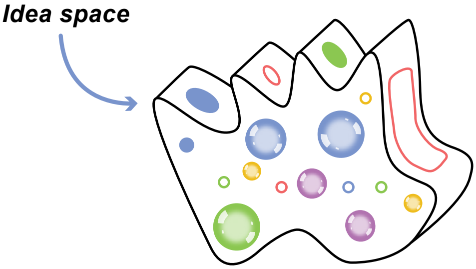


Figure 4. Your idea space.

To locate your idea space, hold something in your hand, like your phone. Clearly, you can see it. You can feel it. Others can see it. Now, close your eyes and bring to mind a mental image of your phone. Can anybody else see that mental image? No. Similarly, no one else can see the range of your thoughts, emotions, sensations, and perceptions. Until computers can transfer idea spaces, no one can see your idea space. To an outsider, it all looks like nothing.

NON-SELF

Non-Self characterizes the fact that "I," your name and identity, is simply another appearance in your idea space. It is the amalgamation of your thoughts, emotions, sensations, perceptions, and consciousness. In other words, "I" is merely one layer of your Self.

To test this hypothesis, let's do a simple experiment called the *Layers of the Onion* from the Headless Way, a meditation technique developed by Douglas Harding.

To start, sit in a comfortable, yet alert position. Imagine asking someone standing ten meters away, "What am I?" They'd probably answer: a person. Now, imagine that person is looking at you through a microscope and you ask them, "What am I?" They'd probably answer: a mixture of cells. If they view you with an electron scanning microscope, they'd probably answer: molecules. As close as they can get, they see nothing. They cannot see who you are at zero measure. They cannot see your idea space.

Similarly, an observer could zoom out and you could ask them the same question: "What am I?" As they zoom out, they'd probably answer: a city, a country, a solar system, a galaxy, and a universe.

So, what are you? A universe? A solar system? A city? Your name? Cells? Molecules? A mixture of all these things? Where do you start and where do you end? The words of physicist Richard Feynman capture the sentiment well:

> *What is a chair? The atoms are evaporating from it from time to time—not many atoms, but a few—dirt falls on it and gets dissolved in the paint; so to define a chair precisely, to say exactly which atoms are chair, and which atoms are air, or which atoms are dirt, or which atoms are paint that belongs to the chair is impossible. To define . . . a single object is impossible, because there are not any single, left-alone objects in the world—every object is a mixture of a lot of things, so we can deal with it only as a series of approximations & idealizations . . .*[1]

In this spirit, "I," your name, is an idealization others, and sometimes even you, use to approximate who you are. In reality, your Non-Self is the amalgamation of all your fractal layers (figure 5). These layers extend to the outer edge of the cosmos as everyone lives at the center of their own observable universe. In other words, everyone experiences their own *Singularity Sunset*, as we'll see in one of the upcoming bonus chapters.

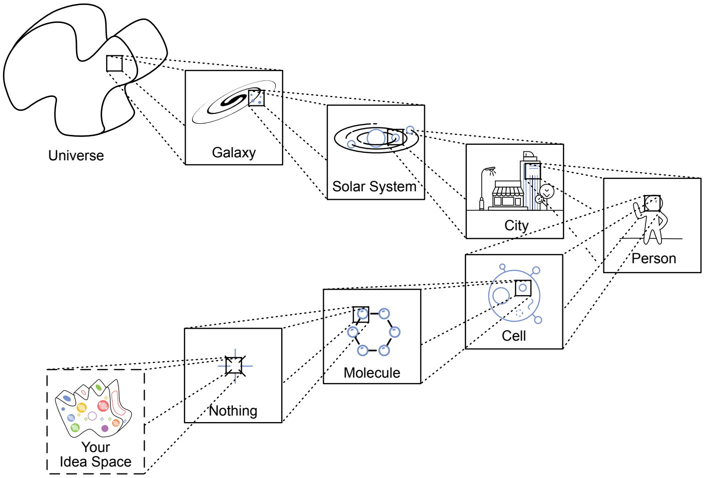


Figure 5. Where do you start and where do you end?

TOPOLOGICAL SINGULARITIES

A *topological singularity* is the name of any object that has uncountable depth and zero measure. For instance, your idea space is a topological singularity. Other examples of topological singularities include a veil of illusion being lifted, a koan forming in your idea space, the observable universe during the Big Bang, and the Cantor Set (figure 6).

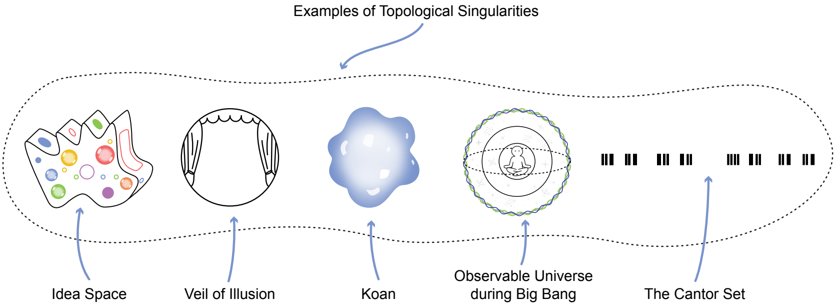


Figure 6. Examples of topological singularities.

Zero measure simply means the object looks like nothing. For example, if I were to measure an object of zero measure with a ruler, then I would get 0. Similarly, if I were to measure nothing, ∅, with a ruler, then I would also get nothing. The trick is that something with zero measure can have uncountable depth. So, if you're looking at the space between these words and your eyes, then can you tell whether there's nothing there or something with uncountable depth? No—you cannot (figure 7). As cosmologist Martine Rees said, "Absence of evidence is not evidence of absence."

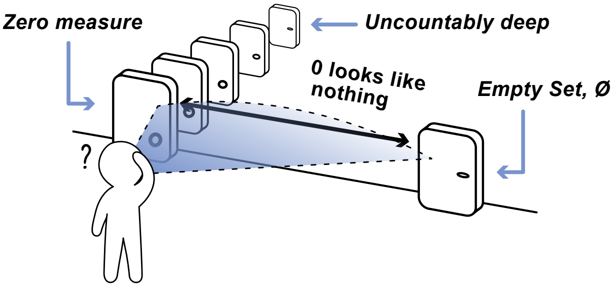


Figure 7. Can you tell the difference between the empty set, ∅, and an object of zero measure and uncountable depth, like your idea space? No.

Uncountability represents a size of infinity larger than infinity we use to count (1, 2, 3, …). A set is deemed uncountable if it follows Cantor's Diagonal Argument: *for every item that you list in a set—even an infinite amount—I can always list an item you did not list.* A tangible example of an uncountable object is spacetime. More on uncountability can be found in Chapter 3 of the book and in the Idea Space Whitepaper.

Overall, a topological singularity is represented as the uncountably many points of the Cantor Set squished into one point (figure 8). This symbol represents any item that has uncountable depth and zero measure; and, since a topological singularity has zero measure, it looks like nothing to an outside observer.

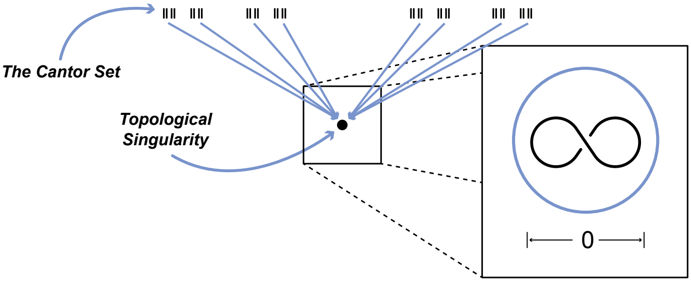
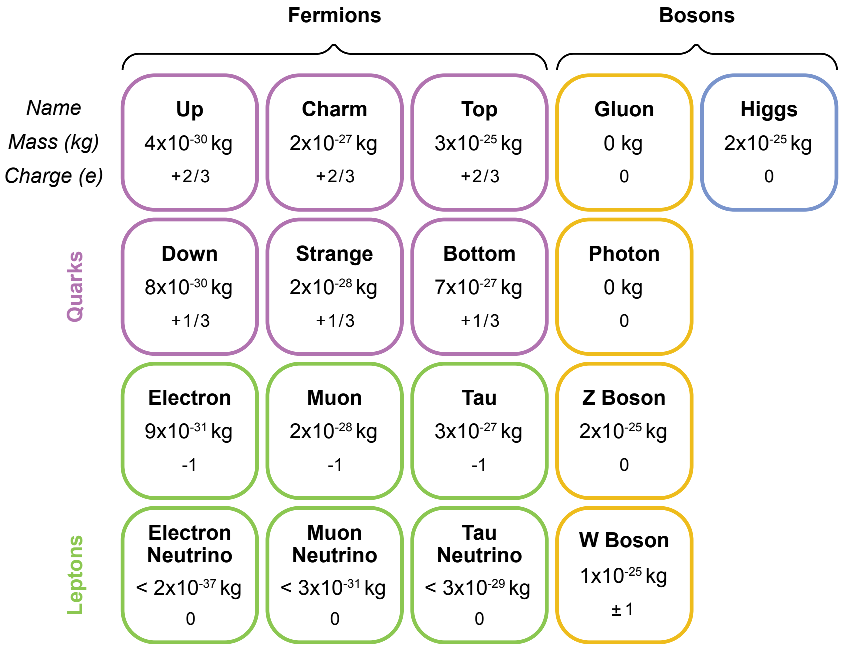


Figure 8. Symbol for topological singularity.

THE STANDARD MODEL

According to the European Space Agency's Planck Telescope, *dark energy* (responsible for the continuous expansion of space) makes up around ~68% of the universe, *dark matter* (gravitational seeds responsible for galaxy formation) makes up ~27%, while regular matter and force-carrying particles make up the other ~5%.[2] The comprehensive classification of regular matter and force-carrying particles is called the *Standard Model* (figure 9).

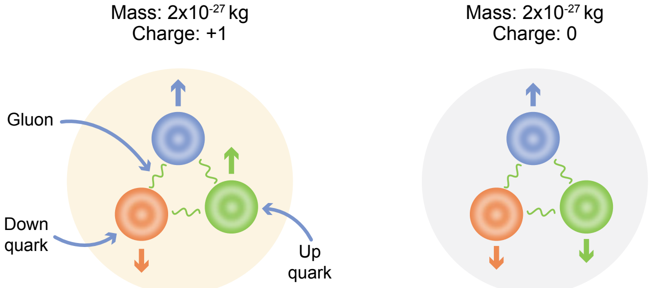
Within this model, the three left columns represent all the matter in our universe, commonly called *fermions*, while the last two columns are the forces carrying particles, called *bosons*. Each particle is characterized by its name, mass, and charge.



	Fermions			**Bosons**	
Name *Mass (kg)* *Charge (e)*	**Up** $4x10^{-30}$ kg +2/3	**Charm** $2x10^{-27}$ kg +2/3	**Top** $3x10^{-25}$ kg +2/3	**Gluon** 0 kg 0	**Higgs** $2x10^{-25}$ kg 0
Quarks	**Down** $8x10^{-30}$ kg +1/3	**Strange** $2x10^{-28}$ kg +1/3	**Bottom** $7x10^{-27}$ kg +1/3	**Photon** 0 kg 0	
	Electron $9x10^{-31}$ kg -1	**Muon** $2x10^{-28}$ kg -1	**Tau** $3x10^{-27}$ kg -1	**Z Boson** $2x10^{-25}$ kg 0	
Leptons	**Electron Neutrino** $< 2x10^{-37}$ kg 0	**Muon Neutrino** $< 3x10^{-31}$ kg 0	**Tau Neutrino** $< 3x10^{-29}$ kg 0	**W Boson** $1x10^{-25}$ kg ± 1	

Figure 9. The Standard Model.

Quarks, the first two rows of fermions, are subatomic particles that combine to make *hadrons*, like protons and neutrons. For example, a proton consists of two up quarks and one down quark (figure 10-a); and a neutron consists of one up quark and two down quarks (figure 10-b). In both particles, the gluon is the force that holds the quarks together. From there, protons and neutrons combine to form the nuclei of atoms.

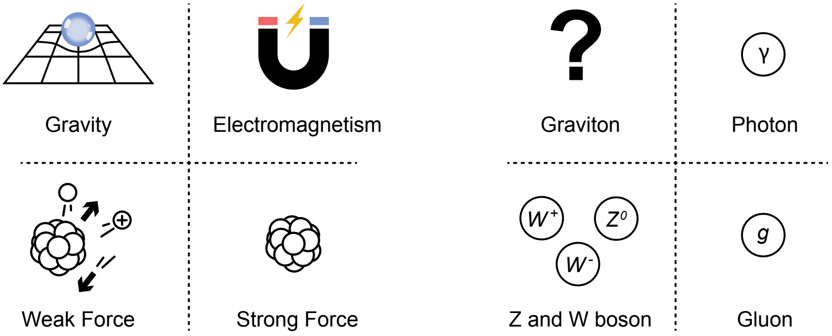


(a) Proton **(b)** Neutron

Figure 10. Quarks make up protons and neutrons.

The *leptons*, the last two rows of fermions, are the other matter particles. They have various functionalities and play a large role in radioactive decay. The most common lepton is the electron, which is usually found "orbiting" the nucleus of an atom. The electron, muon, and tau particles each have a neutrino counterpart. Neutrinos are often dubbed "ghost particles" as they seldom interact with ordinary matter.

Lastly, we have the force carrying particles (figure 11). The *photon*, or light, is responsible for the electromagnetic force. The W$^{\pm}$ and Z^{0} particles represent the weak force, responsible for atomic decay. The *gluon* is responsible for the strong force, which keeps quarks bound. There is no confirmed force particle for gravity, yet. The current hypothesis is the *graviton*. Lastly, not pictured, is the *Higgs Boson*, which is responsible for giving mass to all the fermions, except neutrinos, and the W$^{\pm}$ and Z^{0} particles.



(a) Four forces of nature **(b)** Force-carrying particles

Figure 11. The forces of nature and their force-carrying particles.

Every particle in the standard model has an antiparticle counterpart. This antiparticle shares the exact same properties as its colleague, except it has opposite charge. For instance, the antielectron, or positron, has a charge of +1. The antiproton has a charge of -1. Particles without charge, like the photon, tend to be its own antiparticle. Whether neutrinos have a distinct antiparticle is still up for debate.

UNIVERSAL EXPANSION

The universe is always expanding. This is due to dark energy, which is constant at every point in space and time. In other words, make a circle and you'll get *x* amount of dark energy. Make another circle at a different point in space and time, and you'll also get *x* amount of dark energy.

As the universe continues to expand, matter and radiation get diluted away, while dark energy density remains constant (figure 12). This means that, overtime, dark energy makes up more and more of the universe. For instance, 380,000 years after the Big Bang, there was only a trace of dark energy. Today, it is the dominant player of our observable universe, making up 68% of all energy and matter.

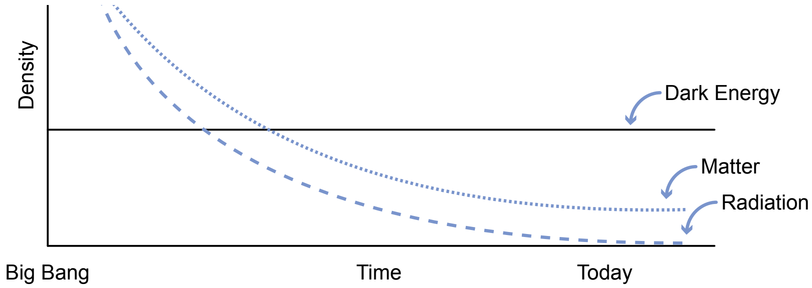


Figure 12. Over time, dark energy makes up more and more of our universe.[3]

Although the universe is constantly expanding, the rate at which it expands has changed over time (figure 13). During the early phases of the universe, where radiation dominated, the rate of expansion was accelerating. Radiation domination means the universe consisted mostly of particles moving close to, or at, the speed of light. So, early on in the universe, expansion is happening at a faster and faster rate.

Around 50,000 years after the Big Bang, matter dominated the universe; and, therefore, the expansion rate slowed down. The universe was still increasing, but it was expanding slower than before. Simply put, if one were to measure the recession velocity, or speed, of a particular object and came back to measure it again one hundred years later, one would find the velocity was now lower. Think of driving a car from point A to point B. You can either drive at a constant speed or you can accelerate or decelerate. Even if you accelerate or decelerate, you're still driving towards point B. The only thing that changes is how fast you're moving.

Then, around 4 billion years ago, dark energy became the dominant player; the expansion rate of the universe began to increase again. So, if one were to measure the recession velocity of a particular galaxy and came back to measure it again one thousand years later, one would find that the velocity was now higher. Today, dark energy makes up the majority of the universe.[4]

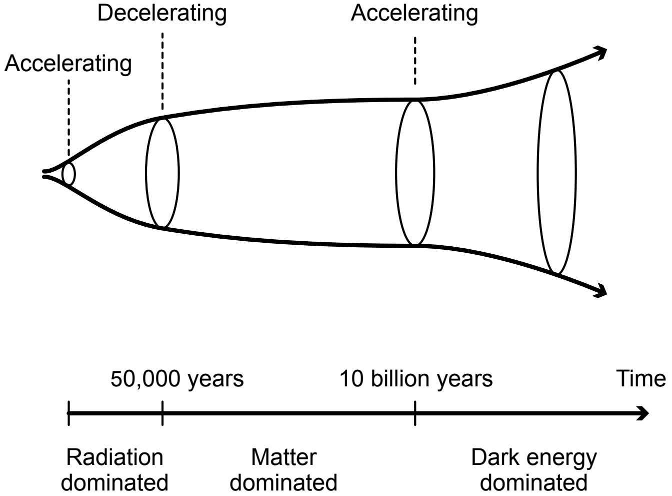


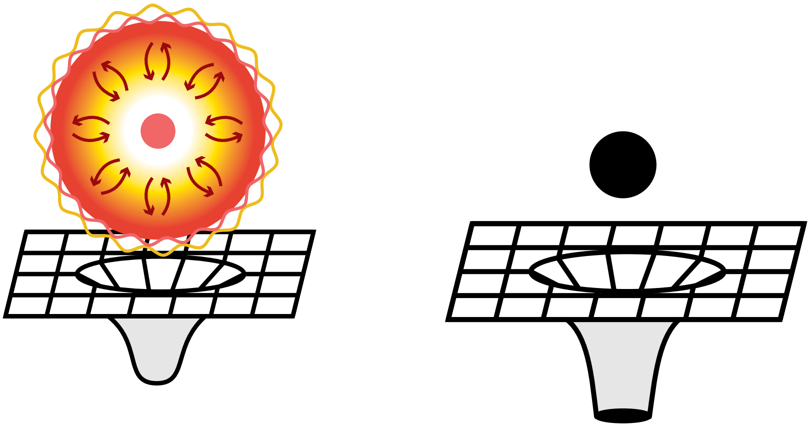
Figure 13. The universe is always expanding, but the rate of expansion has changed over time.

GENERAL RELATIVITY

General relativity dictates how spacetime curves in relation to matter. Then, the curvature of spacetime creates the illusion of gravity.

For instance, picture a taut trampoline. Placing a bowling ball on it causes a noticeable dip or curve. Now, if you were to roll marbles around this bowling ball, they would naturally be drawn towards the ball, mimicking the gravitational pull. This analogy mirrors how celestial bodies like stars, planets, and even us, humans, interact within the fabric of spacetime.

To better visualize this concept, we employ *embedding diagrams*. These are representations in hyperspace that showcase how an object influences the curvature of the space surrounding it. For instance, figure 14-a depicts a star and its impact on hyperspace. In contrast, a black hole, shown in figure 14-b, is a celestial body so dense that it punctures the fabric of spacetime. Think of it as a bowling ball so heavy that it tears through the trampoline, but instead of the fabric snapping back, the trampoline remains indented. This is the profound effect of a black hole on spacetime.



(a) Hyperspace of a star **(b)** Hyperspace of a black hole

Figure 14. Embedding diagrams of a star and black hole.

Bonus Chapter I

The First Idea Space

The book, *The Idea Space: The Science of Awakening your Non-Self*, presents a clear view that we're all different as everyone has their own perspective of the universe. In the words of the Sunset Conjecture: (a) everyone lives at the center of their own observable universe, and (b) at the center lies your idea space of uncountable depth and zero measure.

That said, even though we're all quite different from one another, there is a lot of evidence which suggests we're not that different after all. The simplest way to see this is by understanding that, at the end of the day, we're all human. We all share a common evolution.

To better comprehend this evolution, we're going to dive into the *cosmic calendar* to see if we can answer the age old question:

When did consciousness or the first idea space start?

This powerful question leads to two corollary questions: Can an idea space exist without consciousness? And, can consciousness and idea spaces exist outside of recognizable life forms?

All in all, through exploring the cosmic calendar, we'll see how your world line evolved to this point in time (figure 15). The key: the development of your world line is almost identical to the development of someone else's worldline. The only difference is a mere matter of perception.

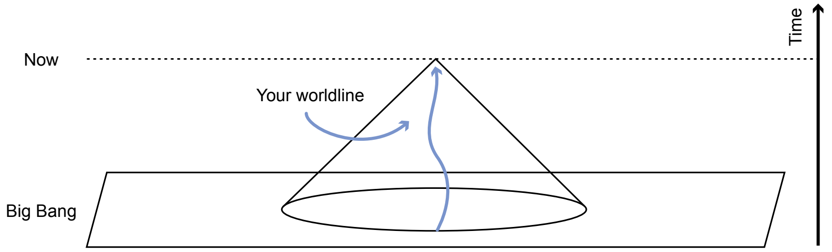


Figure 15. The cosmic calendar explains your world line up to this point in time.

THE COSMIC CALENDAR

The cosmic calendar compresses the entire lifespan of our observable universe, or 13.8 billion years, into the structure of a familiar Gregorian Calendar, serving as an awe-inspiring tool to understand and visualize the vast expanse of cosmic time. By fostering a deeper appreciation for the universe's lifespan and our brief, yet significant existence within it, the cosmic calendar allows us to see our place in the cosmos with newfound perspective. One that acknowledges we're not that different at all.

Our universe is around 13.8 billion years old. If we were to represent this age within a twelve-month framework, then each month would equate to approximately 1.15 billion years. In this scale, one week becomes ~265 million years, each day is ~38 million years, and each second represents a staggering ~438 years (figure 16).

The cosmic calendar, in all its grandeur, is depicted in the following figures 17-20. Within this compressed timeline, *Homo sapiens* arrived a mere eight minutes ago, corresponding to 200,000 years in our conventional reckoning of time.

We are able to build our understanding of the calendar through various mechanics. Since everything we observe is in the past, the vast majority of information from the early universe (13.8 billion years ago – 4 billion years ago) is accessible through telescopes. Meanwhile, most knowledge of our Earth's history (4 billion years ago – present) is gleaned from geological records, fossils, and genetic drift. As for the most recent slice of time, the final minute (2,600 years ago – present), our understanding comes from artifacts, radiocarbon dating, and DNA extraction.

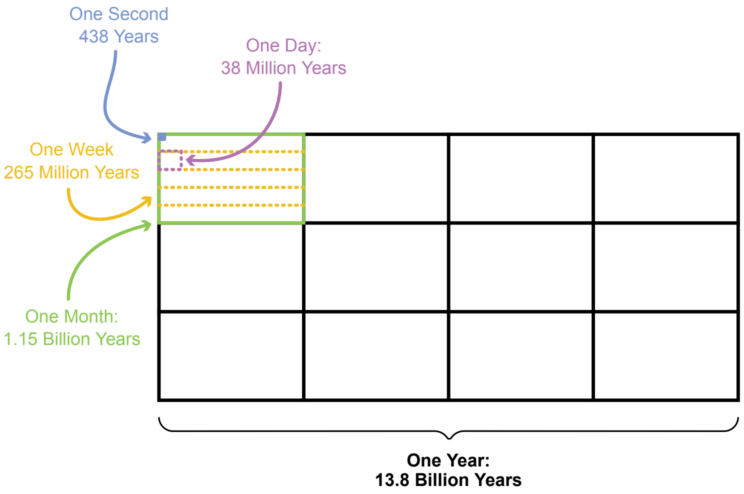


Figure 16. The cosmic calendar legend.

For reference, the remaining section headers in this chapter have the following format:*

Event Name | How Long Ago Event Occurred | Time Elapsed in Cosmic Calendar

With that framing. . . We are now entering the cosmic calendar!

Enjoy the ride. . .

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* Please note all numbers used in the cosmic calendar are approximations.

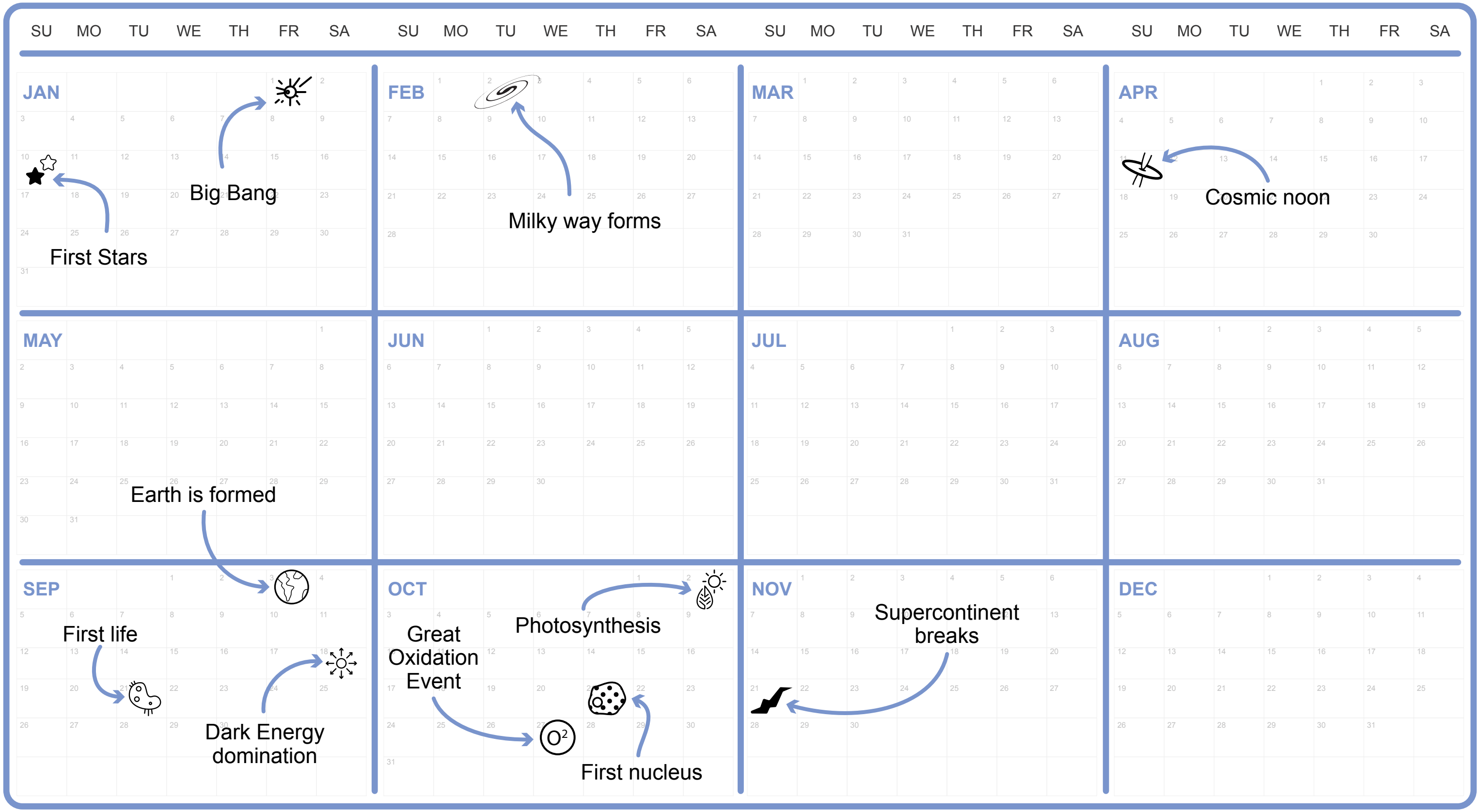
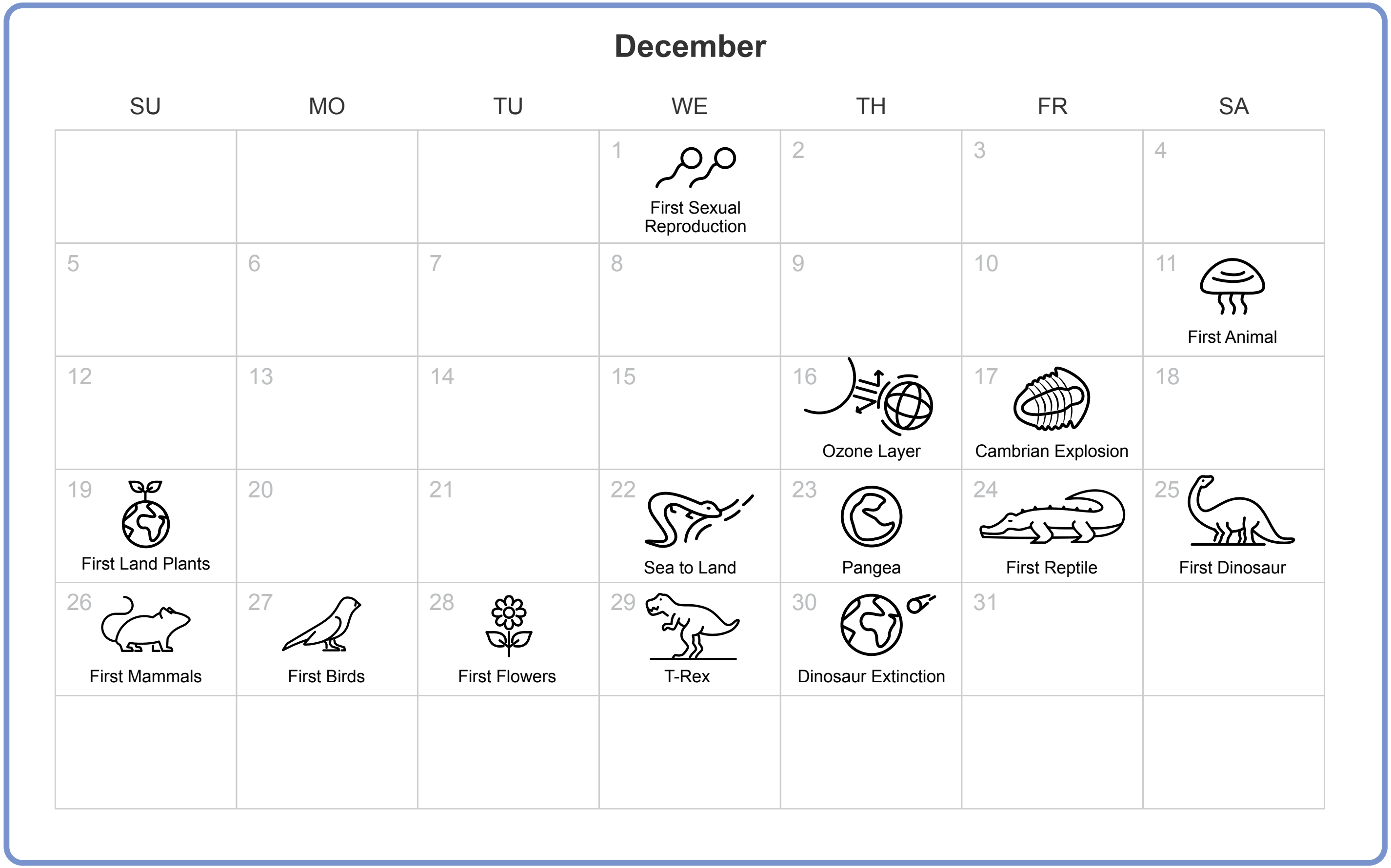


Figure 17. The cosmic calendar represents the 13.8 billion year lifespan of the universe crunched into a one calendar year.



December

SU	MO	TU	WE	TH	FR	SA
			1 First Sexual Reproduction	2	3	4
5	6	7	8	9	10	11 First Animal
12	13	14	15	16 Ozone Layer	17 Cambrian Explosion	18
19 First Land Plants	20	21	22 Sea to Land	23 Pangea	24 First Reptile	25 First Dinosaur
26 First Mammals	27 First Birds	28 First Flowers	29 T-Rex	30 Dinosaur Extinction	31	

Figure 18. December in the cosmic calendar. Only 1.15 billion years left before the new year.

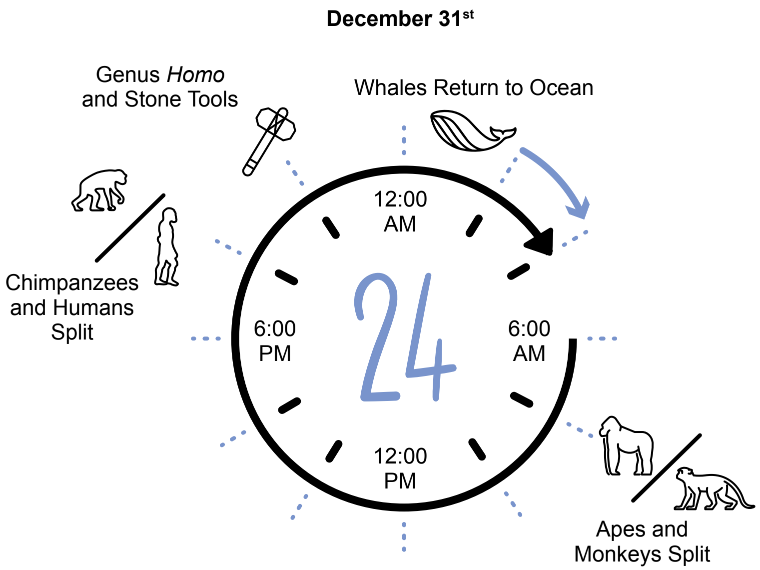


Figure 19. December 31st on our cosmic calendar. 38 million years left until the new year.

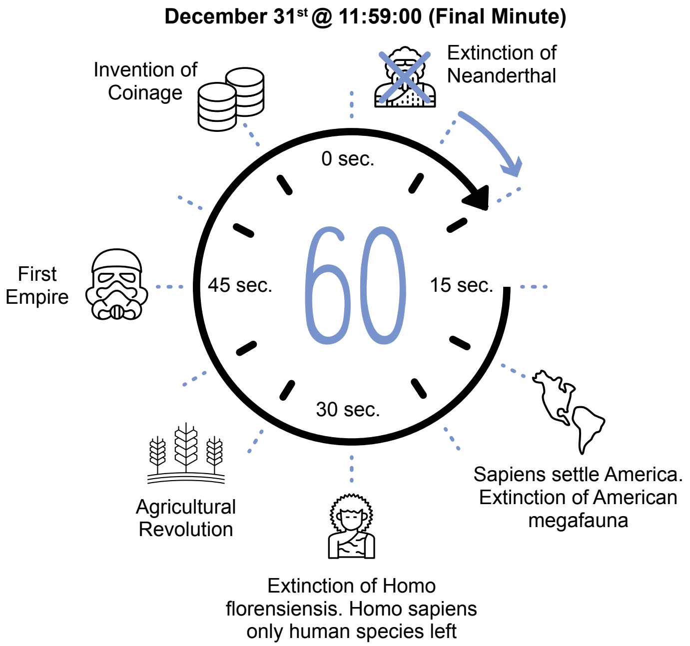


Figure 20. The last minute of the cosmic year.

BIG BANG | 13.8B YEARS AGO | 12:00 AM JAN 1st TO 12:14 AM JAN 1st

The first fourteen minutes of our cosmic calendar represent the initial 380,000 years of our universe, encompassing all the events from the birth of the universe to the emergence of the Cosmic Microwave Background (CMB). In essence, this spans the period when our universe was opaque, because it was so dense. The Big Bang is explored in great detail in Bonus Chapter II.

As for the origins of the universe, the mystery remains. Some theories propose that it began from a singularity, while others suggest the collapse and rebound of an older universe. These ideas lead to profound questions: Could the first idea space or consciousness have started here? Do universes undergo lifecycles of birth and death? Could universes themselves be considered alive?

FIRST STARS | 13.4B YEARS AGO | JANUARY 10th

The era following the Cosmic Microwave Background is often referred to as the Dark Ages of the universe since it remained devoid of visible light until the formation of the first stars. This early period is challenging to study with conventional telescopes, but the newly deployed James Webb Telescope promises to shed light on these ancient mysteries by observing the universe's earliest stars. We touch on a star's lifespan in Bonus Chapters III and IV.

Did the first idea space arrive here with the first stars? Are stars alive? It sure seems as if they are with the way we discuss their lifecycles, which culminates in their "death". Perhaps they possess a form of celestial consciousness, à la *A Wrinkle in Time*. After all, most of the star's cores contain carbon, so you could technically argue that they meet the criteria for "carbon-based life forms".

MILKY WAY FORMS | 12.6B YEARS AGO | FEBRUARY 1st

It's challenging to determine precisely when the Milky Way formed, but according to the European Southern Observatory, it likely took shape within a couple billion years after the Big Bang.[5] Many galaxies form when a supermassive star collapses into a supermassive black hole, a process that tears the fabric of spacetime and forces all nearby objects to be drawn into its gravitational pull. We explore galaxy formation in greater detail in Bonus Chapter V.

The difficulty in pinpointing the age of the Milky Way stems from the ambiguous nature of when a galaxy can be said to have "formed." Is it when the first massive star appears? When the supermassive black hole forms? Or when a certain number of stars have accumulated?[6] For other galaxies, we can observe what they looked like in their youth, because we're always looking back in time. However, since we're located within the Milky Way, it's nearly impossible to discern its appearance in its early days.

So, what about the process of galaxy formation? Could this be the moment when the first idea space emerged? Is the creation of a black hole a necessary condition for the birth of an idea space?

COSMIC NOON | 10B YEARS AGO | APRIL 11th

This is the time when peak star formation occurred, marking a moment of prolific growth and creativity in the universe. During this period, galaxies were churning out new stars at an astonishing rate, leading to a significant increase in the complexity and richness of cosmic structures. The abundance of stars and other celestial phenomena during this era contributed to shaping the universe as we observe it today. The term "Cosmic Noon" encapsulates this moment of zenith in stellar creation, a defining epoch that heralded new possibilities in cosmic evolution.

EARTH FORMS | 4.5B YEARS AGO | SEPTEMBER 3rd

Earth, along with the rest of the solar system, forms during this era. Beyond the planets of our solar system, there are two large structures of icy rocks. The first is dubbed the *Kuiper Belt,* which sits right past Neptune (figure 21). It is a flat, donut shaped object filled with millions of icy objects that orbit the sun.[7] The second, known as the Oort Cloud, is a vast spherical shell surrounding the entire solar system, containing trillions of icy objects. The inner edge of the Oort Cloud lies around 5,000 AU from the Sun, while its outer boundary stretches anywhere from 10,000 to 100,000 AU away. Is a beautiful solar system like ours the key ingredient to an idea space or consciousness?

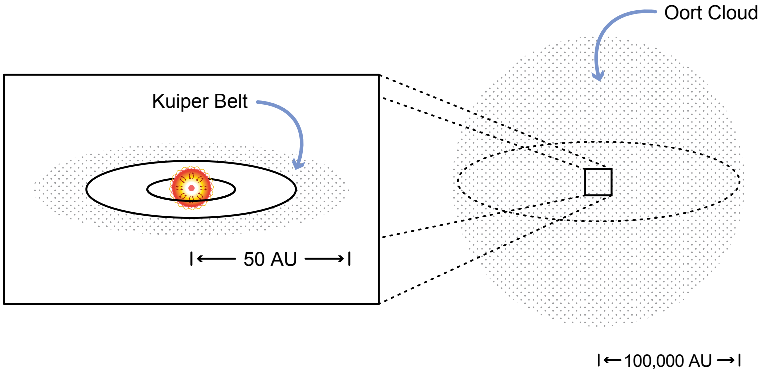


Figure 21. The Kuiper Belt and the Oort Cloud are host to billions of icy objects.

FIRST LIFE | 3.8B YEARS AGO | SEPTEMBER 21st

Ding, ding, ding! We have our first potential beginnings of an idea space! Is there any way to prove that the first life correlates to the first idea space? Probably not, but I think we could all agree that the first life *could* be the first idea space. So, what was the first life like?

To understand what the first organism could have looked like, we turn to David Sinclair's *Lifespan: Why We Age—and Why We Don't Have To.* First, imagine a planet about the size of our own, about as far away from our star, except the atmosphere is filled with toxic gasses. Now, zoom in on that planet and imagine some shallow oceans filled with salty waters surrounded by tumultuous volcanic activity. That was our Earth around four billion years ago.

Then, one day, in tiny ponds, organic molecules start acting funny and a special chemistry takes place. The world's first *ribonucleic acid* (RNA) molecule, the precursor to *deoxyribonucleic acid* (DNA), miraculously forms. This material then becomes encapsulated by fatty acids into a microscopic bubble, or shield—the first cell membrane is created.

At some point, the RNA begins to copy itself and starts to compete for dominance. Why? Because there simply isn't enough resources to go around. As Sinclair states, "May the best scum win." Then, comes a new threat: the dry season. The scums are left to survive on their own against the dry heat without the luxury of water. It is a brutal battle. Those that live on become the precursor to every living creature to come: bacteria, fungi, plants, and animals. . . Those that die are washed up in the tidal waves of history.

Out of the rubble, a unique species lives on. Sinclair calls this fictitious species *Magna superstes*, Latin for "great survivor". *M. superstes* looks eerily similar to the organisms around it, as every species alive at this time shares two genes: *gene A*, which halts reproduction when times are bad, and *gene B*, which is a silencing protein. All in all, these two genes work in tandem. When times are bad, gene A turns on to halt reproduction. When times are good, gene B silences gene A and reproduction occurs.

The majority of the species around *M. superstes* have these special powers. The kicker is *M. superstes's* gene B mutated to give it a second function: to repair DNA. Now, when DNA breaks, the silencing protein encoded by gene B leaves gene A to help repair the DNA. This will turn on gene A, which halts the reproduction of the organism (figure 22).

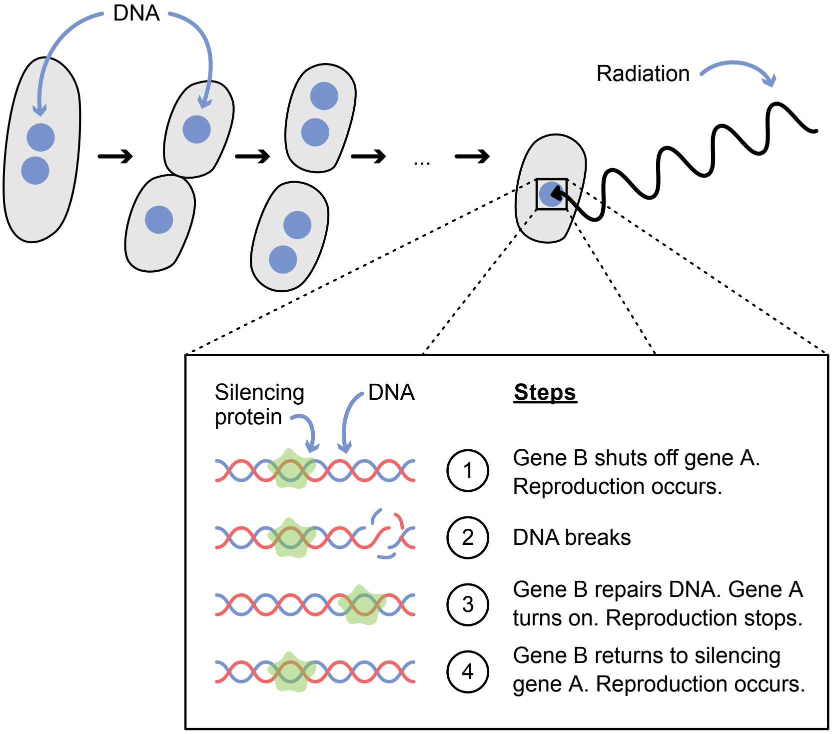


Figure 22. The reproduction cycle of our earliest ancestors, *Magna superstes.*

In short, step 1: times are good. The cell reproduces. Step 2: the DNA breaks. Step 3: the silencing protein, gene B, goes to fix the break, which halts reproduction. Step 4: the DNA is fixed and gene B goes back to silencing gene A. Reproduction continues.

Thus, *M. superstes* has developed an evolutionary advantage. It is able to repair itself in tough times and reproduce in good times. So, as the years progress and the Earth is constantly bombarded with radiation, the genes in *M. superstes* constantly evolve. Some good, some bad. Other organisms will die, but not our great survivor. It will bear the cycles of droughts and floods to eventually become us.

Of course, the idea of *M. superstes* itself is imaginative. However, Sinclair states, "My research over the past twenty-five years suggests that every living thing we see around us today is a product of this great survivor, or at least a primitive organism very much like it."[8]

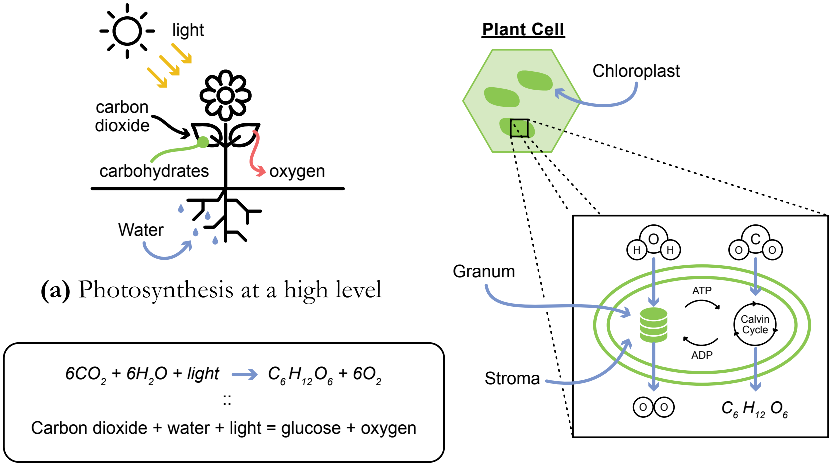
PHOTOSYNTHESIS | 3.4B YEARS AGO | OCTOBER 2nd

As we progress through this chapter, it really makes you question what "life" is. Is there a formal definition for life? Sure, there are certain "criteria" that seem to make something "alive", but the line is definitely muddied. For instance, are viruses alive? Most people say no, because it can't regulate its own internal constants, nor can it reproduce by itself—it must infest a host. That said, it does do some things that deem it "living". For example, a virus can have different levels of organization and it can adapt to its environment.[9]

Could another definition for life be anything with an *internal engine*? This makes plants "alive", because they can photosynthesize. Cows are alive because they have ruminants. Humans are alive because they have stomachs. Are stars alive because they go through a main sequence?

Overall, photosynthesis is the process by which plant cells are able to bring light, or photons, into their membrane and use it as energy. This energy then takes the form of *adenosine triphosphate* (ATP) which is the main currency of a cell. We use coins, cells use ATP.

In figure 23-a, we have the basics: a plant takes light, water, and carbon dioxide and turns it into oxygen. However, when take a deeper look, we see glucose (i.e., the sugar – $C_6H_{12}O_6$) is also produced (figure 23-b). The key to photosynthesis occurs in the *chloroplast* (figure 23-c). Chloroplasts look like giant data centers, except, instead of servers, the towers are a bunch of *thylakoid*s stacked together. The stacked thylakoids are known as *granum* and converts water (H_2O) into oxygen (O_2) and ATP. The ATP is used by the fluid around the granum, which is known as the *stroma*, to turn carbon dioxide (CO_2) into glucose and adenosine diphosphate (ADP). The latter process is known as the *Calvin Cycle* after Melvin Calvin (1911 – 1997).[10,11]



(a) Photosynthesis at a high level

$$6CO_2 + 6H_2O + light \longrightarrow C_6H_{12}O_6 + 6O_2$$

::

Carbon dioxide + water + light = glucose + oxygen

(b) Chemical forumla

(c) Under the hood

Figure 23. The process of photosynthesis in plant cells.

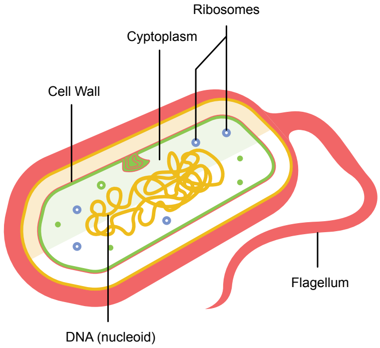
In the early days of Earth, plants didn't exist yet! So, the main culprit of photosynthesis were cyanobacteria. As we shall see shortly, this organism is extremely important, as it played a large role in bringing oxygen to the Earth's atmosphere.

FIRST EUKARYOTES | 2.7B YEARS AGO | OCTOBER 10th

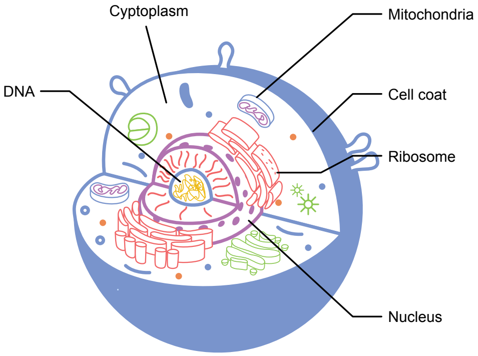
Ding, ding, ding! We have another contender for the first idea space! A *eukaryote* is a cell with a nucleus. Up to this point in time, all cells, including our dear ancestor *Magna superstes*, did not have nuclei and are dubbed *prokaryote*. Could a nucleus, the central command system of a body, be the missing link to the first idea space? If so, is our consciousness simply an amalgamation of all the different levels of consciousness of our cells, molecules, and particles?

Prokaryotes are essentially balls of DNA covered by a fluid called cytoplasm, ribosomes, and a wall (figure 24-a). Ribosomes are tiny particles that are usually associated with the formation of protein through ribonucleic acid (RNA). Think of RNA as the "messenger" that translates and carries DNA signal to the ribosomes to form amino acids and proteins. It takes the DNA, encodes it, then transports it to the ribosomes, at which point it is decoded to form proteins.[12] Prokaryotes are as basic as it gets.

Eukaryotic cells are much more complicated (figure 24-b). Instead of having DNA floating around, each eukaryotic cells have a nucleus which holds the majority of the DNA. Another vital part of the cell is the *mitochondria*. This is commonly dubbed the "power house" of the cell as it produces ATP for the rest of the cell to use. When comparing the sizes of the two, prokaryotic cells are around 0.1 to 5 micrometers (10^{-6} meters), while eukaryotes range from 10 to 100 micrometers. To put it in perspective, the mitochondria by itself is about the same size as a whole prokaryotic cell.[13]



(a) Prokaryote



(b) Eukaryote

Figure 24. A prokaryotic cell vs an animal eukaryotic cell.

At this point in time, things on Earth are starting to get more complicated. With the advancement of the eukaryotes, the kingdoms we've come to know and love are able to grow. The Animalia, Plantae, Fungi, and Protista kingdoms grew from eukaryotic cells, while bacteria and archaea grew from prokaryotic cells (figure 25). At the end of the day, all of our worldlines started with an iteration of these two fellas. Life is built exponentially, not linearly!

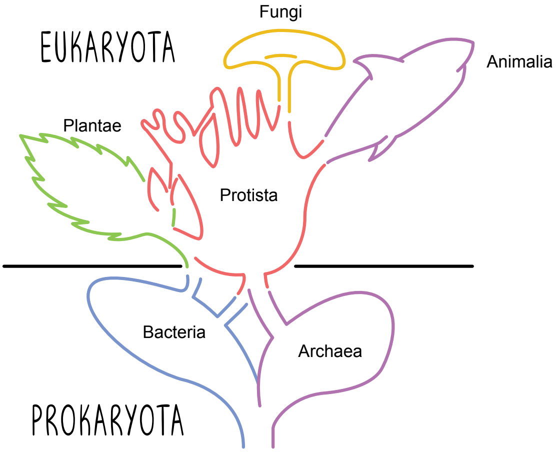


Figure 25. How "life" grew on Earth.

GREAT OXIDATION EVENT | 2.5B YEARS AGO | OCTOBER 10th

Prior to this time, the Earth's atmosphere contained very little oxygen, but our small friend, cyanobacteria, changed all that. Imagine a world where computers and AI take over—just like *Terminator*. In a sense, that's what happened here, but instead of machines, it was oxygen that became the dominant force, triggering one of the world's first mass extinction events. The rise of oxygen levels was poisonous to most anaerobic organisms, creatures that rely on CO_2 as their main source of energy, causing them to die off.[14] Then, aerobic creatures that rely on O_2 took over the world.

This extinction event laid the groundwork for a major shift in life on Earth. Oxygen, now more abundant, became one of the drivers for multicellular organism growth. This makes sense since aerobic respiration in cells produces around 36 ATP, while anaerobic respiration produces only 2 ATP.[15] With more ATP, or free energy, to go around, more sophisticated processes could occur, paving the way for the evolution of more complex life forms.

SUPERCONTINENT BREAKS | 1.5B YEARS AGO | NOVEMBER 21st

Before Pangea, there were other supercontinents. In fact, one of the earliest supercontinents was known as *Kenorland*, and it was no greater than the size of Australia. Since then, the land masses on Earth have gone through various names and forms, like *Artica*, *Atlantica*, *Columbia* (or Nuna), *Rodinia*, *Gondwanaland*, etc. This specific event here is when Columbia was one massive continent and parts of it broke off into Rodinia. In this spirit, let's explore how plate tectonics shape the Earth.

The two main reasons behind the shift in plate tectonics (figure 26). In *sea floor spreading*, there lies massive ridges, or huge underwater mountains, at the bottom of the oceans. These ridges are volcanically active regions that literally create the sea floor—hence the name, sea floor spreading. In a way, as these volcanic ridges form, they push the oceanic crust outward, thereby pushing two plates apart from each other.

As the sea giveth, the sea taketh. Far away from these ridges, near the edges of continents, another process occurs called *subduction*. Here, the heavier oceanic crust gets pushed below the lighter continental crust, creating massive trenches and recycling the crust as it gets melted away in the Earth's mantle. This constant cycle of creation and destruction is a dynamic dance happening right beneath our feet! In fact, the Earth's plate tectonics move at around 2.5 cm per year.[16] Even at this very moment, the Earth is moving below you!

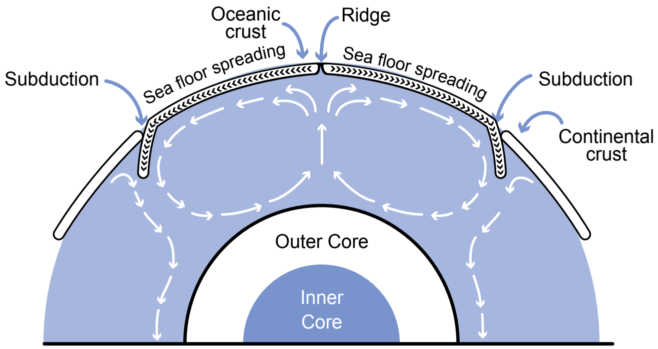


Figure 26. How tectonic plates move the Earth's crust.[17]

We are now entering the last month of the cosmic calendar!

No humans yet. In fact, no animals yet either. We don't even have dinosaurs yet. All that fun stuff happens in the last month, or in the last billion year, of our cosmic calendar.

FIRST SEXUAL REPRODUCTION | 1.1B YEARS AGO | DECEMBER 1st

The first organism to sexually reproduce is the red alga, *Bangiomorpha pubenscens*. Fossil records from Somerset Island, Canada show this red alga has *gametes*, which are an organism's sexual reproductive cells.[18] The two main forms of gametes are the classic sperm and egg.

Although these are the forms of reproduction we're most familiar with, other species reproduce in their own unique ways. For instance, in *isogamy*, which some fungi exhibit, anybody can mate with anybody else. Instead of having two different gametes, there is only one *isogamete*. Then, new individuals are formed by the fusion of two isogametes.[19] Richard Dawkins describes another interesting example of reproduction in the insect group known as hymenopteran, which include ants, bee, and wasps:

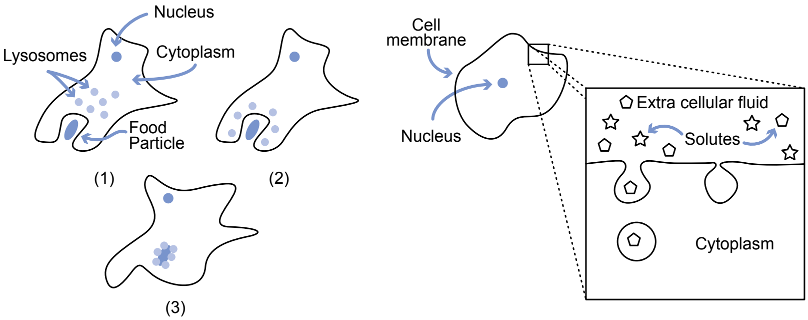
> *A hymenopteran nest typically has only one mature queen. She made one mating flight when young and stored up the sperms for the rest of her long life – ten years or even longer. She rations the sperms out to her eggs over the years, allowing the eggs to be fertilized as they pass out through her tubes. But not all the eggs are fertilized. The unfertilized ones develop into males. A male therefore has no father, and all the cells of his body contain just a single set of chromosomes instead of a double set. . . A female hymenopteran, on the other hand, is normal in that she does have a father, and she has the usual double set of chromosomes in each of her body cells.*[20]

Could the first sexual reproduction represent the birth of the first idea space? Can an idea space only form when two organisms come together to produce an offspring?

THE FIRST ANIMALS | 800M YEARS AGO | DECEMBER 11th

Fossil evidence suggest the comb jelly fish was the first animal over the sponge.[21] Yet, the first animal is still up for debate. All we know is it had to be a rather simple aquatic creature.

All animals come from eukaryotic cells. The main difference between animals, plants, and fungi are their cellular structures. On one hand, plant cells tend to have a thick cell wall made of cellulose. Furthermore, plant cells contain chloroplast for photosynthesis. On the other hand, animal cells have a cell membrane and no cell wall. To get energy, animal cells rely on “eating”, or *phagocytosis*, and “drinking”, or *pinocytosis*. In phagocytosis (figure 27-a), the cell first traps the food particle. Then, lysosomes attach and fuse with the food particle, thus resulting in the digestion of its contents. In pinocytosis (figure 27-b), extracellular fluid and solutes (e.g. nutrients) is absorbed through the plasma membrane of the cell. Maybe the reason we eat and drink is because our cells eat and drink![22]



(a) Phagocytosis **(b)** Pinocytosis

Figure 27. How an animal cell **(a)** eats and **(b)** drinks.

Lastly, fungi cells differ from plants and animals, because fungi cell walls are made of chitin, instead of cellulose. Similarly to animals cells, fungal cells are heterotrophic, meaning they take nutrition from other sources of organic carbon. In many ways, fungi are more similar to animals than plants!

Could the first animal life form represent the first idea space? Or does the first idea space exist in plants and fungi?

OZONE LAYER FORMS | 600M YEARS AGO | DECEMBER 16th

Over time, oxygen produced by cyanobacteria was abundant in the atmosphere. Light from the sun would soon break up O_2 into two single oxygens. However, oxygen doesn't like to be alone. So, the lone oxygen merged with another oxygen pair to form ozone, or O_3. The majority of ozone lies in the *stratosphere*, which sits in between six to thirty miles above the Earth's surface. For reference, the majority of human activity sits below this layer. Mt. Everest sits at about 5.6 miles high. The only thing that goes into the stratosphere are commercial planes, which fly in the lower part of it.[23] Today, the ozone layer stands as a miraculous feat of self-defense engineering, preventing harmful cosmic rays from damaging our brittle DNA.

GREAT CAMBRIAN EXPLOSION | 570M YEARS AGO | DECEMBER 17th

The Great Cambrian Explosion is one of the key milestones for life on Earth, as it marks the start of the Paleozoic Era (570 million years ago – 260 million years ago). In fact, the majority of life on Earth is split up between by Precambrian and Postcambrian explosion. Why? Because before this time, the majority of animals on Earth were quite simple: small multicellular organisms at best. During the Cambrian Explosion, many of our animal ancestors grew and diversified. For instance, one of the most common fossils found during this time are that of the *trilobites* (figure 28).[24] Could the Great Cambrian Explosion be responsible for the first idea space?

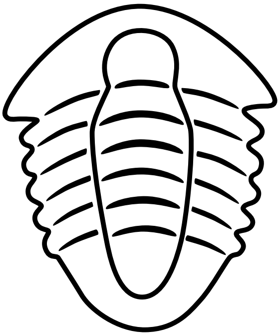


Figure 28. Diagram demonstrating the outline of a trilobite.

FIRST LAND PLANTS | 570M YEARS AGO | DECEMBER 19th

Up to this point, everything basically lived in the water. However, one day, a few brave plant souls decided to make their way onto the land masses. The exact point when land plants arrived is highly contested. For instance, it is possible that land plants arrived 700 million years ago and fungi arrived even earlier, 1.3 billion years ago.

Plants are clearly alive. But, do plants have some form of consciousness or idea space? Are they able to have thoughts or emotions? For instance, the *Arabidopsis thaliana* produces mustard oil as a defense when it *hears* the recording of a caterpillar sound.[25]

FIRST LAND ANIMALS | 380M YEARS AGO | DECEMBER 22nd

The first land animals are considered *myriapods*. These are essentially tiny, creepy crawlers, similar to centipedes and millipedes. The oldest dated fossil is that of the myriapod *Pneumodesmus newmani*.[26] Eventually, various other types of species made their way onto land such as the *tetrapod*. These are fun, amphibian like creatures that basically look like fish with feet. Some of the earliest transitory land tetrapod were the *Ichthyostega* and *Tiktaalik* (figure 29).

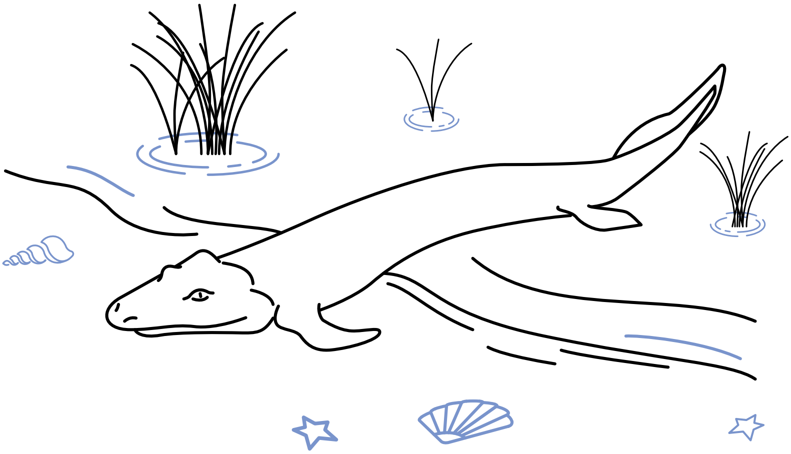


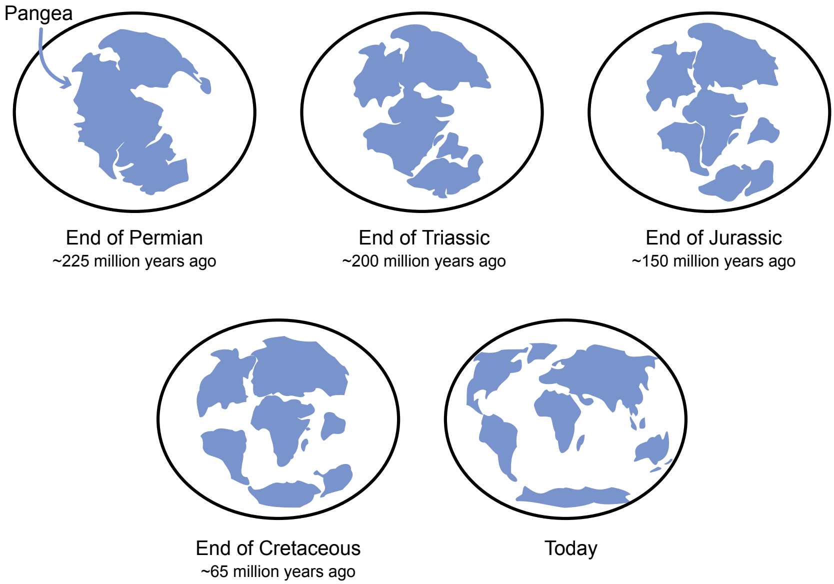
Figure 29. An image of a Tiktaalik.

PANGEA | 340M YEARS AGO | DECEMBER 23rd

Pangea is cool, because it was the latest massive supercontinent. Pangea was not the easiest place to live in. Since it was so massive, moisture of water could not reach the center of the supercontinent and made it pretty dry.

The main piece of evidence that points to Pangea lies in the similarity of fossil records in the geology of the time period. Similar species can be found deeper in the ground. When the world split, the fossil records also split. Instead of more homogenous fossil distribution, there evolved disjoint fossil patterns across various parts of the world.

As with all good things in life, Pangea itself is impermanent. After a couple million years, the plates kept shifting the land masses around until they formed the continents of today. In the figure below, we see what year each of the land masses ended. For example, Pangea ended around 225 million years ago, which demarcates the end of the Permian period and the start of the Triassic period.[27]



End of Permian
~225 million years ago

End of Triassic
~200 million years ago

End of Jurassic
~150 million years ago

End of Cretaceous
~65 million years ago

Today

Figure 30. Pangea breaking apart over time.[28]

FIRST REPTILES | 330M YEARS AGO | DECEMBER 24th

The first reptiles evolved from the now extinct genus *Hylonomous*, which looked very similar to a tiny lizard. Reptiles are cool, because they are cool-blooded: their body temperature changes with their environment. One major difference between amphibians and reptiles is around their dependency of water. For example, various amphibians lay their eggs in water (think tadpoles), which eventually develop into land creatures (like a frog). On other hand, reptiles tend to lay their eggs on land (like a snake).[29]

Could the first reptile, the ancestors to mammals, bring forward the first idea space?

FIRST DINOSAURS | 260M YEARS AGO | DECEMBER 25th

Right before the first dinosaurs, there was one of the largest extinction events of all time, known as the *Great Dying*. Here, 70 percent of land vertebrates and 96 percent of marine species disappeared from the fossil records, including our dear friends, the trilobites. The main cause of most extinction events are either asteroids, high volcanic activities due to the shifting of tectonic plates, or a combination of both. Overall, the Great Dying was one of the largest extinction events ever encountered on Earth and marks the end of the Paleozoic Era.[30]

Afterwards, the Mesozoic Era (260 million years ago to 60 million years ago) took center stage. During this time, it took a couple million years for life to recover, as reptiles and dinosaurs starting thriving across the planet. Dinosaur life is split into three periods: *Triassic*, *Jurassic* and *Cretaceous*. Each periods are demarcated by unique extinction events on smaller scales than the Great Dying.

During the Triassic period, the Earth was very hot and dry. There was neither much grass nor flowering plants, but horsetails, ginkgoes, and conifers grew abundantly. Some dinosaurs of the time include the Coelophysis (10 ft long, 44 lbs), Mussaurus (10 ft long, 330 lbs), and Procompsognathus (4ft long, 2 lbs). These dinosaurs were relatively small, as there wasn't a great diversity of dinosaurs.

During the Jurassic period, we see a larger variety of dinosaurs, including the beloved Brachiosaurus (the one with the long neck). This beast of an animal was around 77ft long and weighed over 50 tons! The increased diversity is most likely due to better climate, which created an environment filled with lush vegetation.

Lastly, during the Cretaceous period, the weather cooled more than previous periods, leading to an even larger diversity of dinosaurs. Here, we see some of the most well-known dinosaurs, including the T-Rex.

Furthermore, since the continents had broken apart from each other, each land mass was home to specific species of dinosaurs. For instance, Velociraptors have only been unearthed in China, Mongolia, and Russia, while the Triceratops has only been found in North America.[31]

Is it possible dinosaurs were the first to awaken to their idea space?

FIRST MAMMALS | 220M YEARS AGO | DECEMBER 26th

The first mammals came around the Triassic period and derived from reptiles. The transitionary animals between the reptiles and mammals are known as *Synapsids*. That said, mammals evolved to be quite different from reptiles. For instance, mammals have hair, a four chambered heart, and are viviparous (the children develop within the mother). Comparatively, reptiles have scales, a three chambered heart, and lay eggs.[32]

Could mammals be the starting point for idea spaces?

FIRST BIRDS | 190M YEARS AGO | DECEMBER 27th

The first bird is claimed to be the ancient *Archaeopteryx*, which is more dinosaur than bird. Some key factors for birds are they can fly—at least most can—and have feathers. Birds evolved from the Theropod dinosaurs, which are characterized by hollow bones and three-toed limbs.[33]

Do birds have an idea space? The way they communicate with each other would definitely make it seem as if they do.

TYRANNOSAURUS REX | 100M YEARS AGO | DECEMBER 29th

Probably the most famous of dinosaurs: the *T-rex*. The first T-rex fossil was found in 1902 in Montana. The T-rex is a fan favorite due to its size, veracity, and popular depiction in *Jurassic Park*. It is the ultimate apex predator. The first skeletal restoration of the fantastic beast was made by William Matthew and is depicted below. The T-Rex was around 39 ft long and weighed 7 tons. Each back foot had four toes, while the two front ones only had two. Furthermore, similarly to how we're on top of the food chain today, the T-rex did not have much competition from other dinosaurs.[34]

Could the mighty T-Rex, the greatest apex predator of all time, be the first to have discovered its own idea space?

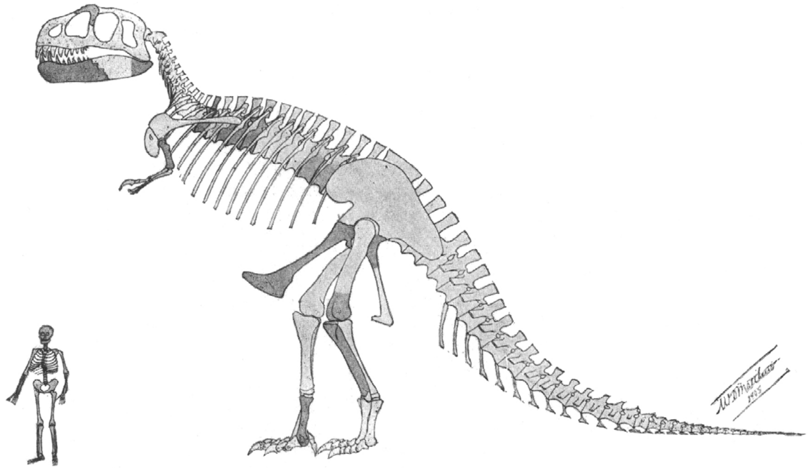


Figure 31. The first skeletal restoration of a T-rex by William Matthew (c. 1905).

DINOSAUR EXTINCTION | 60M YEARS AGO | DECEMBER 30th

This extinction event in known as the *Cretaceous-Paleogene Extinction Event.* It marks the end of the Mesozoic Era and the start of today's era, the Cenozoic Era (60 million years ago - today). The extinction event is hypothesized to be caused by a mix of volcanic activity and an asteroid that hit the Yucatan Peninsula in Mexico, which left a 180km wide crater. The crater contained a high proportion of iridium, a metal that is rare on Earth, but is abundant in outer space; and, the geology of the crater indicates the impact came at a similar time as to when the fossil records shows the extinction of dinosaurs.[35]

This massive extinction event happened *yesterday* in our cosmic calendar. We are now entering the final day of the cosmic calendar!

After this time, mammals thrived and played a large role in developing much of life as we know it.

WHALES RETURN TO OCEAN | 40M YEARS AGO | DECEMBER 31st at MIDNIGHT

Whales, in a twist of evolutionary fate, began as aquatic creatures, ventured onto land, and then made a grand return to the ocean's embrace. This cyclical journey of adaptation raises intriguing questions about nature's course. Perhaps, in the distant future, our own species might feel the pull of the waters once more.

APES AND MONKEYS SPLIT | 25M YEARS AGO | DECEMBER 31st at 8:00

The divergence between apes and monkeys is most visibly marked by the presence of a tail in monkeys and its absence in apes. This evolutionary choice, driven by habitat and lifestyle, makes one ponder the utility of such a feature. Sometimes, I wish I still had a tail.

CHIMPS AND HUMANS SPLIT | 6M YEARS AGO | DECEMBER 31st at 20:00

A mere 6 million years ago, humans came to be. For perspective, the T-rex lived for 30 million years. Humans have been around for less time than the complete lifespan of the T-rex. In other words, humans have been around for a mere four hours in the cosmic calendar. Four hours. What have you done in the past four hours? That's how new we are to the universe.

EVOLUTION OF GENUS HOMO | 2.5M YEARS AGO | DECEMBER 31st at 22:30

Every creature we've covered in this chapter can be grouped into a certain taxonomy. This classifies a living thing all the way from whether it has a nucleus or not (i.e. *domain*) all the way down to species. For example, figure 32 represents the taxonomic rank of a Red fox—*Vulpes vulpes*. Remember, life is built exponentially! We are all similar decedents from old domains.

Animals are said to belong to the same species if they tend to mate with each other to produce a *fertile* offspring. For instance, think of horses and donkeys. They are both members of the *Equus* genus; but, a mule, the offspring of a horse and a donkey, is sterile.

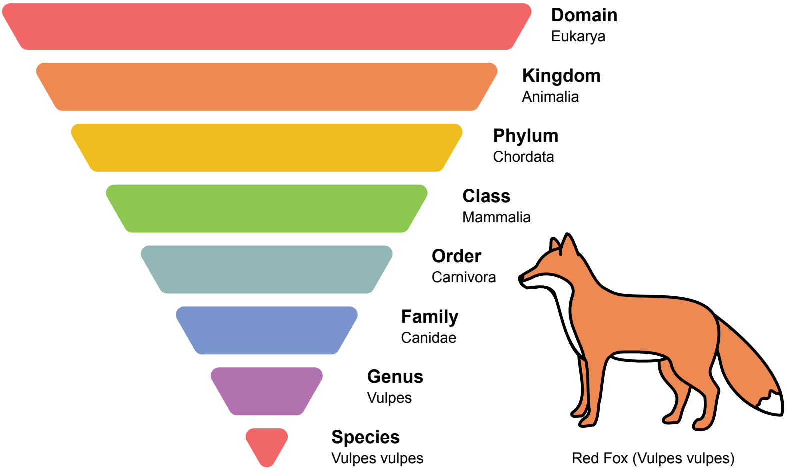


Figure 32. Taxonomic rank of a Red fox (Vulpes vulpes).[36]

Humans also fall somewhere in this hierarchy. If we follow the tree from top to bottom, then we are: *Eukarya Animalia Chordata Mammalia Primates Hominidae Homo sapiens*. Or, *Homo sapiens* ("wise man") for short. Are humans the first creatures to develop consciousness or an idea space?

HOMO SAPIENS ARRIVE | 200K YEARS AGO | DECEMBER 31st at 23:52

When the earliest *Homo* left Africa, many different species of humans evolved, including, but not limited to: *Homo rudolfensis* (East Africa), *Homo ergaster* (East Africa), *Homo erectus* (East Asia), *Homo soloensis* (Indonesian Island Java), *Homo floresiensis* (Indonesian Island Flores), and *Homo neanderthalensis* (Europe and Western Asia). With all these different types of humans, it can be tough to map out an exact evolutionary path. This includes questions such as: *Who came first? Who lead to what?* Yuval Harari, author of *Sapiens*, brings up a good point in regards to this:

> *It's a common fallacy to envision these species as arranged in a straight line of descent, with Ergaster begetting Erectus, Erectus begetting the Neanderthals, and the Neanderthals evolving into us. This linear model gives the mistaken impression that any particular moment only one type of human inhabited the Earth, and that all earlier species were merely older models of ourselves.*

> *The truth is that from about 2 million years ago until around 10,000 years ago, the world was home, at one and the same time, to several human species.*[37]

So, around 200,000 years ago, *Homo sapiens* evolved. Unsurprisingly, *Homo sapiens* shared several defining characteristics with other *Homo* relatives. Our biggest defining trait is that humans have extremely large brains compared to other animals. For instance, a mammal that weighs 130 lbs. has an average brain size of 12 cubic inches. In contrast, the smaller, earlier men and women of 2.5 million years ago had brains of about 36 cubic inches. Today, modern humans have a brain averaging 73-85 cubic inches.[38]

Why did our brain grow larger? There are many theories that try to explain why humans had such an evolutionary advantage with our brains growing the way they did. One could speculate that it probably had to do with some gene that mutated and allowed the process to propagate—similarly to *M. superstes.*

Sure, that's a great theory, but none are as fun as Terrence McKenna's *Stoned Ape Theory*. McKenna's idea is simple. Humans ingested mushrooms containing *psilocybin*—the active ingredient in magic mushroom—which propelled the evolutionary growth of our earliest ancestors. McKenna claims various human species ingested the mushrooms when they needed to look for other food sources. Under the state of the mushroom, humans were better hunters due to their ability to connect with nature. Better hunters means more food, which potentially means a higher reproduction rate.

Unfortunately, gathering evidence for this hypothesis is tricky, but, as we've seen, absence of evidence is not evidence of absence. The idea of our ancestors using psychedelics is not that foreign for two reasons: (a) other species do it, and (b) there's evidence of humans doing it throughout time. All this said, no one can precisely say why humans evolved the way they did, we can only speculate.

As we ponder the origins and evolution of consciousness, it's intriguing to consider the role of psychedelics. Might they have been a catalyst for the development of the human idea space? Terence McKenna offers a compelling perspective on this, suggesting, "Psychedelics will be to the mind as the telescope was to astronomy and the microscope to biology."

COGNITIVE REVOLUTION | 70K YEARS AGO | DECEMBER 31st at 23:57

Around this time, we start seeing the advancement of unique technologies such as boats, oil lamps, bows, arrows, and needles. Furthermore, during this time period, *Homo sapiens* were able to expand across the globe much faster than ever before. For example, around 45,000 years ago, our earliest ancestors were able to cross the open sea and land in Australia—a land never before touched by the genus *Homo*![39]

Another interesting finding around this time is the rise of fictitious language. To be clear, this don't mean communication in general. It is evident other species are able to communicate with each other. For example, killer whales communicate by producing sounds of various frequencies that can travel distances up to 10-15 km! Even monkeys have certain "signals" that allow one monkey to alert the neighboring monkeys of an incoming eagle or lion.

The main difference between these signals and fictitious languages is the fact languages allowed humans to develop social norms by communicating certain features of the tribe. *Homo sapiens* are social creates after all. The rise in this sort of communication built the necessary foundation for beliefs in various myths. Harari summarizes this well, "Ever since the Cognitive Revolution, *sapiens* have thus been living in a dual reality. On the one hand, the *objective reality* of rivers, trees, and lions; and on the other hand, the *imagined reality* of gods, nations, and corporations."[40]

These imagined realities are creations of our macro idea spaces. In other words, when personal idea spaces mix, they create a macro idea space; and, within that macro idea space, lies our imagined realities. More on imagined realities in Chapter 10 of *The Idea Space*.

We are now in the final minute of our cosmic calendar!

SAPIENS SETTLE AMERICAS | 16K YEARS AGO | DECEMBER 31st at 23:59:23

Around 16,000 years ago, *Homo sapiens* made their way to North America via Alaska, after a period of global warming melted some of the obstructing ice caps. Before their arrival, estimates showed that there were around 47 large mammals in North America and 60 large mammals in South America. During the 2,000 years it took for Sapiens to travel from the most northern point of the continent to its most southern point, 72 percent of large mammals were killed in North America and 83 percent in South America! Sabre-tooth cats, who had flourished for more than 30 million years prior to the *Homo sapiens* arrival, vanished and became extinct. So did the giant ground sloth, oversized lions, native American horses, native American camels, giant rodents, and mammoths.[41] Yikes.

The killing started, then never stopped. *Homo sapiens* not only killed large mammals of various sizes, but they also killed various other species of the genus *Homo*. Neanderthals went extinct around 30,000 years ago, and our last relative, *Homo floresiensis,* survived up to 10,000 years ago. Looks like it's just us now. . .

AGRICULTURAL REVOLUTION | 12K YEARS AGO | DECEMBER 31st at 23:59:33

Around 12,000 years ago, humans started making moves into the agricultural business. Up until this point, most humans were categorized as *hunter gatherers*. For nearly two million years, humans lived a lifestyle of constant moving in order to hunt and gather appropriate resources (with pockets of agricultural based cultures). All that changed when we realized we could grow our food in a local area.

Surprisingly, other species also have their own form of Agricultural Revolution. For instance, some ants cultivate their own "fungus gardens". The parasol ants of South America have been found to live in colonies of more than 2 million individuals. These colonies have at times even excavated 40 tons of soil to build their gardens! In these gardens, the parasol ants grow various types of fungi that helps feed and grow their brood.[42]

Yuval Harari raises an interesting point here:

> *Who was responsible [for the Agricultural* Revolution*]? Neither kings, nor priests, no merchants. The culprits were a handful of plant species, including wheat, rice, and potatoes. These plants domesticated Homo sapiens, rather than vice versa.*[43]

What an interesting thought: plants domesticating us. It is extremely informative to look at history through the evolutionary lens of other species, as we tend to look at everything through our own evolutionary lens. So, it builds perspective knowing other living creatures fight the same battle we do. A war Charles Darwin dubs the *survival of the fittest.*[*] For an example explored in the remaining Bonus Chapters, do stars fight their own evolutionary battle against the collapse of gravity?

Furthermore, the whole concept of domestication leads to an interesting questions for the idea space: *Do ideas fight this battle? If so, did we domesticate ideas or did ideas domesticate us?* With the way some imagined realities dominate our world, ideas may surely be up to something.

FIRST EMPIRES | 5K YEARS AGO | DECEMBER 31st at 23:59:48

The dawn of the world's first empires marks a significant pivot in the chronicles of human history. Civilizations, having transitioned from nomadic tribes, began to establish powerful city-states and empires. In Mesopotamia, the Sumerians constructed intricate city structures and developed one of the first written scripts—cuneiform. Meanwhile, along the fertile banks of the Nile, the Egyptian civilization flourished, resulting in the construction of the grand Pyramids of Giza. These first empires not only signified political and territorial dominance but also fostered advances in art, culture, governance, and trade. Their imprints serve as testimony to humanity's desire to connect, conquer, and create.

BUDDHA IS BORN | 2.6K YEARS AGO | DECEMBER 31st at 23:59:52

In the lap of the Indian subcontinent, Siddhartha Gautama took his first breath, destined to become the Buddha, or "Enlightened One." Born into royalty, Siddhartha's life took a transformative turn when he encountered the inescapable truths of aging, sickness, and death. These realizations drove him on a profound spiritual quest, leading to his eventual enlightenment beneath the Bodhi tree. His teachings, crystallized into Buddhism, emphasized the Middle Path—a way of life devoid of

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[*] Darwin has one of the all-time greatest koans: "When we reflect on the struggle for life, we may console ourselves with the full belief, that the war of nature is not incessant, that no fear is felt, that death is generally prompt, and that the vigorous, the healthy, and the happy survive and multiply."

extremes—and introduced concepts such as the Four Noble Truths and the Eightfold Path. The Buddha's philosophies spread across Asia, morphing into diverse branches, like Ch'an and Zen, and influencing countless lives, shaping the spiritual and cultural contours of vast regions.

ISLAM | 1.3K YEARS AGO | DECEMBER 31st at 23:59:57

In the arid expanses of the Arabian Peninsula, a monumental spiritual shift emerged that would dramatically reshape the world's religious, cultural, and political landscapes. Prophet Muhammad received revelations over a span of 23 years, which were later compiled into the holy book of the Qur'an. Islam, meaning "submission" in Arabic, emphasized monotheism, the oneness of God (Allah), and introduced the Five Pillars which guide the life of every Muslim. Rapidly spreading beyond its Arabian roots, Islam forged powerful empires like the Umayyad, Abbasid, and Ottoman, leaving behind a rich tapestry of architectural marvels, academic institutions, and sophisticated art forms. Today, it stands as one of the world's largest religions, influencing billions of lives and diverse cultures.[44]

SCIENTIFIC REVOLUTION | 500 YEARS AGO | DECEMBER 31st at 23:59:59

As the clock's hand edged closer to the end of our cosmic calendar, the world witnessed an unparalleled intellectual explosion. The Scientific Revolution was not just about the invention of telescopes and microscopes; it was a profound transformation in the way humanity perceived the universe. Figures like Copernicus, Galileo, Kepler, and Newton challenged centuries-old beliefs, proposing that the universe operated on discernible and predictable laws. These seismic shifts in understanding laid the foundation for modern physics, chemistry, biology, and astronomy. The Revolution's emphasis on empirical observation and skepticism paved the way for technological advancements that ushered humanity into an age of reason, exploration, and innovation.

Specifically, it gave rise to the Scientific Method. In other words, you build a hypothesis and test it. Once the test is finished, you either (a) reject the hypothesis, or (b) fail to reject (i.e., not enough information). At no point does a scientist "confirm" a hypothesis. Once a hypothesis withstands several tests from different angles, then it is deemed a "natural law." More on this in Chapter 10 of *The Idea Space*.

Overall, science is based on the premise of falsification. The realm of absolute truth belongs to mathematics. As Galileo eloquently put it, "The great book of Nature is written in mathematical language." This philosophical perspective heavily influenced the creation of *The Idea Space*.

YOU READING THIS BOOK | 0 YEARS AGO | JANUARY 1st at MIDNIGHT

Here you are, at the very precipice of our cosmic calendar. Every decision, discovery, battle, love story, tragedy, and triumph has led to this very moment. You, reading this sentence, seeking knowledge and connection. Your existence is the culmination of billions of years of cosmic events and human endeavors. While it might seem that you're just a tiny speck in the vast expanse of time, remember that in this present moment, you hold the power to influence the future, to continue the legacy of curiosity and exploration, and to write the next chapter in the ever-evolving story of the universe.

We are now at the end of our cosmic calendar. . .

We hope you enjoyed the ride. . .

THE FIRST IDEA SPACE?

Despite our unique experiences and diverse backgrounds, there's an intrinsic sameness in all of us—a universal connection stemming from our shared evolutionary history. Even if an idea space may differ from one person to the next, our collective journey through time highlights our shared essence. To be human means there will always be at least one thing we have in common.

In this captivating journey across time and existence, we've pondered the origins of the first idea space. Potential candidates span vast epochs: the emergence of first life (3.8 billion years ago), the formation of the nucleus (2.7 billion years ago), the advent of sexual reproduction (1 billion years ago), the rise of animals (800 million years ago), the birth of humans (6 million years ago), and the appearance of *Homo sapiens* (200,000 years ago).

These are mere conjectures; yet, as is evident, the boundaries demarcating consciousness or the first idea space are nebulous. If the origins of consciousness remain shrouded in mystery, could it have been a timeless companion? Could consciousness—or even idea spaces—transcend our traditional understanding of life?

Perhaps stars, primarily composed of carbon, possess a life-force or consciousness of their own. An ancient Zen adage proclaims, "The main cause of death is birth." In this light, might not every entity that is born and eventually dies possess an idea space? The nature of existence beyond death remains one of life's great enigmas. Graham Hancock's perspective offers solace: "Death is only the beginning of the next great adventure." Furthermore, could an idea space and consciousness have evolved separately? Perhaps the idea space initially arose as a mechanism to interpret the world, with consciousness emerging later to process this vast reservoir of perceptions through a single lens.

In closing, it's worth contemplating whether entities beyond humans—animals, plants, or any other ancient ancestor—harbor their own forms of consciousness. For example, if cells possess their own sentience, then are we a mere conglomerate of their collective awareness? In other words, is our perspective of our own personal idea space simply what a cell would perceive to be their macro idea space (figure 33)? In the same vein, is our macro idea space, responsible for our governments, religions, laws, and other imagined realities, the personal idea space of a greater cosmic entity?

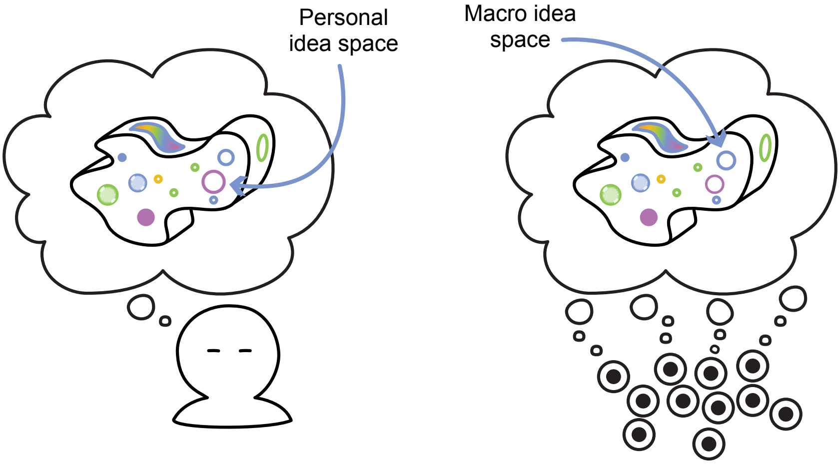


Figure 33. Is our personal idea space the macro idea space of cells?

Bonus Chapter II

Big Bang: Sunset Singularity

In Chapter 9 of *The Idea Space*, we discovered your idea space mirrors the vast expanse of your universe. Just like stars bend spacetime, ideas can shape your idea space. Moreover, in Bonus Chapter I, we touched on key milestones, such as the Big Bang, star formation, black holes, and the emergence of galaxies, in our cosmic calendar.

Therefore, a deeper exploring of the aforementioned topics complements both Chapter 9 and Bonus Chapter I. Bonus Chapter II zeroes in on the Big Bang, while subsequent chapters illuminate the remaining topics of stars, black holes, and galaxies. As stated in Bonus Chapter 0, having read *The Idea Space* will help facilitate this conversation. Some of the text from the book is repeated in the appropriate sections to provide cognitive ease.

To frame this chapter, according to the Sunset Conjecture, everyone is at the center of their own observable universe and experiences their own *Sunset Singularity*. Your observable universe is a giant sphere centered on you, where everything you see is in the past, because it takes time for light to go from point A to point B, even at 186,000 miles per second (see Chapter 6 in *The Idea Space*). Furthermore, if everything we see is in the past, then the edge of our observable universe is its beginning, or its creation: the *Big Bang*. So, the Sunset Conjecture postulates that the gravitational effects of the Big Bang are unique to everyone, similarly to how a sun can set on two people simultaneously. This is what is meant by Sunset Singularity: everyone has their own perspective of the Big Bang, or their own perspective of the beginning of their own observable universe.

HOT BIG BANG MODEL

No one knows how the universe began exactly. We have some ideas, but the first 10^{-10} seconds of the universe remain an enigma. There are plenty of theories, which we shall explore here, but none are set in stone, as it's difficult to get observational proof for much of what is happening early on in the universe.

We therefore have to rely on models; and, the *Hot Big Bang Model* constitutes an approximation of the first fourteen minutes of the cosmic calendar, or the first 380,000 year of our universe. A lot happened during this time. As a wise physicist once said, "More happened in the first three minutes of the universe than the remaining 13.8 billion years." So, this chapter will cover everything from the Big Bang (time zero) to Recombination (380,000 years after the Big Bang), which is where, and when, our Cosmic Microwave Background (CMB) is (figure 34).

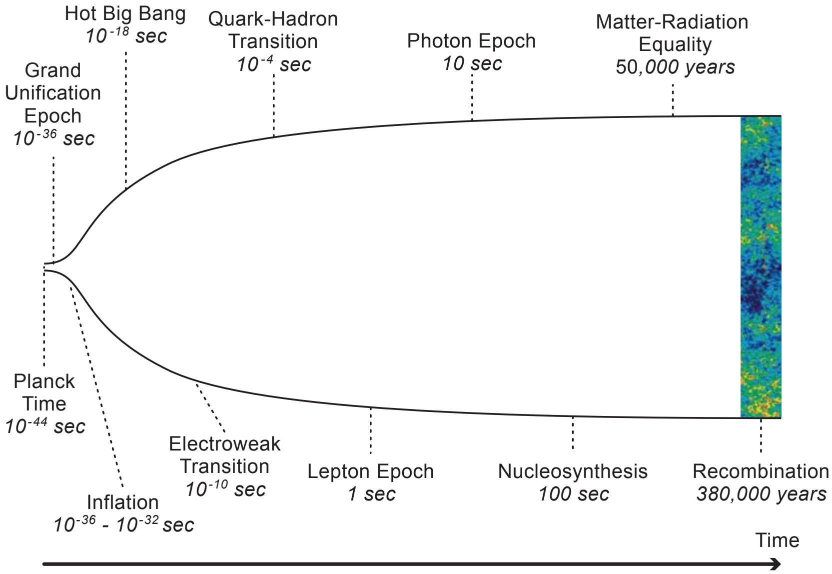


Figure 34. The early history of the Big Bang: 12:00 AM January 1st, 2021 to 12:14 AM January 1st, 2021 on our Cosmic Calendar..

This model is termed the Hot Big Bang Model, while the Big Bang itself is simply the point where time starts. If you remember from the main text, the Cosmic Microwave Background is a sort of wall, which prevents light from inside of it to escape and reach us. So, you may be thinking to yourself, *how do we know what happened before that time period, if light from that time can't reach us?* Well, physicists can create scenarios in the laboratory that resemble the earliest stages of the Big Bang back to the Electroweak Transition, at around 10^{-10} seconds. Up to that point, physicist are pretty confident as to what happened; but, before that time, it remains highly theoretical.[45] As we proceed throughout this chapter, we'll fill the gaps in this figure to build a complete mental model of the Hot Big Bang.

The following events are labeled with the name of the event, time after the universe started, and the corresponding temperature (in Kelvin), if applicable. Explicitly,

Event Name | Time after Big Bang | Temperature

To convert Celsius to Kelvin, simply add 273. For instance, 23C is 296K. As we shall see, the early universe is very hot! For reference, the center of the sun is around 10^6 K, and the universe 10^{-44} seconds after the Big Bang is around 10^{32} K.[46]

Lastly, it is worth re-iterating *these numbers are approximations*. As Richard Feynman said, "In order to understand physical laws, you must understand that they are all some kind of approximation." The numbers are more-so there to give you a sense of the magnitudes, while the flow is key.

BIG BANG | 0 SECONDS | ? K:

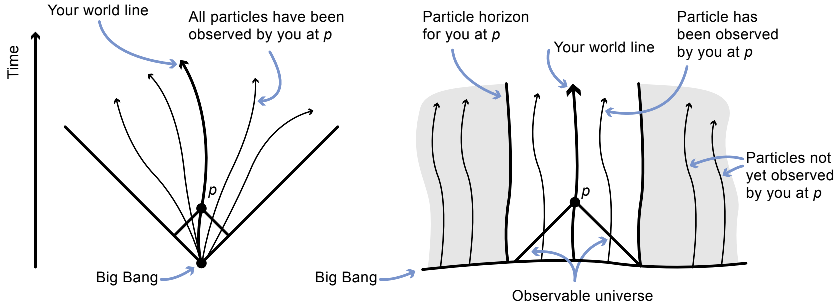
Ahhhh… The Big Bang…

What existed before the Big Bang? No one knows. The first idea is nothing existed before our universe. Then, all of a sudden, a random "gravitational quantum fluctuation" caused the birth of our universe. Something came out of nothing. A *singularity* occurred.

A singularity is a point where general relativity breaks down, which explains why no one knows exactly what happened. As physicist Stephen Hawking aptly states, "The singularity is outside the scope of presently known laws." The main idea behind this singularity is a potentially infinite, "space-like" surface. In other words, the Big Bang happened everywhere, all at once. BOOM.

The key to a space-like surface is it creates a *particle horizon*. To better understand this, let's look at an example and bring back our light cones and event *p*, our present moment in spacetime, from Chapter 6. As we saw there, the bottom edge of the light cone is your observable universe, which gets larger as it flows upward through time. On one hand (figure 35-a), we have a fictional universe created from a point. In this instance, you can see the history of all the particles that exist—all the particles have been observed by you. On the other hand (figure 35-b), the Big Bang is an infinite, space-like surface. You *haven't* seen the history of all the particles that exist. As you move up in time, you are continuously exposed to more and more particles.

In truth, your universe acts like figure 35-b, with a particle horizon. The particle horizon represents the limit of the observable universe, the Big Bang, beyond which you cannot receive any information. The beauty of the particle horizon is stated in the following paragraphs.



(a) The Big Bang as a point. An observer has seen all existing particles

(b) The Big Bang as an infinite space-like horizon. An observer has yet to see all existing particles

Figure 35. The Big Bang singularity is hypothesized as an infinite space-like surface with a particle horizon.

Everything we see is in the past. Looking at the stars is like looking back in time; the light we see had to travel a long way to reach us. This means the edge of our observable universe is the Big Bang, the very beginning of time. So, the Big Bang didn't just happen—it is still happening everywhere, right now. In other words, the universe is always being created, and its creation impacts you uniquely.

Furthermore, as we saw in the fractals chapter (Chapter 5), it is impossible to pinpoint exactly where we start and where we end. Thus, your Non-Self includes every unique layer of your entire observable universe, all the way to the Big Bang, the outermost layer.

This brings us to a beautiful insight: Your Non-Self is in a state of perpetual renewal, because your unique perspective of the Big Bang, your "Source", is constantly being created. In essence, as the universe continues to unfold, your Non-Self is continually rebirthed. This ongoing process gives you the opportunity to constantly reinvent yourself. In this ever-evolving cosmos, your Non-Self is always a work in progress.

So, if the greater universe started out as this infinite, spacelike surface, then what did our observable universe look like at time zero, or at the Big Bang? Well, according to Stephen Hawking, our observable universe must have started with zero measure to evolve in a qualitatively similar manner. Thus, a fantastic mental model for our presently observable universe as it was during the Big Bang is a topological singularity (see Primer and Chapter 4), which is represented as the uncountable points of Cantor Set condensed into a single point (figure 36). In other words, it is possible—though not definite—that our observable universe started out as nothing, ∅, then turned into something.

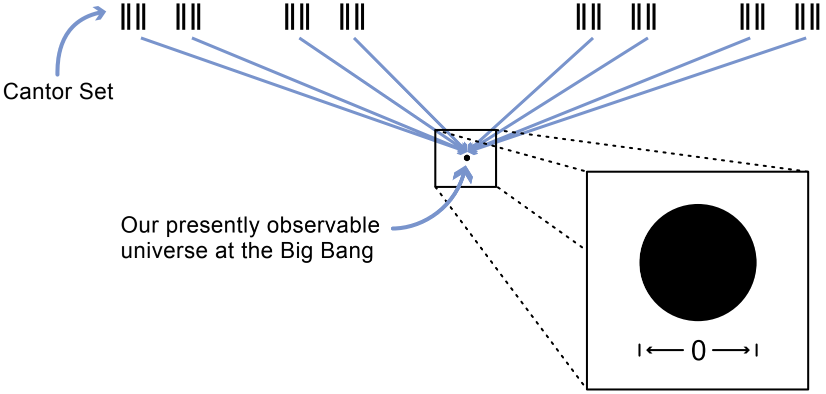
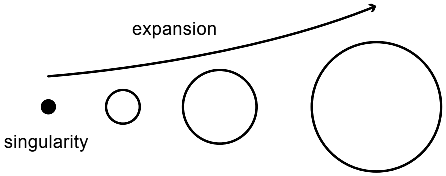
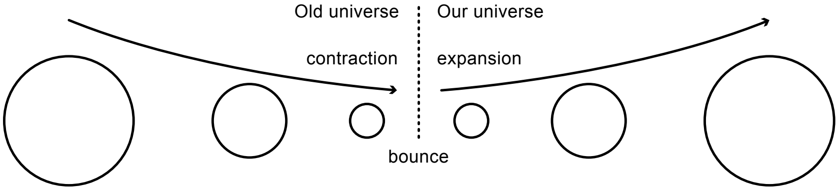


Figure 36. During the Big Bang, the region of spacetime, which eventually grew to become our presently observable universe, can be represented as a topological singularity.

The universe starting out as nothing, then growing into something is one possibility (figure 37-a). Another possibility is the Big Bang wasn't actually a singularity, but instead a sort of "re-bound" from an old universe re-bounding to create ours (figure 37-b). In other words, another universe existed before ours that contracted to a small-enough size, skipped the singularity, and re-bounded to create our observed universe. All in all, the only thing we know for sure is no one knows how the universe started.



(a) A cosmological model where our universe starts as a singularity



(b) A cosomological model where our universe starts as a bounce

Figure 37. Potential beginnings of our universe.

For our mental model, we'll assume something came out of nothing and use the symbol for a topological singularity—the uncountable points of the Cantor Set crushed into a single point—as our first visualization (figure 36). That said, it is important to understand it is not a definite truth.

PLANCK TIME | 10^{-44} SECONDS | 10^{32} K

In everyday life, there are seven base units: length (meters), mass (kilograms), time (seconds), amount of chemical substance (Mole), electric current (Amperes), temperature (Kelvin), and luminosity (Candela). Max Planck (1858 – 1947) thought differently. Instead, he believed these units could be represented by the four fundamental units of the universe: speed of light (c), Newton's gravitational constant (G), reduced Planck constant ($\hbar$), and Boltzmann constant (k_b). For instance, you can rearrange the first three fundamental constants to obtain what is known as Planck time:

$$Planck\ Time, t_p = \sqrt{\frac{\hbar \cdot G}{c^5}} = 5.4\times 10^{-44} seconds.$$

Planck time is to the universe as seconds are to humans. In the form of an analogy:

Planck Time : universe :: seconds : humans.

You can rearrange the fundamental units in other ways to get Planck Length, Planck Mass, etc. (see supplemental material to *The Idea Space*).

For Planck Time, or 10^{-44} seconds after the Big Bang, there's two things you have to know: (1) no one knows for sure what is happening here, and (2) it is hypothesized that gravity broke off from the other forces at this time. In other words, the four primary forces—gravity, weak, strong, and electromagnetic—were once unified; and, at Planck Time, gravity broke off from the rest. So, gravity is its own thing at this point in time, while the weak, strong, and electromagnetic forces are unified as one force. More on the concept of forces breaking in the Grand Unification Epoch section, covered next.

Let's return to the visualization of our universe. First, we remember the universe is always expanding. Second, some time has passed. So, our observable universe has grown from having zero measure to some measure (figure 38). As for numbers, some estimates by physicists Edward Kolb and Michael Turner put the diameter of the presently observable universe during this time at around 3.5×10^{-3} cm.[47]

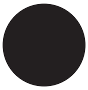


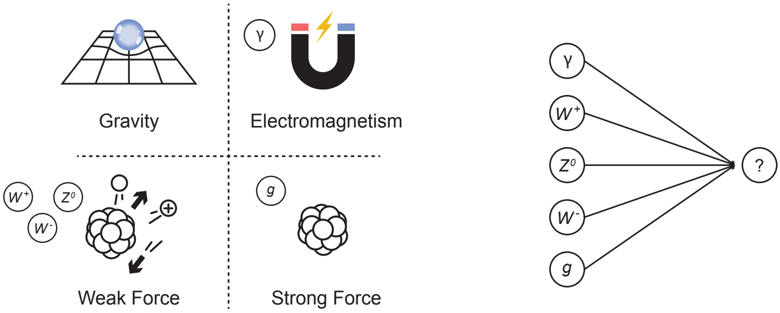
Figure 38. Our presently observable universe as it was during Planck time.

GRAND UNIFICATION EPOCH | $10^{-44} - 10^{-36}$ SECONDS | $10^{32} - 10^{28}$ K

After the Planck Time, we enter the Grand Unification Epoch, associated with the Grand Unification Theory (GUT). It bears resemblance to the Theory of Everything (TOE), but with a distinct difference: TOE aims to explain why all four fundamental forces were unified at the universe's inception; GUT seeks to describe the unification of the electromagnetic, weak, and strong forces. Thus, TOE concerns events up to the Planck Time, while GUT is applicable right after.

For further context, our universe operates under four distinct forces: gravity, electromagnetism, the weak force, and the strong force. These forces are represented by specific force-carrying particles (Figure 39-a). Electromagnetism has a photon (γ), or light. The weak force has three associated particles: the two $W^{\pm}$ bosons and the Z^0 boson. The strong force has the gluon (g). Lastly, gravity has no particles assigned to it, because quantum theory does not yet have a method for describing gravity. There is a semi-theorized particle, called the graviton, but we'll set it aside until the challenge of *quantum gravity* is solved.[*]

Before the Planck Time, these forces were indistinguishable. Yet, post-Planck Time, gravity diverged, setting the stage for the gravity we're familiar with. This division is termed *symmetry breaking*. The ensuing Grand Unification Epoch witnessed the unification of the photon, and bosons, and the gluon were all one (figure 39-b). Furthermore, during this epoch, leptons and quarks too were unified into one particle.[48]



(a) Four forces of nature and their particles

(b) During GUT, the photon, W$^{\pm}$, Z^{0}, and gluons were all one

Figure 39. **(a)** The four main forces and their particles. **(b)** During Grand Unification Epoch, the photon, W$^{\pm}$ and Z^{0} bosons, and the gluon were all one.

The remaining three forces all broke off at various junctures, which we'll explore as our timeline progresses. The phenomena of symmetry breaking is best described by Stephen Hawking in *A Brief History of Time*:

> *The effect is rather like the behavior of a roulette ball on a roulette wheel. At high energies (i.e. when the wheel is spun quickly) the ball behaves in essentially only one way—it rolls round and round. But as the wheel slows, the energy of the ball decreases, and eventually the ball drops into one of the thirty-seven slots in the wheel. In other words, at low energies there are thirty-seven different states in which the ball can exist. If, for some reason, we could only observe the ball at low energies, we would then think that there were thirty-seven different types of balls!*[49]

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[*] You must remember that gravity is an illusion caused by the curvature of spacetime. So, solving quantum gravity is like asking the profound question: What is the fabric of spacetime?

Those "37 different types of balls" are a representation of our various types of forces. At low energy states, the forces all seem different from each other. At higher energy states, they all look the same. Since the early universe was at a much higher energy state than it is today (i.e., it was hot), everything looked the same. Put another way, at this point in time, the energy levels of the early universe are too high for there to be "atoms".

Let's continue our visualization. The universe looks awfully similar as to before, except gravity has gone rogue. As always, the universe is expanding, so let's represent our presently observable universe as it was during GUT with a slightly larger circle.

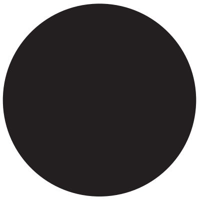

Figure 40. Our universe during the Grand Unification Epoch.

INFLATION | 10^{-36} – 10^{-32} SECONDS | 10^{28} K

The universe, as we've come to understand, is perpetually expanding. During inflation, the universe as a whole experienced a dramatic burst of growth. This phenomenon was first explained by Alan Guth in the 1980s.[50] During this brief interval, the universe expanded at an astounding rate, with some speculating that inflation increased the size of our universe at least by 10^{26} fold.[*,51] Physicist Sean Carroll humorously likens this inflationary period to the effects of "super-dark energy," given its similarities to regular dark energy, but with significantly higher energy density.[52]

So, why is this concept of inflation so pivotal? There are many reasons, but one of the primary ones is that it offers a solution to the *Horizon problem.*

Here's the quandary: observations of the Cosmic Microwave Background (CMB) show that distant points are virtually at the same temperature. Yet, points on opposite ends of the CMB are beyond each other's past light cones. So, how can they share the same temperature if no signals were exchanged between them (figure 41-a)? Isn't there a particle horizon between the two points (figure 41-b)?[53]

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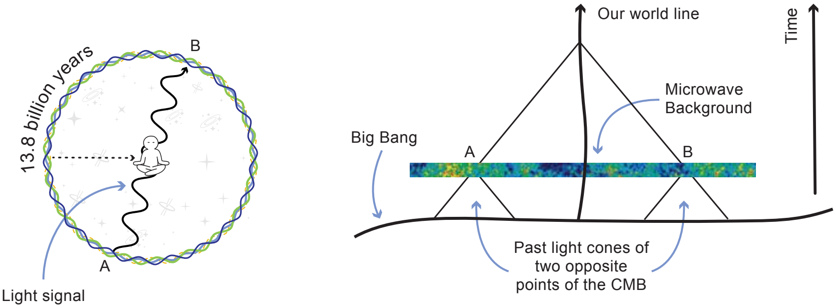
[*] 10^{26} is the length increase. So, the volume increased $(10^{26})^3 = 10^{78}$!



(a) How does a light signal from A reach B, if the signal from A just reached us?

(b) How does light from A reach B, if they have non-overlapping past light cones?

Figure 41. The *Horizon Problem*: How can a signal from one side of the cosmic microwave background be sent to the other side if they are each outside the other signal's particle horizon?

Assuming an inflationary period early on in the universe fixes this problem. Namely, prior to the inflation period, points that were initially quite close get pushed far apart. In our example, A and B were once much closer together and therefore were able to "share" similar conditions.[54]

Besides the Horizon problem, inflation also provides insight into the *flatness problem*. On vast scales, the universe appears notably "flat" or "smooth." An apt analogy is a crumpled picnic blanket. When you stretch it out rapidly, it smoothens out. A similar experience occurred early in the universe with inflation. In other words, the universe stretched out rapidly, thereby potentially explaining its current "smooth" appearance, barring the gravitational wells of nebulas and galaxies.[55]

Furthermore, recalling our earlier analogy of the roulette wheel, during inflation, the strong force separated from the other fundamental forces, resulting in gravity and the strong force becoming distinct entities.[56] Meanwhile, electromagnetism and the weak force remained intertwined, collectively known as the *electroweak force*. As the division of the strong force unfolded, quarks and leptons emerged as independent particles as well.

To better visualize inflation, consider the universe transitioning from the Grand Unification Epoch to the post-inflationary period, undergoing a massive transformation (Figure 42).

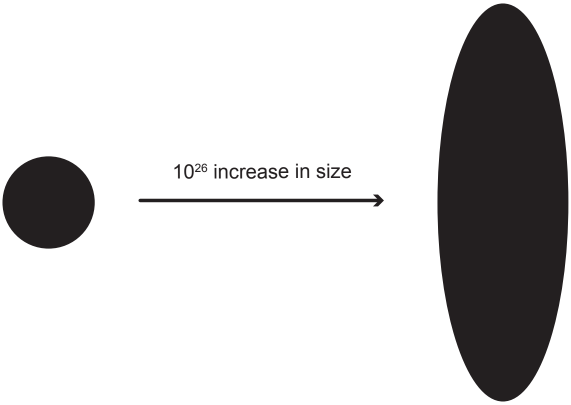
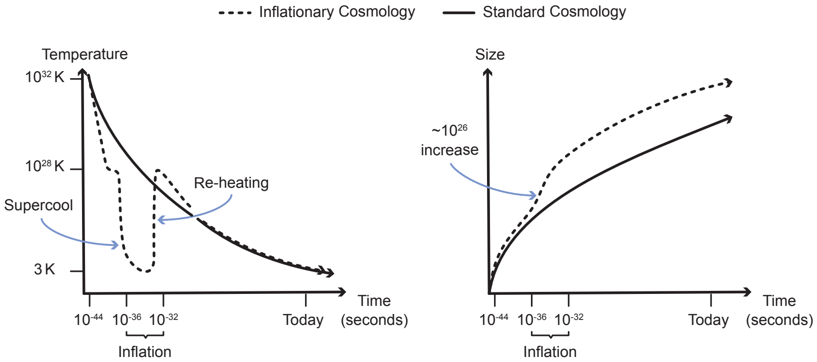


Figure 42. A visualization of our early universe transitioning from the Grand Unification Epoch (left) to post inflationary period (right). The universe may have increased by at least 10^{26} folds during this extremely short period of time; and, the strong became its own force.

HOT BIG BANG | 10^{-18} SECONDS | 10^{19} K:

Hot Big Bang? Doesn't our universe simply get cooler as it expands? According to standard cosmology—yes. However, with inflation, things are a bit different. Essentially, during the inflation period the universe *supercooled* (figure 43-a) and expanded greatly (figure 43-b). Then, as soon as inflation ended, the universe got hot again, almost instantaneously, to temperatures reminiscent of pre-inflation.



(a) Temperature of the universe (inflationary vs standard)

(b) Size of the universe (inflationary vs standard)

Figure 43. Inflationary cosmology vs standard cosmology.[57]

So, why did the universe heat back up? After inflation ends, the field that caused inflation, imaginatively called the *inflaton*, converted its energy into a thermalized gas of matter and radiation. This process is called *re-heating*. [58]

It's tough to pinpoint exactly what's around during this time, but there seems to be a dominant sea of quark/antiquark pairs often dubbed *quark-gluon plasma*.[59] By definition, a plasma has equal mixture of positively and negatively charged particle within a volume of interest.[60] Thus, although there might be local pockets of positively and negatively charged areas, the universe as a whole tends to be neutrally charged.

At this stage of the universe, everything seems to be interacting with everything. Therefore, the universe this early on is said to be in *thermal equilibrium*.[*] As a good rule of thumb, thermal equilibrium occurs when the interaction rate between particles is greater than the expansion rate.[61] In other words, particles are colliding more often than they are given a chance to roam around freely. This is in part why the universe was opaque for so long! If particles, like light, are continuously interacting with other particles, then light can't really travel across great distances. Imagine the universe as a giant pinball machine with endless bumpers. There's nowhere to go! As we progress forward in time, this thermal equilibrium will break as the universe continuously expands and cools, thereby allowing particles to roam freely.

Let's continue our visualization with the Hot Big Bang. Well, we know it's hot during this time. If it's hot, then there's a lot of energy. High energy means everything mushes together in thermal equilibrium and looks completely opaque. Oh, and did I mention it was hot? For our mental model visualization, we'll keep it simple. Let's just make it hot (figure 44).

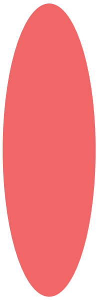


Figure 44. Visualization of the Hot Big Bang at 10^{-18} seconds.

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[*] As noted by physicists Edward Kolb and Michael Turner, it's mathematically impossible for the universe to be in *perfect* thermal equilibrium. For practical purposes, it is said to be in *local thermal equilibrium*.

ELECTROWEAK TRANSITION | 10^{-10} SECONDS | 10^{15} K

Up until this point, our story has been extremely theoretical and abstract, because most tests in the laboratory can only collide particles together at energy levels reminiscent of the electroweak transition. So, everything from the electroweak era on out can be tested in a laboratory!

During the electroweak transition, we finally see the electromagnetic and weak forces split (i.e., roulette wheel example). Up until this point, the energy levels were so high that the electromagnetic force and the weak force were one in the same. But, with the continued expansion of the universe, enough cooling had occurred for the two forces to split up. So, at this point in time, all the forces are finally split up to represent the four common forces of today.

The breaking of electroweak symmetry leads to another interesting phenomenon, known as the *Higgs mechanism*. At energy levels, or temperatures, higher than the electroweak transition, elementary particles are considered massless, so they move at the speed of light. However, after this symmetry breaking, most fermions (i.e., quarks and leptons other than neutrinos) and the and   bosons finally gain their mass by interacting with the Higgs particles. So, as particles gain mass, they can finally move slower than the speed of light.[62] Thereby setting the stage for structure formation (e.g., nebulas, stars, etc.) throughout the cosmos.

Due to the joy experienced from seeing all the forces finally split up, we can use that as our visual mental model of the universe (figure 45). And, as always, the universe is still expanding.

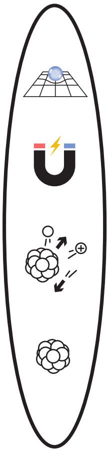
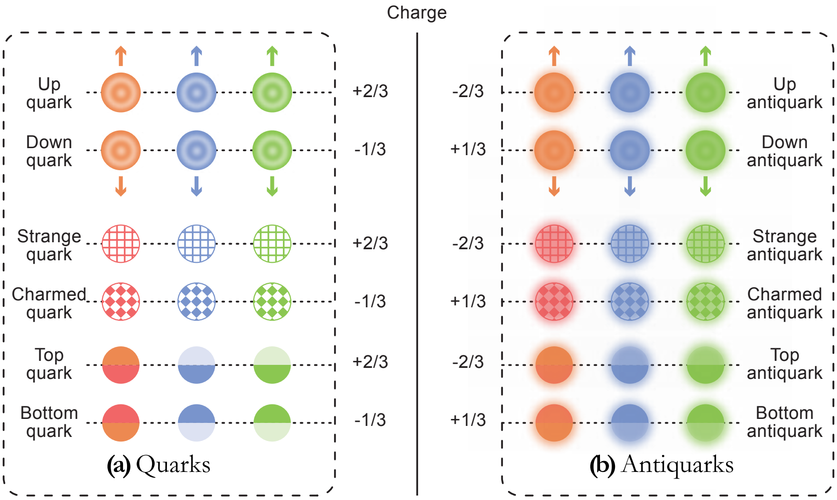


Figure 45. The universe during the electroweak transition. Finally, the temperature is low enough for the four forces split up.

QUARK-HADRON TRANSITION | 10^{-4} SECONDS | 10^{12} K

About 10^{-4} seconds after the Big Bang, the universe had cooled enough for quarks to start forming into *hadrons*. Hadrons are anything that quarks make up, like protons, neutrons, and more exotic particles, like mesons. To ground this concept, when we're talking about the Large Hadron Collider (LHC) at CERN, we're talking about launching particles made up of quarks at very high speeds towards each other. Quarks are pretty cool, so let's talk about them in a bit more detail.

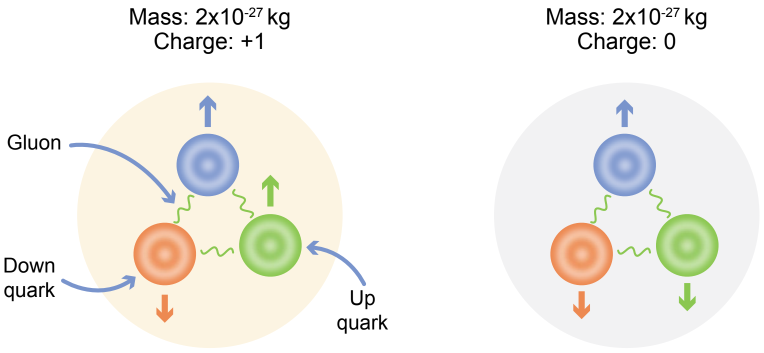
There are six different "flavors" of quarks, including: up, down, strange, charmed, bottom, and top. From there, each flavor comes in three different "colors": red, green, and blue. Please note this is not the same thing as the red, green, and blue we see—it's just a grouping physicists use. The reason we use the colors is because when quarks combine, they tend to produce a neutral white color. The quark family is represented in the below figure—and, yes, all these quarks have anti-quarks (anti-up, anti-down, etc.) and anti-colors (anti-red, anti-green, and anti-blue)!



(a) Quarks **(b)** Antiquarks

Figure 46. Each of the quarks with their respective antiquarks.

Let's look at concrete example of hadrons. A proton has two up quarks and one down quark. One quark has to be red, one quark has to be blue, and one quark has to be green (figure 47-a). Similarly, the neutron is made up of two down quarks and one up quark, each a separate color (figure 47-b). The green squiggly lines in the figure are the gluons, or the strong force carrying particles.[63]



(a) Proton **(b)** Neutron

Figure 47. (a) Proton (charge +1) with two up quarks and one down quark. **(b)** Neutron (charge 0) with two down quarks and one up quark. The green squiggly in both is the gluon.

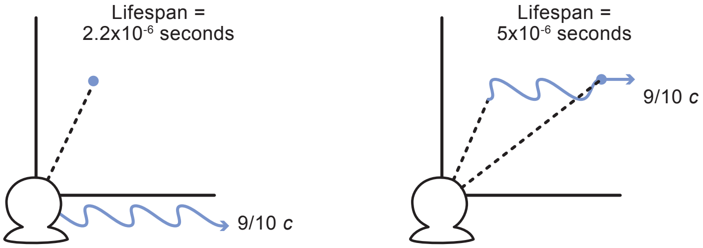
The astute reader will note that the proton and neutron mass isn't simply the mass of the quarks themselves. In fact, hadrons only get a portion of their mass (about 1%) from the quarks themselves. The rest of the mass comes in the form of the binding energy between quarks. This is possible through the mass-equivalence proposed by Einstein, $E = mc^2$.

For instance, a proton weighs around 2×10^{-7} kg. An up quark and down quark weigh around 4×10^{-10} kg and 8×10^{-10} kg, respectively. The sum of two up quarks and one down quark is only $\sim 1.6 \times 10^{-29}$ kg, which is about 1% of the total mass of a proton. As stated, the majority of the rest of the weight comes from the binding energy of the quarks. Quarks are a weird and whacky world.

Protons and neutrons aren't the only creations of quarks. In general, particles made up of three quarks are called *baryons*, while particles made of a quark/antiquark pair are called *mesons*.[64] You may say, *I thought you said quarks can only combine to produce a neutral white? How can that be with only two quarks?* The answer lies in the fact a quark/antiquark pair can be colorless if it meets with its anti-color counterpart, like a red quark meeting with an anti-red quark. Overall, baryons tend to be stable, while mesons tend to be unstable. This is because mesons consists of a particle meeting with an antiparticle. So, mesons live for a very, very short period of time.

The lifespan of these subatomic particles is fascinating and worth a short aside. Let's say that we have a *muon*, which is a type of lepton, moving at 9/10th the speed of light. How long will it last before disintegrating?

Well, it depends. On one hand, let's say that you move parallel to the particle, so it appears as if the particle is at rest (figure 49-a). Here, you would measure the particle's lifespan is about ~2.2 × 10^{-6} seconds, before it decaying spontaneously. On the other hand, if you were to measure it from a stationary frame, then it would live for ~5 × 10^{-6} seconds (figure 48-b). In other words, the muon appears to live longer in a stationary frame compared to the dynamic frame! This is an interesting phenomena that relativity brings forth.[65]



(a) Moving observer **(b)** Static observer

Figure 48. The stationary observer **(a)** sees a particle live for seconds, while **(b)** a moving observer sees a particle live for seconds.

Ok—back to quarks, hadrons, and our visualization. During this era, the universe has expanded and cooled enough for quarks to start forming into various proton and neutron structures. These are the necessary building blocks for our atomic nuclei—but, it is still too hot for the atomic nuclei to actually form yet. In other words, no protons and neutrons are combining, and no electrons are attaching to the nuclei. That said, to celebrate the hadrons forming during this time, our visualization of our universe gets our favorite hadrons: protons and neutrons. And, you guessed it—our universe is still getting larger too (figure 49)!

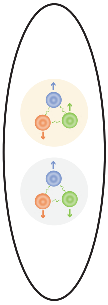


Figure 49. Quarks are coming together to form various hadrons.

LEPTON EPOCH | 1 SECOND | 10^{10} K

We've now advanced beyond time scales best expressed in scientific notation, welcoming the Lepton Epoch. During this phase, leptons (e.g., electrons) took center stage, making up a greater portion of the universe's mass than quarks. You might ask, How is this possible, given that quarks are significantly heavier than leptons?

A valid question! Remember, quarks fused to form hadrons; and, for each hadron, there was a corresponding anti-hadron. The result? Most hadron/anti-hadron pairs annihilated each other. Despite hadrons being the heavyweight champions in earlier phases, these annihilation events left only a smattering of hadrons behind.

You might then ask, Why didn't all the hadrons find their anti-counterparts and vanish? The answer lies in a process known as baryogenesis. There existed a slight imbalance between the number of particles and antiparticles formed post-inflation. For reference, before 10^{-6} seconds, there seemed to be 30 million and 1 quarks for every 30 million antiquarks.[66] Although this seems like a minuscule difference, given the vastness of the universe, even such tiny discrepancies are significant. Ultimately, this leftover fraction is what constitutes the hadrons we see today; and, baryogenesis offers a compelling reason for the current scarcity of antimatter in our universe.

Furthermore, a notable change occurred in the universe's temperature profile during this epoch. Up to this point, quarks, leptons, and photons maintained a thermal equilibrium. Yet, as the universe continued its cooling expansion, neutrinos began to decouple from the plasma. In essence, the interaction rate between the neutrinos and the rest of the plasma was less than the universe's expansion rate. Imagine neutrinos finally escaping a pinball machine's endless bumpers—they began to move freely, interacting sporadically with the residual matter.

The implications? As the era advanced, electron/antielectron pairs commenced their annihilation process, similarly to the quarks and antiquarks.[*] The energy produced from these annihilations was subsequently shared with surrounding particles, like photons. But, since neutrinos decouple and fall out of thermal equilibrium with the rest of the plasma, they do not receive any of this energy. Overall, when this occurred, another sort of cosmic microwave background developed, called the cosmic neutrino background.[67]

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[*] Lepton and anti-lepton annihilation also follows from baryogenesis. In other words, there were slightly more leptons than anti-leptons formed after inflation.

Thus, we shall keep our mental model visualization going with this finding. If our "Hot Big Bang" mental model was solid red (i.e., thermal equilibrium), then our lepton era classifies a change in thermal equilibrium (figure 50).

Figure 50. The lepton dominated era of the universe. During this time, leptons dominated the mass of our universe and the universe was no longer in complete thermal equilibrium.

PHOTON EPOCH | 10 SECOND | 10^{10} K

In a fleeting nine-second window, leptons relished their reign, as they commenced their annihilation with antileptons. Emerging from this tumultuous period was the photon epoch, an era earmarked by the dominance of photons in the universe's energy composition.[68] Given the paramount significance of photons, or light, let's delve deeper into their nature.

Photons are the force carrying particles for the electromagnetic force. They interact with any entity bearing charge—quarks, antiquarks, bosons, and the first row of leptons/antileptons in the Standard Model.

Light's significance in human life cannot be understated. You reading this chapter is light. You seeing someone else is light. Light not only contributes to our understanding of not how the world is, but also how the world *was*. It takes time for light to travel from one place to another, even when traveling at 186,000 miles per second. So, whether we are looking at our friends and family or at the stars way above us, we are interacting with past light. In the spirit of Charles Dickens, light is like the Ghost of Christmas Past.

Humans primarily interact with *visible light*. However, if we were bees, *ultraviolet* light would take center stage. Light's spectrum even extends beyond our vision—encompassing microwaves, radio waves, infrared light, X-rays, and gamma rays.

Recalling Chapter 8 of *The Idea Space*, light's duality means it can manifest as a particle or wave. In our current context, considering light as a wave is apt. Waves have a property called *wavelength*, which denotes the distance covered by one wave cycle. Shorter wavelengths denote greater energy, as the wave oscillates rapidly. Conversely, longer wavelengths indicate slower oscillations and lesser energy.

The different wavelengths, and their energies, allows us to categorize light into the buckets that we've come to know and love (figure 51). Radio waves have the longest wavelengths and lowest energy, while gamma rays have the shortest wavelengths and highest energy. Visible light sits in the middle from red (740 nanometers) to violet (380 nanometers).

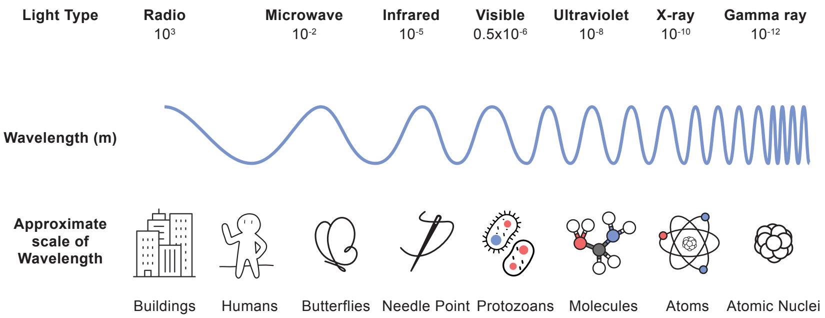

Figure 51. The complete electromagnetic spectrum.

Radio waves rarely interact with atomic nuclei, or even us, because they're too massive. However, as we keep going down in scale, light is able to penetrate deeper and deeper, eventually reaching the nucleus of atoms. For example, only 0.0025% of a radio wave's full 1,000 meter wavelength would travel through a one-inch-thick hand. That's why we don't see much harm from the constant radio waves travelling across our skies, producing illustrious sounds, like *Baby Shark*. For contrast, a gamma ray traveling through the same hand would oscillate 10^{10} times through it! Hence why exposure to gamma rays can be so dangerous.

To summarize, during this time, the majority of quarks and leptons have annihilated with their antiparticle counterpart to leave us with photons, or light, as the dominant source of energy in our universe. To be clear, even though light is the dominant particle, it does not mean that our universe is transparent! Things are still too dense and light has nowhere to go. It keeps crashing into quarks, leptons, and other photons in a universe filled with endless bumpers. So, for our visualization, let's focus have light as the key element (figure 52). As always, the universe is still expanding.

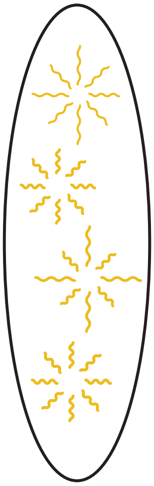

Figure 52. Mental model of the universe at this time. Light is the dominant particle in this phase of the early universe.

NUCLEOSYNTHESIS | 100 SECOND | 10^9 K

At long last—nucleosynthesis. In layman terms, the nucleus of atoms are finally able start forming—hence nucleo (core) synthesis (put together). In other words, neutrons and protons start to bind together. As the universe kept cooling and expanding, it reached a stage where atomic nuclei could finally come into existence.

Up until this point, the universe was a tad too hot and restless for atoms to form stably. But as it cooled further, the nuclei of basic elements, notably Hydrogen, Helium, and a smidge of Lithium, began taking shape. Why just these three elements? A peek at the periodic table shows that they're among the lightest atoms, sporting 1, 2, and 3 protons, respectively. The saga of heavier elements arises in the lifecycle of stars, which we'll touch upon here and detail in the remaining Bonus Chapters.

During stellar nucleosynthesis (distinct from Big Bang nucleosynthesis), Hydrogen (element 1) gets compounded to form various elements until it hits Iron (element 26)—the heaviest element a star's core can form. A massive star's dramatic death in a supernova then paves the way for the genesis of most other elements in the periodic table. Yet, some elements have more unique origin stories—arising from cosmic ray fissions, stellar mergers, or even human-made processes (figure 53).

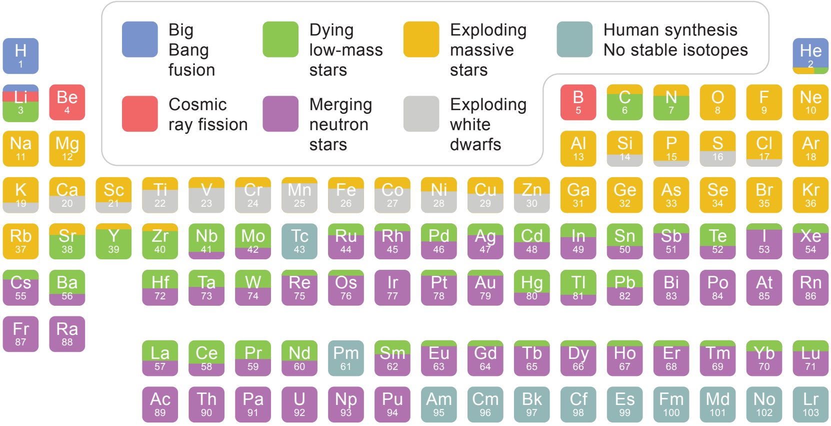

Figure 53. The handy dandy periodic table (note: elements 104-118 are not listed). Finally—after a mere 100 seconds, the lightest of the atomic nuclei are able to start forming.[69]

It's essential to clarify that electrons aren't cozied up to these atomic nuclei just yet. The universe's ambient temperature still keeps them at bay, so they swirl around, unbound, in a vast sea. In other words, we don't have complete atoms yet, we only have the nuclei. Considering the importance of this phase—where atomic structures first take root in our universe—we use this as our visualization for this stage in life (figure 54).

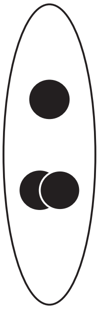

Figure 54. At 100 seconds, the basic nuclei of hydrogen and helium are able to start forming.

MATTER-RADIATION EQUALITY | 50,000 YEARS | 11,000K

After delving deep into the early universe, it's astonishing to realize that everything preceding matter-radiation equality transpired in mere moments. We're talking seconds! Now, fast forward to 50,000 years after the Big Bang.

For context, 50,000 years is approximately the time elapsed since the rise of languages and imagined realities, during the Cognitive Revolution.

But what is "matter-radiation equality?" Similar to the quark, lepton, and photon-dominated epochs, it indicates a pivotal transition: the universe moving from being radiation-dominated to matter-dominated. Radiation signifies objects moving close to, or at, the speed of light, while matter is anything moving significantly slower than the speed of light. So, after radiation-matter equality, there are more objects moving slower than the speed of light than objects moving close to, or at, the speed of light.

This shift is pivotal for two reasons. Firstly, matter-radiation demarks the point where modern structure formation, like stars, can truly start occurring.[70] Secondly, the equality creates an interesting scenario where the expansion of the universe is no longer accelerating, but actually decelerating. In other words, the universe continues expanding, except at a slower rate. This deceleration occurs because matter tends to clump together through gravitational attraction.* When there's more matter relative to radiation, these gravitational forces can counteract the expansion, leading to a slowdown in the universe's expansion. What's worth noting is the matter this early on not only consists of quarks and leptons, but also dark matter, which we'll touch on in a later bonus chapter.[71]

So, the narrative goes: the universe cools, expands, and matter finally finds its footing. After tens of thousands of years post-Big Bang, radiation handed over the universal crown to matter. And, for almost 10 billion years thereafter, matter ruled, until the era of dark energy. Therefore, envision this epoch as the *Age of Matter* (figure 55). The universe still expands, just with a tad more restraint than before.

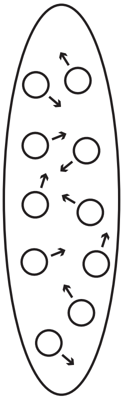

Figure 55. The transition between a radiation dominated universe to a matter dominated universe.

RECOMBINATION | 380,000 YEARS | 12:14 AM JANUARY 1st, 2021 | 3,000 K

380,000 years after the Big Bang, a transformative event occurred: the universe became transparent. This milestone, known as recombination, marked the point when photons could finally move about without constantly colliding with electrons. In essence, the photon interaction rate dropped below the universe's expansion rate.[72] No more pinball machine.

Two major consequences arose from this decoupling. Firstly, with electrons no longer being bombarded by photons, they could combine with nuclei, forming complete atoms. Secondly, with photons no longer confined, light began to travel freely, granting the universe its transparency.

The term recombination can be slightly misleading, as it suggests that atomic nuclei and electrons, at some point, had been together. They weren't—but, what's in a name anyways.

During this era, the universe is approximately made up of 63% dark matter, 15% photons, 12% atoms, and 10% neutrinos.[73] Notably absent in large quantities at this point was dark energy. However, dark energy is persistent. By slowly injecting itself over time, it soon (10 billion years after the Big Bang) became the dominant player in the cosmic stage.

In *The Idea Space,* we likened this event as a sort of wall. When we gaze into the vastness of space, we witness this wall as the cosmic background radiation, detectable due to its microwave wavelengths. This is why it's often called the cosmic microwave background.

Overall, because of this wall-like structure that forms and finally makes the universe transparent, we use the beautiful wall that is the cosmic background as our final step in our Big Bang mental model. Remember, we can see everything that happens after that by simply looking up at the stars, because we are always looking back in time!

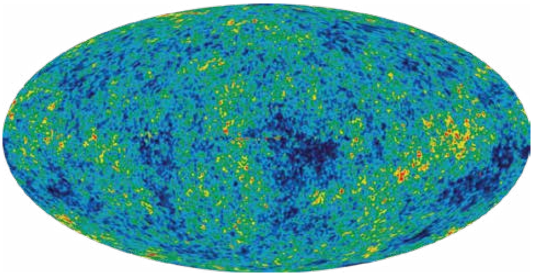

Figure 56. The final piece of our mental model of the Big Bang. The magical wall that is the cosmic background radiation.

BIG BANG RECAP | 13.8 BILLION YEARS AGO | 12:00 AM JAN 1st TO 12:14 AM JAN 1st

As we pause to reflect on the Big Bang model in the context of our cosmic calendar, it's astounding to realize that we've only journeyed through a mere 14 cosmic minutes. Yet, these initial moments have been pivotal in molding the universe we inhabit today. Let's revisit our Big Bang graphic with the added insights from our recent discussions (figure 57).

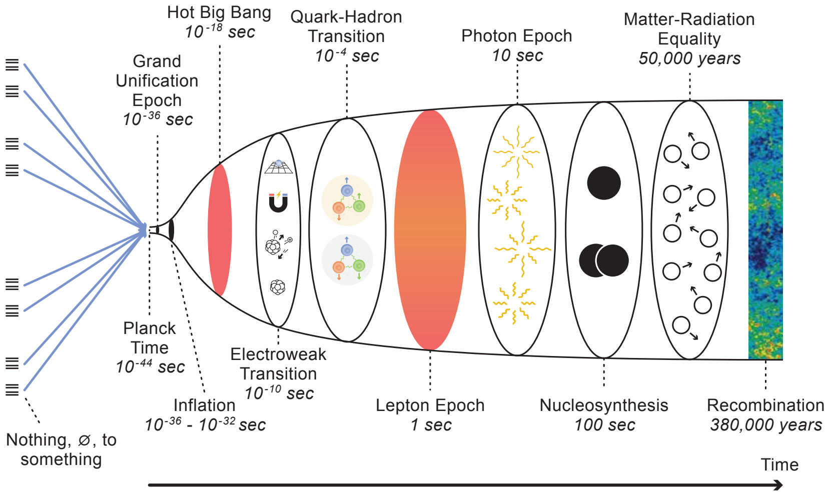

Figure 57. The completed mental model of the Big Bang.

Our journey starts at the Big Bang—our observable universe's potential origin as a topological singularity. From nothingness, Ø, it burgeons into existence. Of course, the universe could have started as a bounce. In either case, there is a particle horizon that uncovers more and more of the universe the deeper in time we go.

We then experienced Planck time, which is around 10^{-44} sec and is when gravity broke off from the other forces. This ushered in the Grand Unification Epoch, an era hinting at the unification of the strong force, electromagnetic, and weak force, while simultaneously converging quarks and leptons (recall Hawking's roulette analogy). Next was inflation, from around 10^{-36} to 10^{-32} seconds, where the strong force broke off and the universe surged by at least 10^{26} in size.

By 10^{-18} seconds, we get our standard Hot Big Bang—a quark-gluon plasma soup. Come 10^{-10} seconds, all four primary forces are in their defined roles. From there, we started having various dominance epochs starting with quarks and hadrons. Then, after quarks collided with all the antiquark particles, leptons, like electrons, took over. During the Lepton Epoch, the temperature profile of the universe was no longer ubiquitous as neutrinos broke the thermal equilibrium. Finally, after all those leptons and antileptons annihilated one another, photons, or light, took hold. The fact that not all quark-antiquark and lepton-antilepton pairs annihilated is attributed to baryogenesis—a process leading to a slight matter-antimatter imbalance post-inflation.

The universe reached another milestone after 100 seconds—nuclei formation. Fast forward to 50,000 years, radiation's dominance waned, giving way to matter. This transition implies that not all entities were moving at light speed, causing the universe's expansion rate to decelerate. At 380,000 years, we enter the recombination era. Electrons began bonding with atomic nuclei, liberating photons and making the universe transparent. However, transparency didn't equate to luminosity. Before the birth of the first stars, the universe was submerged in the "Dark Ages" due to a paucity of light.

From a temperature perspective, the universe underwent significant fluctuations. Early on, temperatures might have soared to around 10^{32} K. By the recombination era, it had cooled down to approximately 3,000 K. Presently, outer space stands at a chilly 2.7K.[74]

To summarize, figure 58 is a representation of the Big Bang model through time.[*] Remember, everything you see is in the past. So, no matter where you are in time, the edge of your observable universe is its creation: the Big Bang—a hypothetical infinite, space-like surface. What's on the other side of this surface? No one knows. . .

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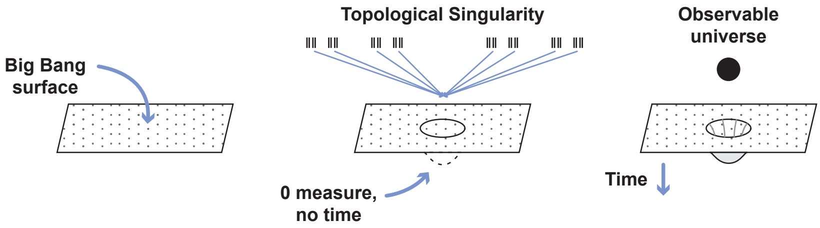
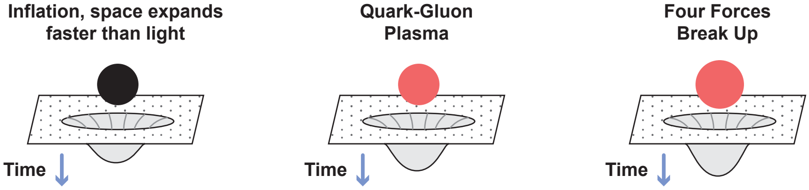
[*] While this looks like an embedding diagram, it is not. It is an illustration aimed at demonstrating we are always looking back in time and the edge of your observable universe is the Big Bang.



(a) ?????

(b) Big Bang

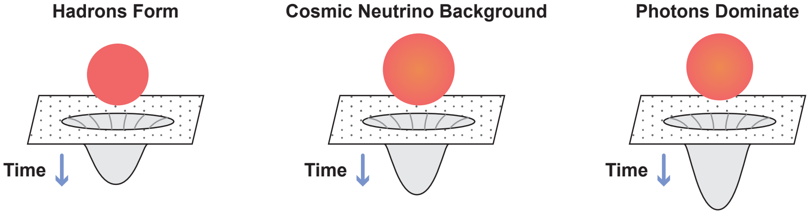
(c) Planck Time



(d) Inflation

(e) Hot Big Bang

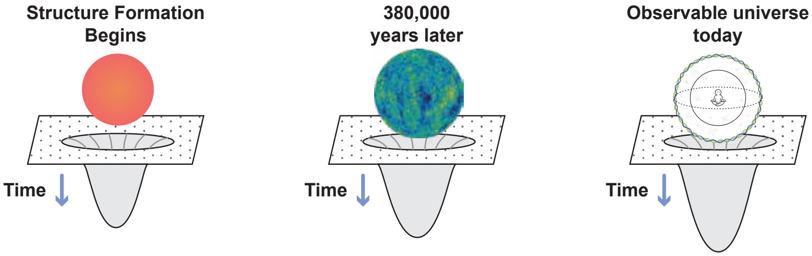
(f) Electroweak Transition



(g) Quark-Hadron Transition

(h) Lepton Epoch

(i) Photon Epoch



(j) Matter-Radiation Equality

(k) Recombination

(l) Today

Figure 58. Evolution of our universe. You are at the center, falling through time.

THE BIG BANG AND NON-SELF

As we saw in *The Idea Space*, it is impossible to pinpoint where you start and where you end. At arm's length, you are a person—your name and identity. Zoom in and this identity dissolves into a bustling metropolis of cells and bacteria. Probe further, and you unravel into a dance of molecules. At the deepest core, there's an intangible realm—your idea space—beyond physical observation. Inversely, as we zoom out, you transition into a city, a country, a planet, a galaxy, and so forth. At one point we identify with an aching tooth. At another, with our country. We contract and expand like this, all the time.

This insight aligns with the Sunset Conjecture, which posits (a) everyone is at the center of their own observable universe, where everything you see is in the past, and (b) at the center lies your idea space (figure 59). Consequently, since it is impossible to pinpoint where *you* start and where *you* end, your Non-Self is, in essence, synonymous with your entire, unique observable universe. Specifically, your Non-Self is an intricate tapestry of your observable universe's fractal layers, stretching from the immediate realm of your idea space to the distant echoes of the Big Bang, whose gravitational ripples have taken 13.8 billion years to kiss the edge of your consciousness.

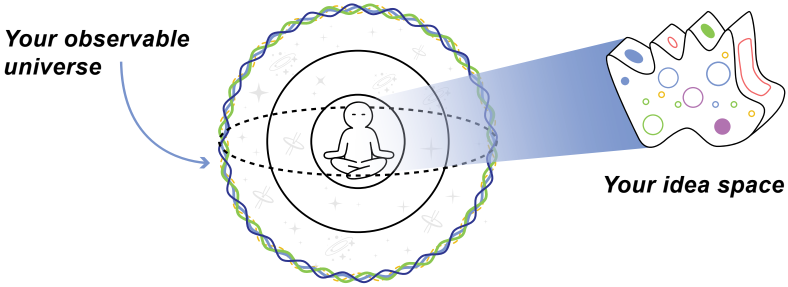


Figure 59. Your idea space sits at the center of your observable universe.

The feint, blue, green, and yellow line around the edge of your observable above, represents the CMB and the myriad preceding event. A truer representation of our observable realm would encapsulate milestones from the Cosmic Microwave Background down to Inflation, Planck Time, and the Big Bang Singularity (figure 60). All these layers are imprinted on the fringes of our observable universe. In other words, the Big Bang didn't just happen, but it is still happening in our observable universe today! How? Because, everything we see is in the past.

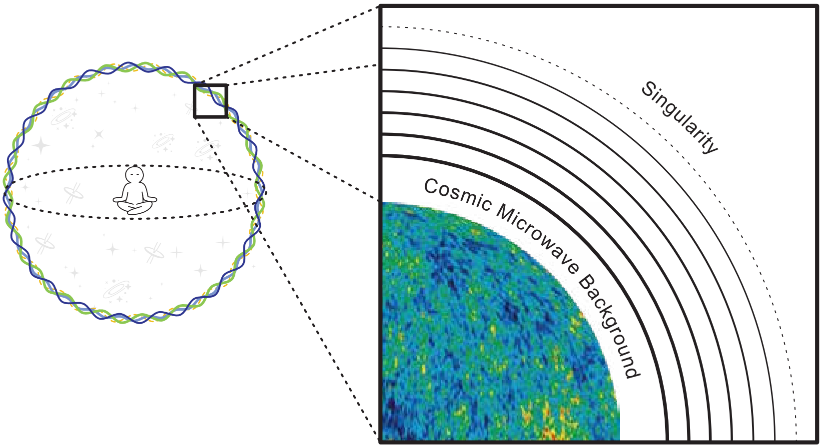


Figure 60. The Big Bang is still happening!

Enter the Singularity Sunset. Your Non-Self is always being rebirthed from moment to moment, because your Non-Self consists of every layer of your observable universe, including the Big Bang. Like the uniqueness of each sunset, the Big Bang's gravitational whispers are tailored just for you. To hear it speaking, simply listen to the silence in between sounds. Can you sense the ancient, gravitational push of the Big Bang, reaching out to you, right here, right now?

Bonus Chapter III

Stars: Our Earliest Ancestors

In our exploration of the cosmic calendar, we recognized that the boundaries defining life are nebulous at best. Could stars, with their distinct lifecycles of birth and demise, be considered "alive"? As the ancient Zen adage suggests, "The primary cause of death is birth." Intriguingly, many stars harbor carbon at their cores, leading us to wonder if they might, in a sense, be viewed as "carbon-based lifeforms" with their own forms of consciousness. With this perspective in mind, this chapter delves into the evolution of what might be considered our most ancient progenitors.

THE EARLY STAGES OF STAR FORMATION

As we saw in the last bonus chapter, while the universe became transparent after recombination, it wasn't necessarily luminous. This period was so profoundly dark that it earned the moniker "Dark Ages". But what exactly did these Dark Ages look like? Gaining clarity on this is challenging, especially since the James Webb Telescope has only recently been deployed. While we anticipate more comprehensive data in the future, for now, we can marvel at an image it captured of the galaxy GLASS-z13 (figure 61), dating back to the first stars, 13.5 billion years ago—merely 300 million years post-Big Bang.

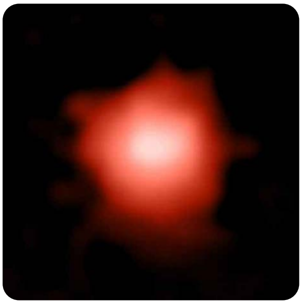
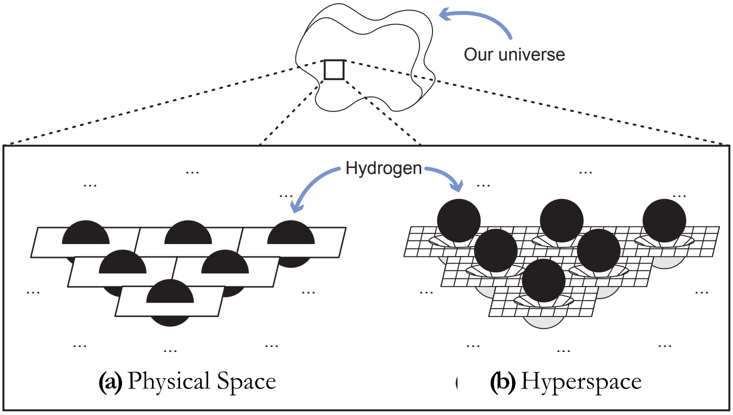


Figure 61. GLASS-z13 galaxy [NASA/STScI/GLASS-JWST].

While we wait more comprehensive data, it's reasonable to theorize that early stars formed in much the same way as their later counterparts, only earlier in cosmic history. One key distinction is that these pioneering stars are believed to have been exceptionally massive.[75] With that in mind, let's delve into the captivating tale of how a star comes to be.

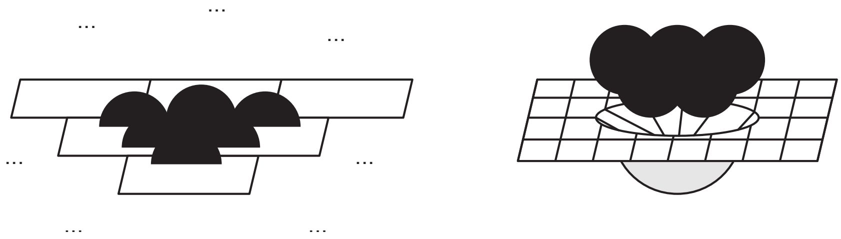
After the Big Bang, there was a good amount of hydrogen floating around. On the left (figure 62-a), we have the *physical space*, which is what you would see regularly. On the right (figure 62-b), we have something called *hyperspace*, which is represented through an embedding diagram. Imagine placing a bowling ball on a trampoline. That bowling ball will create curvature as it sits there. In a similar manner, objects in our universe curve the space around. This curvature creates the illusion of gravity. For instance, if you were to place marbles on the trampoline, then those marbles would "gravitate" towards the bowling ball. Although small in mass, hydrogen atoms also curve spacetime and create their own gravitational pull.



(a) Physical Space **(b)** Hyperspace

Figure 62. Our universe is filled with hydrogen

Over countless eons, these hydrogen atoms began to gravitate towards one another. Picture adding more marbles to our trampoline; as their number increases, they roll toward the center, intensifying the central dip. So, several million years post-Big Bang, these hydrogen atoms began coalescing, forming vast gas clouds known as *nebulas* (figure 63).



(a) Physical Space **(b)** Hyperspace

Figure 63. The hydrogen atoms start amalgamating together into a nebula.

As hydrogen accumulates in a dense region, collisions between these atoms become more frequent. Every collision releases energy in the form of heat, which counters the compressive force of gravity. Imagine feeling pressure from all sides, squeezing you into a tight space. Naturally, you'd resist, pushing back against this force. In much the same way, as a star's hydrogen atoms face relentless gravitational collapse, their collisions generate increasing heat. In turn, this heat acts as an internal pressure that fights the gravitational contraction, known as *resistance.*[76]

Over time, the resistance generated by these gas collisions releases sufficient heat to counterbalance the gravitational forces acting on the star (figure 64). In the early stages of a star's life, when the thermal pressure from these collisions equals the gravitational forces trying to collapse it, the celestial body is termed a *protostar.*[77] While there are four primary types of resistance throughout the lifespan of a star—thermal pressure, fusion, electron degeneracy pressure, and neutron degeneracy pressure—during this nascent stage, the primary force at play is thermal pressure, which is the result of atomic collisions. We'll delve into the other resistive forces as we journey through the star's life cycle.

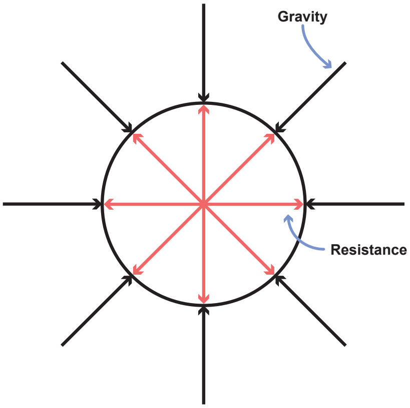
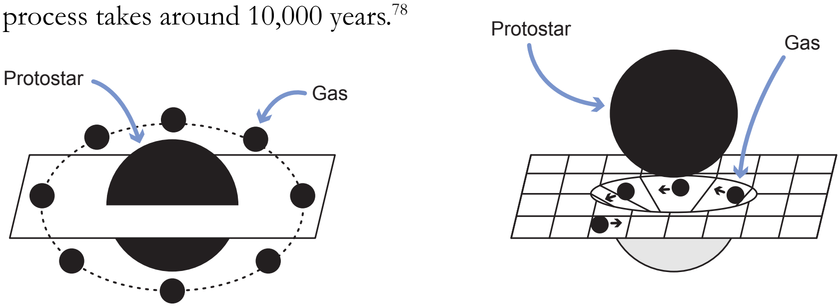


Figure 64. When the internal pressure caused by the collision of hydrogen atoms is as strong as the gravitational contraction, a protostar is born.

So, what does our nascent star look like at this stage? At a glance, it might resemble one of the objects from our initial hydrogen diagram, but with a couple of significant differences. First and foremost, it's considerably larger—we're now comparing a protostar to mere hydrogen atoms. Consequently, the gravitational dip in hyperspace is more pronounced. As this gravitational pull intensifies, it begins attracting more gas, leading to the formation of an accretion disk—essentially, a ring of gas encircling any object with sufficient gravitational might. In the tangible realm of physical space, this accretion disk manifests as a whirling cloud of gas around the protostar (figure 65-a). If you were to visualize it in hyperspace (figure 65-b), think of the protostar as the bowling ball on a trampoline, with the orbiting gas resembling tiny marbles. For a star like our sun, the protostar process takes around 10,000 years.[78]



(a) Physical Space **(b)** Hyperspace

Figure 65. An accretion disk starts forming around the protostar.

These are still in their stellar infancy. Fusion has yet to occur within the star at this juncture. The existing heat, and the consequent outward pressure, is solely the outcome of gas particle collisions within the protostar. Yet, as our Sun-sized star approaches the 100 million-year mark, fusion steps into the limelight. With enough gas accumulated and its core adequately contracted, hydrogen atoms collide at velocities conducive to fusion.[79]

Fusion is when the nuclei of atoms combine to form heavier elements and releases a huge amount of energy (figure 66). For instance, in our case, the earliest stars all started out as mostly hydrogen (one proton). These atoms no longer just randomly collide to produce heat; they strike each other with such vigor that fusion takes place. This event turns the hydrogens atoms into *deuterium* (one proton and one neutron). From there, the deuterium collides with a lone hydrogen atom to form helium-3 (two protons and one neutron).[80] This process is nothing short of alchemical magic—a phenomenon that would have left our forebears astounded!

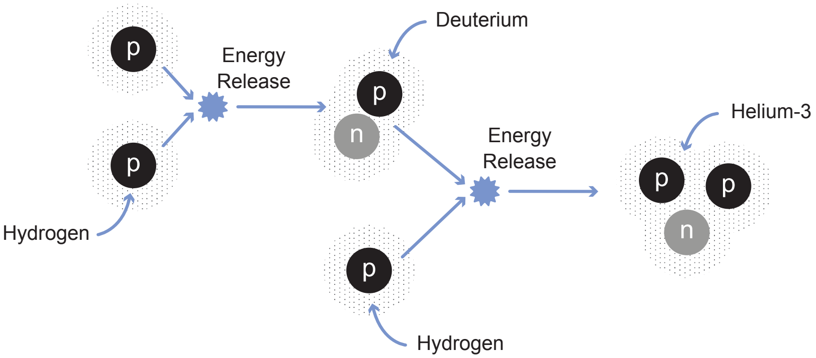
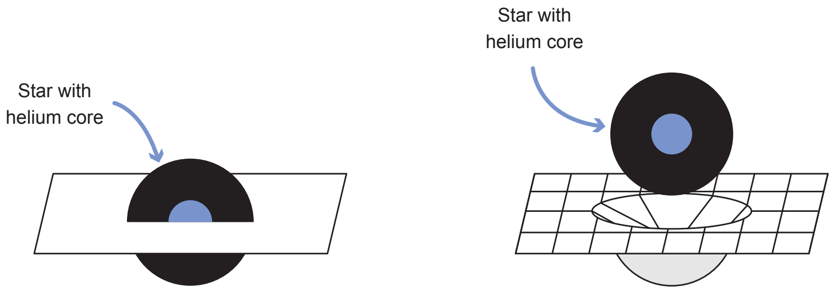


Figure 66. The fusion process that occurs in early stars. Two hydrogens collide to form deuterium. That deuterium then collides with a lone hydrogen to form helium.

In this phase of a star's lifecycle, the energy generated from fusion emerges as the dominant resistive force against gravity. This contrasts with our previously discussed protostars, which leaned on the thermal pressure from hydrogen collisions. When a star commences this fusion of elements, it's said to enter its *main sequence*, as it develops a helium core, surrounded by a hydrogen shell (figure 67).



(a) Physical Space **(b)** Hyperspace

Figure 67. Stars that go into main sequence fuse hydrogen into helium.

It's vital to note that not all stars possess the energy required for fusion. Small stars that aren't able to fuse elements, or are only able to fuse elements for a short period of time, are called *brown dwarfs*. These are failed stars. Brown dwarfs are marginally bigger than Jupiter and smaller than most stars. For instance, a brown dwarf size is usually less than 0.08 solar masses.[81] For reference, our sun's radius is ~432,700 miles, and it weighs one solar mass, or 1 $M_{\odot}$. Jupiter's radius is ~43,000 miles, and it weighs around 2×10^{27} kg. Earth has a radius of about ~4,000 miles and sits at a weight of 6×10^{24} kg. So, overall, brown dwarfs are a small compared to our sun.[82]

What happens from here on out depends on the size and mass of the star. Let's look at smaller stars first and then larger stars.

SMALL STARS

When we say smaller stars, we mean stars smaller than 1.4 $M_{\odot}$ at "death". Stars get less massive as they live; so, if we're looking at the early stages of a star, then we'd say a small star starts at around, or below, 8 $M_{\odot}$.[83] Therefore, our sun would be considered a small star. The ultimate "death" occurs when a star has no more fuel left to burn, or when fusion stops. At that point, the star is deemed *cold, dead matter.* [84]

Once a small star starts burning hydrogen into helium, it will continue to do so for billions of years. During this phase, the small star stays around the same size and luminosity as it continuously combats the inward force of gravity.[85] If you were to look inside the star, then it would have the following layers: a core, a radiation zone, a convection zone, the photosphere, the chromosphere, and lastly, the corona (figure 68).[86]

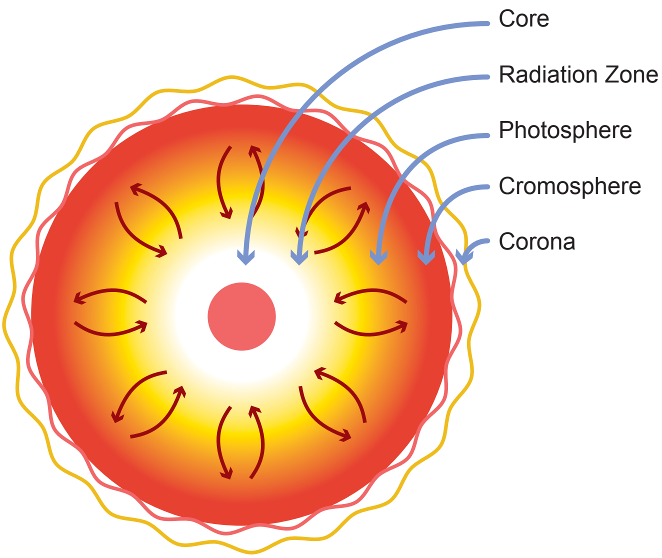


Figure 68. The different layers of a smaller star.

The core of a star is its fusion powerhouse, where energy is generated. This energy, primarily in the form of photons, or light, then moves into the radiation zone. Here, it diffuses radially outwards from the core. As we move further out to the convection zone, the energy's behavior shifts. Rather than radiating directly outward, the energy begins to flow in intricate patterns, similar to eddy currents. The star's outermost layers—its "atmosphere"—consist of the last three zones. Light in these regions escape towards the cosmos, which we detect as sunlight. It's interesting to note that a photon liberated at the center of the star takes around 10^7 years to make its way towards the surface![87]

After several billion years, a star begins to exhaust its supply of hydrogen for conversion into helium. As the hydrogen reserves diminish, there's less resistance from fusion reactions to counteract gravity, causing gravity to further contract the helium-rich core. This spurs the star to burn the residual hydrogen in the shell surrounding the core at a much faster rate, releasing energy more rapidly. Consequently, the outer layers of the star expand, transforming it into a *red giant.*

This red giant phase persists for roughly a billion years. As it nears its end and the hydrogen is nearly depleted, the core contracts to a degree where the helium atoms themselves initiate fusion, giving rise to heavier elements like carbon and oxygen. The result is a layered structure with a carbon-oxygen core, encased by helium and hydrogen shells. As this helium starts to fuel fusion, the star undergoes pulsations and contracts in size. When the core shrinks sufficiently, the star consumes the remaining helium and hydrogen at an even greater accelerated rate, leading the star to expand once again.

Ultimately, after expending all the helium and hydrogen fuel, the star's outer layers drift off into space, creating a striking formation known as a *planetary nebula*. Contrary to what its name suggests, a planetary nebula has nothing to do with planets. It is a luminous cloud of gas that disperses the remnants of the star into the universe. To showcase the allure of these nebulas, here's an image of the Helix Nebula captured by the renowned Hubble Telescope.[88]

Figure 69. The Helix Planetary Nebula by the Hubble Telescope. When a small star finishes fusion, its atmosphere drifts into the cosmos forming a planetary nebula.

After exhausting its nuclear fuel, the core of the small star continues to contract, producing a series of elements from neon to silicon, culminating in iron. Once iron is formed in the core, fusion halts, and the star evolves into a *white dwarf*.[*,89] This state is considered the "death" of a small star, as the iron core can contract no further. But why does this contraction stop? The answer lies in a quantum mechanical phenomenon called *electron degeneracy pressure*.[†]

Within atoms, electrons orbit the nucleus in what is known as an electron cloud. As gravitational forces increase, the available space for these electrons decreases, effectively compressing the electron cloud.

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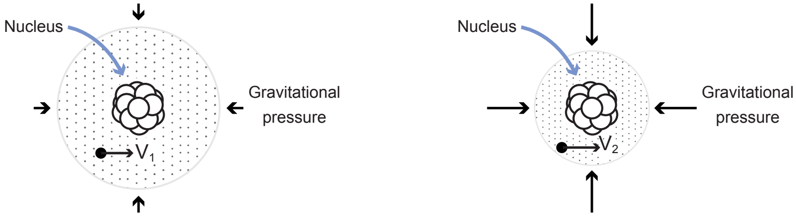
[*] There are other types of smaller white dwarfs that have carbon-oxygen cores or oxygen-neon-magnesium cores.

[†] See supplemental material for a more detailed analysis of electron degeneracy pressure. A short overview is provided in the text.

This compression leads to a higher electron density. Consequently, the electrons move more rapidly, creating a counteracting force or resistance against the contracting influence of gravity. The renowned physicist Kip Thorne quantified this relationship in his book *Black Holes & Time Warps*, noting that for non-relativistic electrons (those moving much slower than the speed of light), a 1 percent rise in density leads to a 1.667 percent increase in pressure, or resistance. However, for electrons that approach the speed of light, a 1 percent density uptick results in only a 1.333 percent pressure increase.[90]

Overall, the concept of electron degeneracy is depicted below. On one hand, in figure 70-a, there's a lower gravitational pressure, which allows the electron to move around freely with less speed. Since the electrons aren't moving as fast, there is less outward resistance from them fighting the gravitational contraction. On the other hand, in figure 70-b, there is an increased gravitational contraction. This contraction confines the electrons to less space and the electrons start moving around much faster. The increased speed causes the third form of resistance that prevents stellar collapse, known as electron degeneracy pressure. When the equilibrium between electron degeneracy and gravitational pressure is achieved, a white dwarf is created.*



(a) Electron cloud at a certain gravitational pressure

(b) Electron cloud shrinks as gravitational pressure increases; thereby, increasing the electron's speed

Figure 70. The concept of electron degeneracy: an increase in gravitational pressure decreases the size of the electron cloud, thereby speeding up the electron. The increased electron speed causes an internal pressure which resists the gravitational collapse.

White dwarfs can only form in stars less than 1.4 $M_\odot$ at death. Why? For larger stars, electron degeneracy no longer works. The electrons start

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* Fun Fact: electron degeneracy pressure is the same reason you don't fall through cold, solid objects, like the ground or your chair!

moving too fast and something more intricate and interesting happens: the electron turns into a neutron. More on this in the next section. For now, this 1.4 $M_\odot$ limit is known as *Chandrasekhar's limit* and is the maximum size of a stable white dwarf.[91] Stars exceeding this limit are destined for a different fate.

To summarize the life journey of smaller stars: they begin their existence as protostars, resisting gravity primarily through atomic collisions. With time, they initiate the fusion of hydrogen into helium, which becomes the dominant mechanism resisting gravitational collapse. As the hydrogen fuel depletes, the star evolves into a red giant phase. Subsequently, its core starts the fusion of helium into heavier elements, causing the star to undergo pulsations and eventual contraction. However, once the core predominantly consists of iron, the star's outer layers drift away, forming a mesmerizing planetary nebula. The iron-rich core, stabilized by electron degeneracy pressure, marks the star's death as a white dwarf. A white dwarf can only emerge from stars with less than 1.4 solar masses at their end. Lastly, this entire lifecycle spans several billion years, varying with the star's initial mass.

MASSIVE STARS

With small stars out of the way, let's delve into the realm of massive stars. The classification of massive starts hinges on their size and mass, leading to two main categories based on their eventual fate.

Massive stars that form *neutron stars* are around 8 to 20 $M_\odot$ in their early days and around 1.5 to 3 $M_\odot$ at their death.[92] Massive stars that from *black holes* are greater than 20 $M_\odot$ in their early days and greater than 3 $M_\odot$ at their death.[*] So, how does the main sequence for these colossal stars unfold? Surprisingly, it mirrors that of their smaller counterparts in many aspects. The major distinctions lie in the duration, diversity of core elements, and sheer size.

While smaller stars span over billions of years, massive stars race through their main sequence in mere millions of years. The reason? The intense energy in their core facilitates rapid fusion, consuming the available fuel at a faster pace.[93] This accelerated lifecycle is somewhat analogous to the lifespan discrepancy observed between large and small dogs on Earth, where larger breeds tend to live shorter lives.[94]

Furthermore, the increased mass of these stars leads to greater

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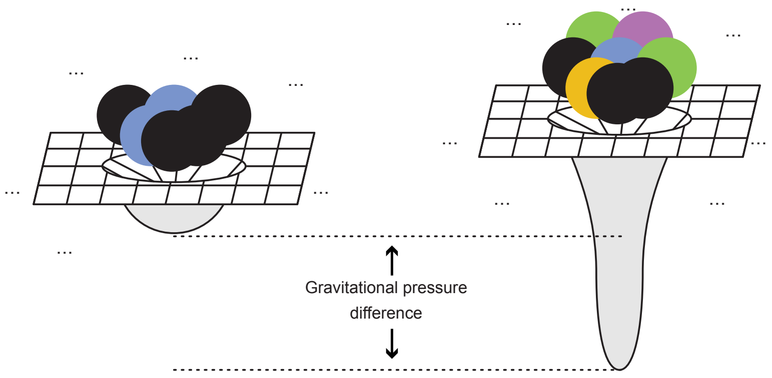
[*] Hawking says 30 $M_\odot$, while Thorne says 20 $M_\odot$ here—take your pick.

gravitational forces at play. This heightened gravitational contraction facilitates the fusion of heavier elements earlier on (figure 71). Much like their smaller counterparts, the cores of massive stars can only fuse elements up to iron. Beyond iron, fusion doesn't release energy, so no heavier elements are produced via stellar nucleosynthesis in the star's core.



(a) Small star **(b)** Large star

Figure 71. (a) Early on, the hyperspace of a small star consisting only of helium and hydrogen atoms. **(b)** Early on, the hyperspace of a massive star consists of a diverse array of atoms, up to iron.

In essence, the lifecycle of massive stars parallels that of small stars. They ignite by burning hydrogen which transforms into helium, then carbon, and so forth. As the core produces heavier elements, energy is expelled, causing the outer layers of the star to expand. Consequently, massive stars evolve into *red supergiants*.

As the star consumes more fuel and its gravitational well deepens, the core undergoes rapid transitions. Carbon transforms into neon in mere centuries, neon evolves into oxygen in about a year, oxygen becomes silicon within months, and silicon finally yields iron within a single day.[95]

Once the core reaches iron, fusion grinds to a halt. But why does this occur? The nuclear force binds neutrons and protons together more tightly in iron nuclei than in any other atomic nucleus. If nuclei in the core are lighter than iron, energy is liberated when these lighter nuclei fuse together to produce iron (i.e., nuclear fusion). Conversely, if atomic nuclei in the core were to exceed the mass of iron, energy would be released by breaking these heavier nuclei down into iron (i.e., nuclear fission). Ultimately, the inescapable fate of the red supergiant's core is to become dominated by iron.[96]

What happens next is breathtaking. In small stars, we saw the iron core could withstand gravity because of electron degeneracy pressure. However, in massive stars, the gravitational contraction confines the electron to such a small space that the electron starts moving at speeds very close to the speed of light. When an electron becomes relativistic, they induce something called *inverse beta decay* with the protons.[97] Essentially protons (p) and electrons (e) combine to produce neutrons (n) and electron neutrinos (v_e) (figure 72). This is the weak force at work! This will happen until all the atoms in the iron core turn into neutrons; thus, forming a *neutron star*.[98] A neutron star is around 20 km in diameter and has a maximum weight of 3 solar masses—around kg.[99] To grasp the density, imagine compressing a million Earths to fit within the confines of New York City.

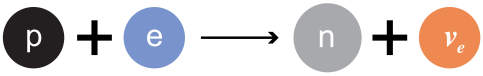


Figure 72. When electrons become relativistic, they combine with protons to produce neutrons and electron neutrinos.

Furthermore, once all the protons and electrons turn into neutrons, the main resistance force to gravity becomes *neutron degeneracy pressure*. This concept is extremely similar to electron degeneracy pressure, except this time it is occurring within neutron clouds instead of electron clouds. Simply put, the space neutrons live in gets smaller and smaller; and therefore, the neutrons speed up. This speed up causes the fourth and final resistive force against gravity, neutron degeneracy pressure.

Electron degeneracy pressure occurs in an electron cloud around 10^{-8} cm. In contrast, neutron degeneracy pressure occurs in the nucleus of atoms, which is around 10^{-13} cm.[100] Such a large, instantaneous contraction has to lead to something cool, right?

Indeed, it does. One of the most awe-inspiring cosmic phenomena follows—a *supernova*. When neutron degeneracy pressure occurs, the whole star, and all of its outer layers, collapse onto the core in a fragment of a second.[101] This makes sense since all the atoms themselves contract from 10^{-8} cm in size to 10^{-13} cm! When the gases on the outer layer strike the core, they rebound from the iron-rich surface, triggering a supernova.

Supernovas are extremely bright—around 10^{10} (10 billion) times more luminous than our sun! An example of a supernova can be seen below. Another way supernovas can form is through the merger and explosion of two neutron stars.[102] Significantly, supernovas are responsible for the formation of many heavier elements beyond iron (element 26). Given that

118 elements are currently known, this means supernovas play a key role in synthesizing a vast array of elements! However, it's worth noting that elements ranked 26-118 are far rarer than their lighter counterparts. This rarity can be attributed to the fact that stars, which create lighter elements, are far more common than the supernovas responsible for producing the heavier ones. The complete chart showing how elements in the periodic table are formed was found in the previous bonus chapter.

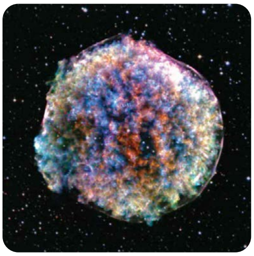


Figure 73. The Tycho Supernova [NASA/CXC/RIKEN & GSFC/T]

After the supernova, all that is left is the extremely dense core of the neutron star. This core contains one of the strongest magnetic fields known to our universe; and, when the neutron star spins, it creates something known as a *pulsar*. As defined by Kip Thorne:

> *A pulsar is a magnetized, spinning neutron star that emits a beam of radiation (radio waves and sometimes also visible light and X-rays). As the star spins, its beam sweeps around like the beam of a turning spotlight; each time the beam sweeps past Earth, astronomers receive a pulse of radiation.*[103]

As stated earlier, the typical size of neutron stars at death is around 1.5 to 3 $M_\odot$. What happens when the star is bigger than 3 $M_\odot$ at death? Well, in those instances a *black hole* is formed. In such cases, instead of forming a neutron star post-supernova, the core of the massive star undergoes complete implosion, tearing a hole in the very fabric of spacetime. It's akin to overloading our metaphorical trampoline. It's worth noting, however, that black holes can also come into existence through other means: (a) the collision of two neutron stars or (b) the merger of two black holes, resulting in an even more massive black hole. An illustration depicting the nature of a black hole is presented below. A deeper dive into the fascinating world of black holes awaits in Bonus Chapter IV.

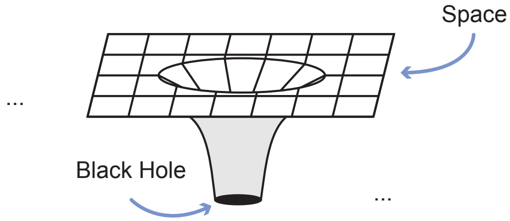


Figure 74. The hyperspace of a blackhole. At a certain point, the density of the black hole is too large that it rips the fabric of space

THE COMPLETE LIFECYCLE OF STARS

Stars exhibit a captivating lifecycle. Beginning as humble hydrogen atoms, around 10^{-8} cm in size and weighing $\sim 2 \times 10^{-27}$ kg, they can evolve into massive celestial bodies weighing up to 200 solar masses. As with everything in life, gravity seems to be the driving force for a star's creation, life, and ultimate death. . .

The lifecycle of stars is summarized in figure 75. For cognitive ease, $M_\odot$ signifies 1 solar mass (i.e. the mass of our sun, 2×10^{30} kg). So, 0.08 $M_\odot$ is 0.08 solar masses. Moreover, note that the planetary nebula and the supernova remains can be recycled to produce new stars. Nature's efficiency at its finest. Different forces sustain stars at different life stages: thermal friction during their nascent phase, fusion during their prime, and either electron or neutron degeneracy pressure as they approach their twilight. And yet, in the most massive of stars, gravity prevails, culminating in the formation of a black hole.

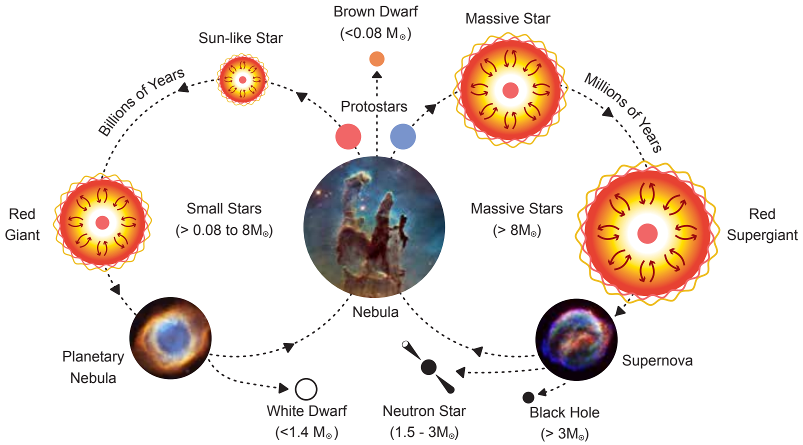


Figure 75. The lifecycle of a star.

Gazing at the night sky, one can't help but marvel at the stellar beauty. Our galaxy alone is home to between 100 billion to 400 billion stars, many of which have the potential to become black holes.[104] Given the existence of trillions of galaxies in the observable universe, the sheer number of stars is staggering.[105] For instance, assuming an average of 100 billion stars per galaxy and 1 trillion galaxies, means there are 10^{23} stars in the observable universe!

Like our ancestors, can we derive meaningful insights from these celestial beacons?

Stars aren't just cosmic ornaments—they're foundational to our very existence. The early universe was dominated by hydrogen and helium. Stars, through their transformative processes, birthed heavier elements like carbon, the cornerstone of life. Echoing the words of Carl Sagan: "We are all made of star stuff. We are a way for the cosmos to know itself." So, are we merely cosmic instruments for stars to comprehend their own existence?

As Chapter 9 of *The Idea Space* suggests, star formation illuminates our quest for self-understanding and a deeper connection with the cosmos. In short, we are a way for the cosmos to know itself; the cosmos is a way for us to know ourselves.

Lastly, could stars possess a form of consciousness, à la *A Wrinkle in Time*? While that remains speculative, one thing's certain: stars embellish our universe and are instrumental in our creation.

Bonus Chapter IV:

Black Holes: Cosmic Death

We now turn our attention to one of the most fascinating objects in our universe: *black holes*.[*] Specifically, we'll look at how black holes collapse, the three main properties of black holes, what happens when you jump into a black hole, and how black holes evaporate through *Hawking Radiation*.

GRAVITATIONAL COLLAPSE OF A BLACK HOLE

Let's start by looking at the various things that happen when a black hole collapses. This includes (a) speculating as to how a singularity forms in a black hole, (b) identifying the key triggers for black hole formation, and (c) looking at the final state of a black hole.

We pick up where we left off in the last chapter: stars weighing more than 3 $M_\odot$, or three solar masses, at death. Overall, no one knows what the *exact* collapse of a black hole looks like, because the star gets so dense that the properties of the material become unknown.[106] That said, we can definitely speculate.

First, we know that the outer shell of the star at this stage has to be iron, because that is the maximum element the core of a star can fuse into. Second, we know near the center of the collapsing star there is a singularity that forms and creates the black hole. That's the basis for all we know: an iron core with a singularity at the middle (figure 76). The question now becomes: *what's in between and how does the singularity form?*

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[*] Black hole is a term coined by the legendary physicist John Wheeler.

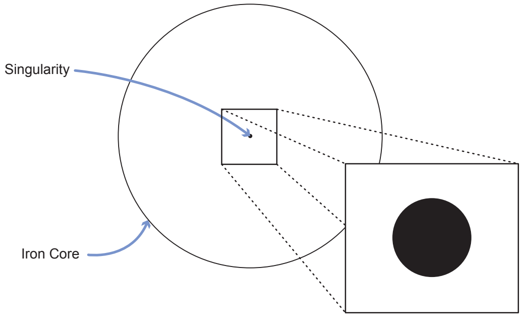

Figure 76. What's inside the core of a collapsing star that's greater than 3 $M_\odot$?

One idea, shared by revolutionary physicists Kip Thorne and Stephen Hawking, is the reverse of what happened in the Big Bang occurs during the gravitational collapse.[107] As we saw in an earlier Bonus Chapter, the Big Bang Model includes all the phases from the formation of a singularity to recombination. So, if the gravitational collapse of a star is similar to the Big Bang in reverse, then what would we see?

Well, at some point, the gravitational contraction becomes so big that the star becomes opaque—you can't see through it. Then, atoms dissolve into a particle soup in thermal equilibrium. From there, electromagnetism, the strong force, and the weak force recombine once again; a massive *deflation* occurs; and, lastly, in one Planck time, the curvature of spacetime is so great that a singularity forms, puncturing through the fabric of spacetime (figure 77). The singularity is hypothesized to have infinite density and curvature, yet zero volume.[108] This is a similar juxtaposition to the Cantor Set (uncountable, yet zero measure) except in three dimensions.[*]

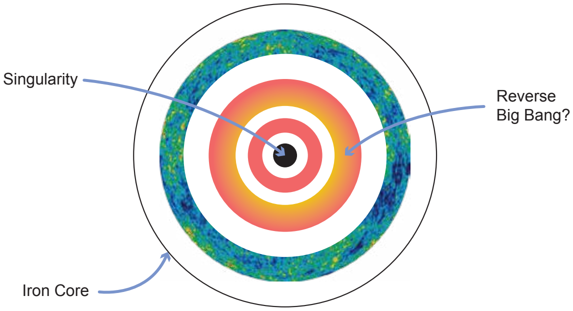

Figure 77. What happens inside the core of a collapsing black hole? Does the reverse of the Big Bang happen?

With this framing, we can now identify the key triggers for black hole formation. The first is the star's mass, as black holes can only form in stars larger than 3 $M_\odot$. In these behemoths, gravity overwhelms neutron degeneracy pressure and the star collapses on itself. Second, the star will only turn into a black hole when its mass fits within its *Schwarzschild radius*.[109] Thus, the Schwarzschild radius defines the size of the *event horizon*—the point at which no light can escape (figure 78).

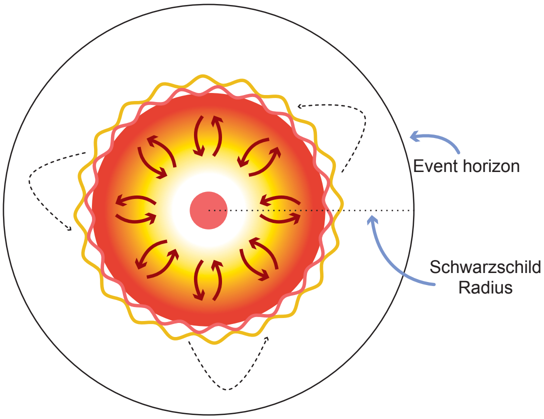

Figure 78. The Schwarzschild radius defines the event horizon of a star. Any signal sent from inside the event horizon will never be able to escape into the cosmos.

For example, the sun weighs 1 $M_\odot$, or 2×10^{27} kg, and has a radius of 692,000 km. In order for the sun to turn into a black hole, it would need to collapse all of its mass into a radius of 3 km. For a second example, the Earth weighs 6×10^{24} kg and has a radius of 6,300 km. For Earth to turn into a black hole, it's mass would need to collapse into a radius of 1 cm, the size of your fingernail.[110]

With this base understanding, we can extrapolate the concept of gravitational collapse to our embedding diagrams. Here, the Schwarzschild radius is discussed through the concept of a *critical circumference*, which is defined to be 18.5 kilometers times the mass of the star in solar masses.[*,111] For example, our sun, which weighs 1 $M_\odot$, would have a critical circumference of 18.5 kilometers.

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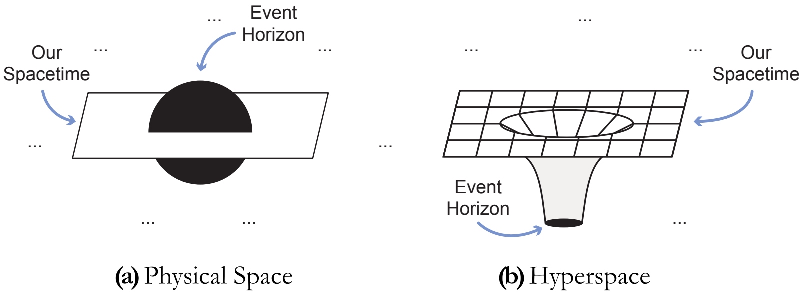
[*] The critical circumference is equal to $2\pi \times$ Schwarzschild Radius. The circumference is essentially the length of a stationary black hole's equator.

If we look in the physical space (figure 79-a), we would simply see the event horizon, which looks like nothing since light cannot escape. We can only detect an object with an event horizon through its gravitational effects on the surrounding area. In our embedding diagram (figure 79-b), we are able to more clearly see the effects of the black hole as it distorts and curvature of spacetime around it. Imagine placing a ball on a trampoline so heavy that it breaks the trampoline. But, even though the trampoline has a hole in it, the trampoline remains pulled downward instead of flinging back up.

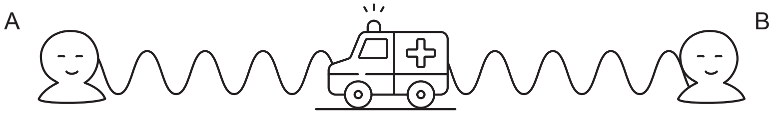


(a) Physical Space **(b)** Hyperspace

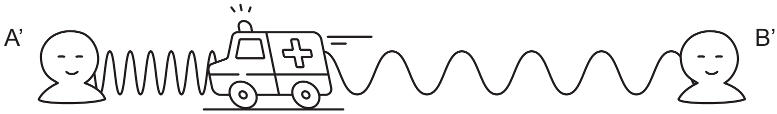
Figure 79. The critical circumference of a black hole is the point where the event horizon appears and tears through the fabric of spacetime.

A couple other interesting things happen as a black hole collapses. The three other concepts that we will discuss to deepen our understanding of the gravitational collapse are the *Doppler Effect*, the *Hoop Conjecture*, and the "*No Hair" Conjecture*. Afterwards, we'll look at the characteristics of a black hole.

The Doppler Effect is something we're all familiar with whenever we hear a loud siren whizzing past us in the streets. On one hand, in figure 80-a, an ambulance is stationary and equidistant from person A and person B. Therefore, the sound wave is the same for both observers. On the other hand, in figure 80-b, the ambulance moves toward person A'. In this scenario, the sound wave is "stretched out" to lower frequencies for observer B'; and, the sound wave is compressed to higher frequencies for observer A'. This is why there appears to be a "higher pitch" when you hear an ambulance coming towards you and a "lower pitch" when the ambulance is moving away from you.[112]



(a) Stationary ambulance



(b) Moving ambulance

Figure 80. The Doppler Effect explained. **(a)** Stationary ambulance—everything sounds the same. **(b)** Moving ambulance—sound is perceived differently by both observers.

In physics, when light from a source is compressed towards an observer, it is called *blueshifted*. If the light from another source is stretched away from an observer it is called *redshifted*. This essentially tells us whether something is moving towards us (blueshifted) or away from us (redshifted). For instance, what happens when we look at distorted visible light? Extremely blueshifted visible light would look like gamma rays (short wavelengths), while extremely redshifted visible light would appear as radio signals (long wavelengths).

Understanding the Doppler Effect becomes vital when studying space, because it allows us to see whether a star or galaxy is moving towards us or away from us. In our observable universe, almost everything seems to be moving away from us (i.e. redshifted). This excludes a few hundred galaxies nearby, like Andromeda, which are blueshifted. This means that in 4 billion years or so, the Milky Way and Andromeda will collide in a beautiful merger of galaxies.[113]

That said, it is not as simple as "galaxies are receding away from us". In fact, the reason we see a redshift in most galaxies is because the space between us and the other galaxies is expanding. This phenomena is due to dark energy, which is constant at every point in space and time, and is responsible for the universal expansion of space. So, as a photon from a distant galaxy traverses through the cosmos to get to us, the distance it takes to reach us continuously gets larger and larger.[114] Therefore, due to the continuous expansion of space on the photon's path, the photon gets more and more redshifted as it makes its way towards us. For example, in Chapter 6, The Sunset Conjecture, we observed a point that was once 42 *million* light years away actually took 13.8 *billion* light years to reach us! That same point today is around 46 *billion* light years away. All in all, the constant expansion of space increases the wavelength of the photon making it appear redshifted.

To see how the expansion of space and the Doppler Effect relates to black holes, we turn to Kip Thorne's catch all book *Black Holes & Time Warps*. As stars contract, they continuously deepen the curvature of spacetime around it, which adds more space the light needs to traverse. More space to traverse means more time for the light to reach its final destination. Therefore, the deeper the gravitational well, the more redshifted the light becomes (figure 81). At 4× the critical circumference, light is redshifted 15%. At 2× the critical circumference, light is redshifted 41%. Once a star reaches the critical circumference, no light is emitted, as no light can escape the curvature of spacetime.[115] At this point, the star forms its event horizon.

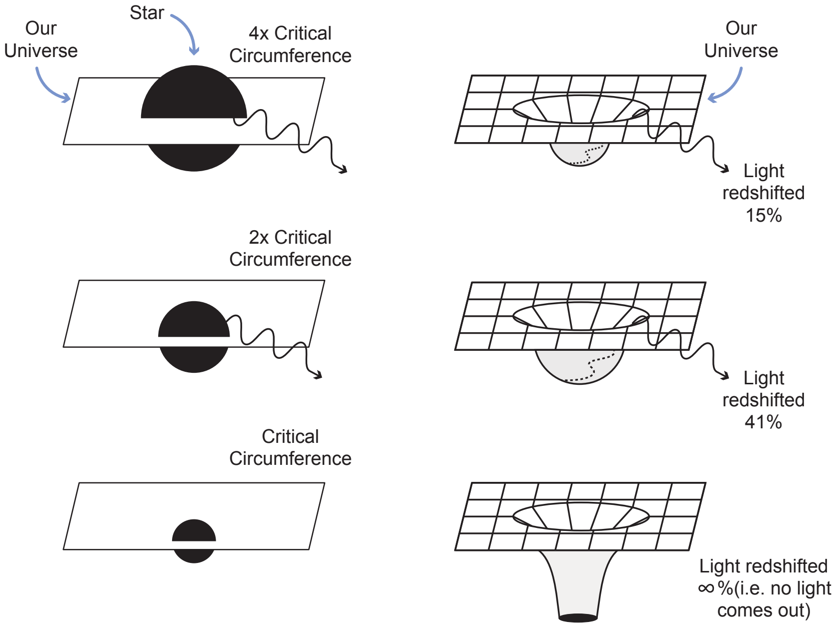


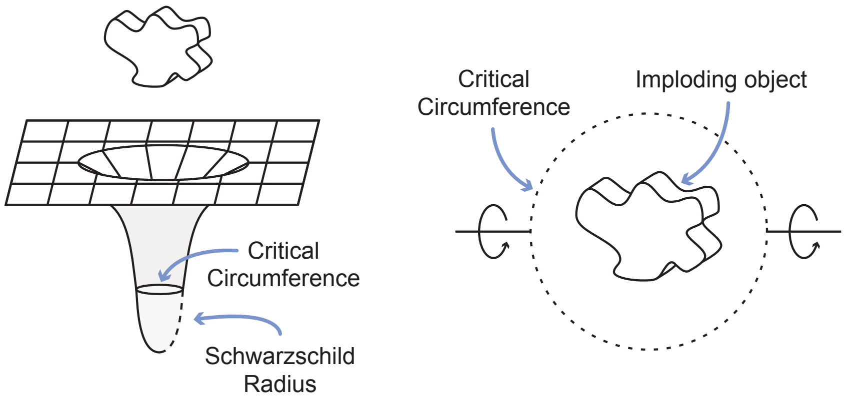
Figure 81. The redshift of light at various circumferences of an imploding massive star.

Let's delve into the Hoop Conjecture next. While we've previously discussed the critical circumference—essentially the threshold size an imploding object can reach before becoming a black hole—that discussion largely pertained to spherical objects. But what about objects that aren't perfectly round? Enter the Hoop Conjecture, a concept introduced by Kip Thorne.

The Hoop Conjecture posits:

> *An imploding object forms a black holes when, and only when, the critical circumference can be placed around the object and rotated.*

In simpler terms, imagine drawing a sphere around an object using the Schwarzschild radius as the sphere's radius. The object will only collapse into a black hole if the objects fits entirely within this sphere (figure 82). Even if a tiny portion of the object extends beyond this critical boundary, it won't collapse. The intriguing aspect is that an imploding object doesn't need to be perfectly spherical to collapse. Yet, once it does collapse, the resulting black hole is always spherical, regardless of the original object's shape. We'll delve deeper into this phenomenon next.[116]



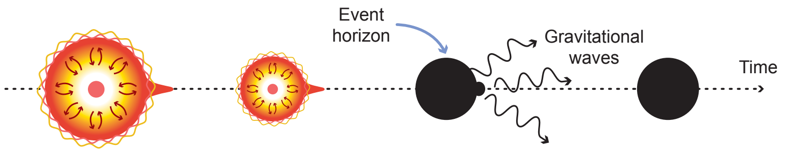
(a) Imploding object in hyperspace **(b)** Hoop conjecture visualized

Figure 82. The hoop conjecture. An imploding object will form a black only when the critical circumference can be placed around the object and rotated.

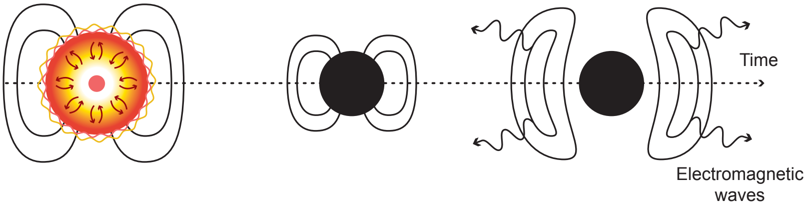
[*] As Thorne states, this conjecture has not been explicitly proven, yet.

The Hoop Conjecture naturally segues into our final topic on gravitational collapse: the "No Hair" Conjecture. This principle asserts that regardless of an imploding object's initial size or shape, the end result is always a spherical black hole. Whether it's a massive cube or a colossal pyramid, the outcome is the same: a sphere.

It's worth noting that this transformation applies even if the imploding object has significant deformities, such as a large mountainous protrusion on its surface (figure 83-a). Once the object surpasses the critical circumference, any excess mass is shed as gravitational waves. As aptly put by physicist Richard Price, who introduced the No Hair Conjecture, "Whatever can be radiated will be radiated." This principle also extends to any magnetic field lines associated with the star (figure 83-b). As the star reaches the critical circumference, its magnetic field lines are expelled as electromagnetic radiation, or light.[117]



(a) Emission of gravitational waves due to excess matter



(b) Emission of electromagnetic waves due to star's magnetic field

Figure 83. The transformation during a star's collapse leaves it with "no hairs". **(a)** Gravitational waves ensure the black hole's spherical shape. **(b)** The star's magnetic field is released into space during the formation of the black hole.

Let's visualize the entire process of a black hole's collapse in a single graphic (figure 84). This illustration chronicles the star's journey through time, progressing from the bottom upwards. At the outset, we witness the star in its prime, radiating brilliantly. As time progresses, the star begins its implosion, culminating in the formation of a singularity. This event heralds the emergence of an absolute horizon, which continues to expand until it breaches the star's surface, giving rise to the familiar event horizon. The diagram also traces potential trajectories of particles, or signals, labeled as AA', BB', CC', and DD'. The absolute horizon is the boundary between events that can send signals to the distant Universe (like AA' and DD') and events that cannot send signals to the distant Universe (like BB' and CC').[118]

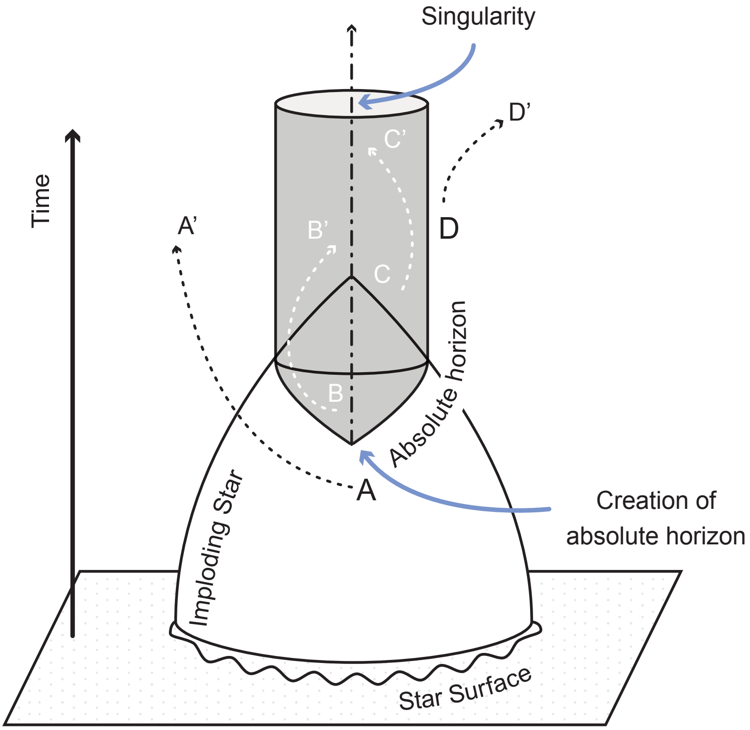


Figure 84. The gravitational collapse of a star forms an absolute horizon which eventually engulfs the star.

The horizon's expansion is fueled by the material it consumes from the imploding star. Yet, a peculiar phenomenon is observed: the black hole seems to expand in anticipation of the incoming matter. It's as if the "effect" (the expanding horizon) manifests before its "cause"(the approaching material). Kip Thorne encapsulates this enigma:

> *When matter falls into a black hole, the absolute horizon starts to grow ("effect") before the matter reaches it ("cause"). The horizon grows in anticipation that the matter will soon be swallowed and will increase the hole's gravitational pull.*[119]

This observation challenges our conventional understanding of cause and effect. It raises intriguing questions: What drives this anticipatory growth? Does it influence other existing phenomena, like dark matter? The answers remain elusive.

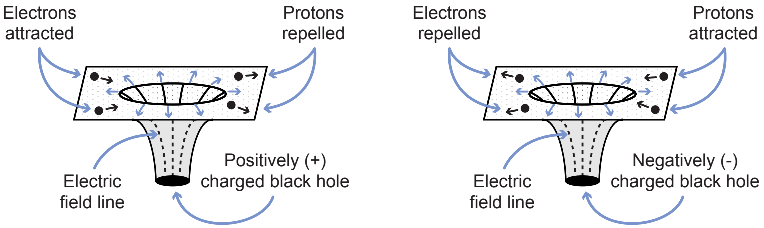
In summary, a black hole emerges when an object is compressed within its Schwarzschild radius. This compression births a singularity that consumes the star from the inside, until the event horizon surfaces. Anything emitted within this horizon remains trapped, rendering black holes elusive. However, their profound impact on surrounding space offers alternative detection methods. We also learned that upon collapse, black holes assume a spherical form, devoid of "hairs". In the subsequent section, we'll delve into the properties of black holes

PROPERTIES OF A BLACK HOLE

In describing a black hole, three key properties come to the fore: its mass, charge, and spin.[120] While we've delved into the mass aspect, let's turn our attention to the latter two.

First on deck: *charge*. As discussed in an earlier bonus chapter, a charge is indicative of the electromagnetic force. It is a property pertaining to a particle or object, making that object either positive (+) or negative (-). Opposite charges attract, while like charges repel. This principle explains why negatively charged electrons form a cloud around the positively charged nucleus in atoms.

When black holes acquire a charge, they emit electric field lines radiating outward. A positively charged black hole will repel protons and attract electrons (figure 85-a), while a negatively charged one does the opposite (figure 85-b). below.[*, 121]



(a) Positive **(b)** Negative

Figure 85. **(a)** Positive and **(b)** negatively charged black holes.

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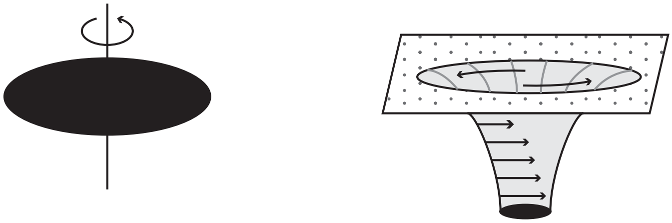
[*] It's worth noting that the field lines do not go through the hole. The surface charge of the horizon is precisely the right amount as to terminate all field lines which intersect the horizon.

Now, let's discuss spin. Black holes can spin in two primary ways. They can inherit spin from a rotating star that collapses into a black hole or gain spin when infused with rapidly rotating matter. When the hole spins, it bulges out at the center, similarly to how the radius of the Earth's equator is 22 km longer that the radius to its poles.[122]

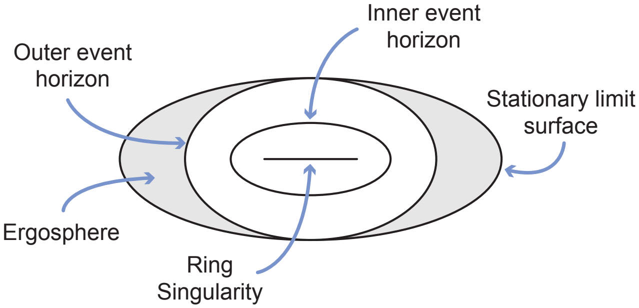
Intriguingly, black holes have a spin speed limit. For instance, for a sun-massed black hole, the maximum spin rate is one revolution every 0.000062 seconds (62 microseconds). With the hole's critical circumference being around 18.5 km, this creates a spin rate around (18.5 km) / (0.000062 s) ~ 186,000 miles per second. Surprise, surprise—the maximum spin rate is the speed of light![123]

The concept of a spinning black hole is illustrated in the below pictures. Here, we have a black hole spinning in physical space (figure 86-a) and in hyperspace (figure 86-b). Spinning black holes have a couple other interesting properties (figure 86-c).



(a) Rotating black hole in physical space

(b) Rotating black hole in hyperspace



(c) Rotating black holes have a ring singularity and two event horizons

Figure 86. A rotating black hole. Particles in the ergosphere can escape the black hole's gasp, while particles inside the event horizons cannot.

First, spinning black holes have a *ring singularity* as opposed to a singularity at the center. Second, spinning black holes have an *ergosphere*. Anything in this region cannot sit still and is forced to move in the direction of the spinning black hole. Stepping into the ergosphere would be like jumping onto a merry-go-round. Once you're on, you're forced to move in the direction of the ride. That said, just like a merry-go-round, you can still move toward or away from the event horizon—you're not trapped yet. The edge of the ergosphere is dubbed the *stationary limit surface*, as it is the point where an observer can no longer simply sit still. Once inside the ergosphere, you are forced to go on the ride.[124]

Furthermore, unlike stationary black holes, spinning black holes have two event horizons. The outer event horizon acts like a typical event horizon—particles inside the horizon cannot escape to the greater cosmos. That said, the inner event horizon acts a bit differently. Inside the inner event horizon, closed timelike paths loops are possible (figure 87). In this whacky scenario, we could travel in a timelike path towards the future and, eventually, we would meet ourselves at some moment in our past.[125]

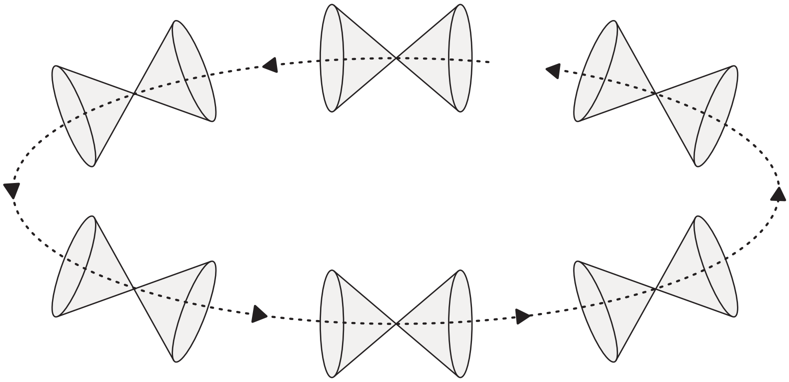


Figure 87. A closed timelike loop inside the inner ring of a spinning black hole. In the future, you would meet your past self.

As physicist Sean Carroll insightfully remarks, "You can therefore meet yourself in the past, with all that entails. . . Of course, it is unlikely that realistic gravitational collapse leads to these bizarre spacetimes. It is nevertheless always useful to have exact solutions."[126] In simpler terms, while the theory tantalizingly suggests a rendezvous with one's past self, it's improbable in real-world scenarios. Nevertheless, it's a captivating concept to muse over.

FALLING INTO A BLACK HOLE

In the realm of black holes, perception is everything. The experience of an object falling into a black hole varies dramatically depending on the observer's vantage point. This idea of differing reference frames was first introduced by David Finkelstein. Let's delve into this concept with a thought experiment inspired by Kip Thorne, featuring our illustrative companions, Joe and Misty.

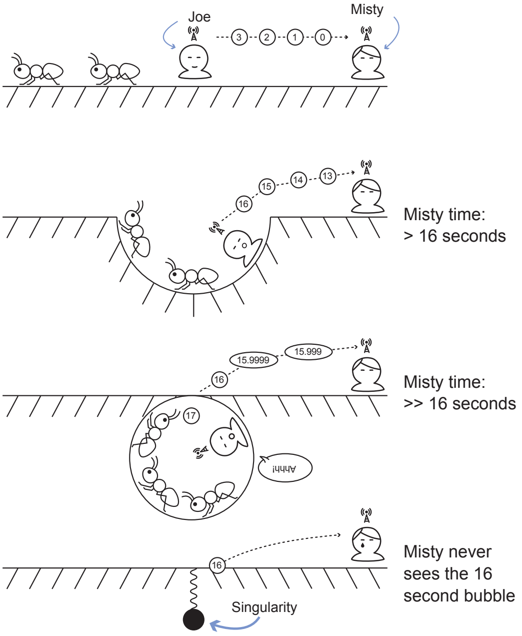
One day, Joe and Misty decide to use their imagination to travel to a collapsing star with some friendly neighborhood ants. Joe decides he will enjoy the gravitational collapse, while Misty watches from a safe distance. They've heard wacky things happen near black holes and therefore decide to remain in constant contact through a radio. Using these radios, Joe will send Misty continuous signals to let Misty know how much time Joe has experienced.

At the beginning (figure 88-a), Joe starts his journey with the ants and is able to emit radio waves at constant intervals to Misty. How much time Joe has experienced is illustrated in the bubbles. At this point, Joe's time and Misty's time are nearly identical.

Suddenly, the star Joe is on starts to collapse—the beginnings of a black hole (figure 88-b). When this happens, the curvature of spacetime starts to change. As the contraction occurs, Joe experiences a different time than Misty. For instance, when Joe sends the signal for "16 seconds," Misty's watch reads something more than 16 seconds. In other words, the spacing between the balls, which was at one point constant, changes. The balls are received by Misty at more and more widely spaced time intervals.

Eventually (figure 88-c), the star collapses completely and turns into a black hole when the star's mass fits inside its Schwarzschild Radius. Let's say this happens at 16 seconds in Joe's time. For Joe, his "16 seconds" signal is unable to escape the grasp of the collapse. The signal gets stuck with him and the ants. For Misty, she still continues to see a signal from Joe, but never sees the "16 seconds" signal. Instead, Misty sees Joe's signals asymptotically approach the "16 seconds" signal. First, 15.999 seconds. Then, 15.99999 seconds. Then, 15.99999999999 seconds...

In the end (figure 88-d), Misty will continue seeing the signal approach the 16 seconds bubble, but will never actually see the full 16 second bubble! The 16 second bubble will eventually get fainter and more red as Misty continues to wait for the signal until her final days. . .



(a) No collapse, Joe and Misty perceive the same time

(b) Collapse, Joe and Misty perceive different times

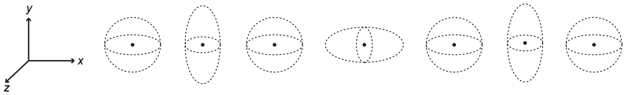
(c) Full Collapse, Joe can no longer send messages to Misty

(d) Full Collapse, Joe and the ants are crushed into a singularity. Misty is in dispair

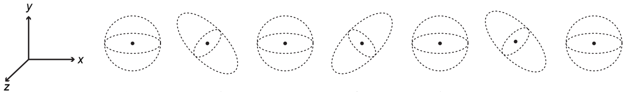
Figure 88. What happens during the gravitational collapse of a black hole.

This example does a great job capturing what actually happens during the collapse of a black hole. Misty, at a safe distance away from the collapse, would never actually see Joe go through the black hole. Instead, Misty would see the Joe and the 16 second signal frozen in time. The signal would get fainter and "redder" (i.e. redshifted) and would never fully disappear. Joe's experience, however, is drastically different. After crossing the event horizon, he's inexorably drawn towards the black hole's singularity.

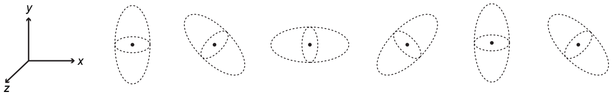
As Joe and the ants near the singularity, they encounter intense gravitational waves. These waves distort spacetime based on their polarization. For example, in figure 89-a, the "+" polarization causes the object to stretch vertically while compressing horizontally. After this deformation, the object returns to its original shape before the roles reverse: it then stretches horizontally and compresses vertically. This cycle continues indefinitely. Figures 89-b and 89-c depict other polarizations: the "x" polarization and the right-hand polarization, respectively.[127] In reality, the gravitational wave would probably be a superposition (i.e. a random mix) of the different types of polarizations, amongst three spatial dimensions .[128]



(a) "+" polarization in the x-y plane



(b) "x" polarization in the x-y plane



(c) Right hand polarization in the x-y plane

Figure 89. Different types of polarization of gravitational waves.

If we had to guess as to what Joe and the ants would experience—we can imagine that it would look a little something like figure 90. Basically, they'd get stretched out into all sorts of funky directions as they approach the singularity. The closer they get to the singularity, the faster the oscillations become and the stronger they get. Joe and the ants would most likely get stretched infinitely in one direction and squeezed to nothing along the other directions. Or, the singularity could rip them apart.[129]

That said, no one actually knows what happens inside a singularity. As Stephen Hawking states: "The singularity is outside the scope of presently known laws."[130] Time could cease to exist. Space and time could even split up. At this juncture, the realm of quantum gravity dominates, a field still shrouded in mystery and uncertainty.[131] So, I guess we'll have to jump into a black hole to find out—any volunteers?

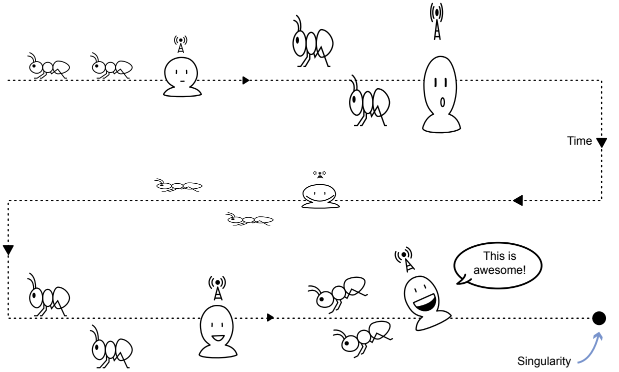
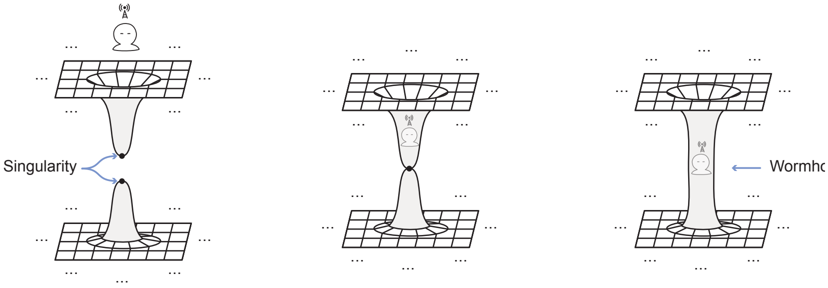
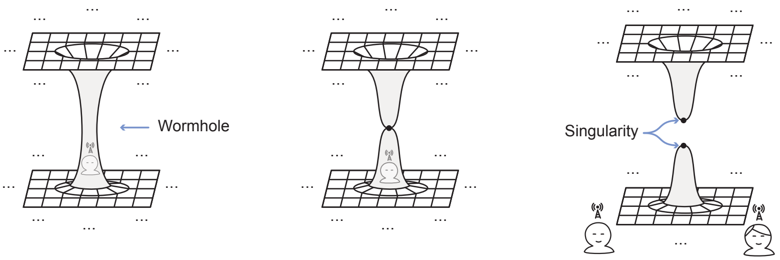


Figure 90. The gravitational waves distorting the reality of Joe and the ants in all different shapes and form until the singularity is reached.

Now, something else can happen when one jumps into a black hole. A *wormhole* can occur. Wormholes are theoretical play toys, but they are possible in general relativity. Wormholes are exactly what you expect them to be: they take you from one point in spacetime to another. This is similar to the concept of the re-bounding universe at the initiation of the Big Bang. Essentially, one could avoid hitting the singularity and be ejected into another point in spacetime, or another point in a different spacetime![132] If that's the case, then it is possible that Joe and the ants could be reunited with their dear friend, Misty (figure 162)![*, 133]



(a) Two singularities at far apart distances **(b)** Two singularities annihilate **(c)** Annihilation causes wormhole



(d) Wormhole begins to contract **(e)** Wormhole is "pinched off" **(f)** Two final singularities

Figure 91. The creation process of a wormhole. Joe could pass through the wormhole and end up at a different point in the same, or another, spacetime.

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[*] Wormholes can occur if there is "exotic material" in the form of negative pressure density or when the charge density is larger than the matter density.

BLACK HOLES EVAPORATION

Black holes evaporate. What a thought. Only a guy as smart and crazy as Yakov Borisovich Zel'dovich could think of such a thing. Though his reasoning was a bit off, it inspired a wacky and charismatic character in Stephen Hawking to come up with a more concrete description of the evaporation of black holes; hence the name *Hawking Radiation*.[134] This is where we continue our story.

How can black holes evaporate? The concept is puzzling. If nothing can escape a black hole, how can it lose energy? It's not quite like stars radiating energy. The key lies in the quirky realm of quantum mechanics and the behavior of antimatter.

Antimatter is the anathema to regular matter. Antiparticles are the exact same as their counterpart, except they have the opposite charge. When a particle-antiparticle pair comes together, they annihilate into energy. Of course, it is possible for energy to spontaneously disintegrate into a matter-antimatter pair as well. For instance, when an antielectron and electron annihilate they create a photon (i.e. light). After a short period of time, the photon can turn back into another pair, such as an antimuon-muon pair (figure 92). The below diagram is an example of a Feynman diagram.

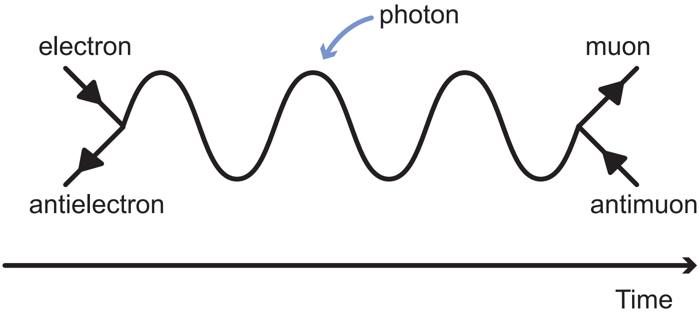
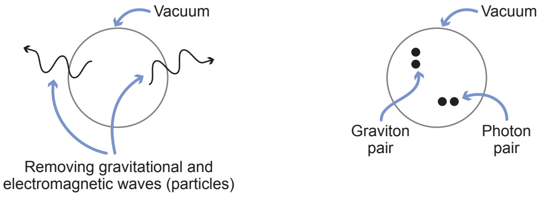


Figure 92. An antielectron and electron collide to create a photon. Over a short period of time, the photon disintegrates into a muon and antimuon.

Now, what happens when we try to create a perfect vacuum, devoid of all particles? It turns out that the universe abhors a perfect vacuum. In these near-empty spaces, tiny fluctuations occur, leading to the spontaneous creation and annihilation of particle-antiparticle pairs, known as *vacuum fluctuations* (figure 93).



(a) Removing matter or radiation from a space

(b) Virtual particles appear for a short period of time in pairs

Figure 93. Vacuum fluctuations occur when removing too many particles/waves in an area, which causes new pairs of particles/antiparticles to appear.

The behavior of these fleeting particles can be likened to the principles of electron and neutron degeneracy pressures discussed before.[135] In those scenarios, as particles were increasingly confined to tighter spaces, they sped up, creating a resistive force against gravitational collapse. Similarly, when attempting to clear a region of all electromagnetic and gravitational particles, the universe responds by spontaneously producing new particle/antiparticle pairs. For instance, in the realm of electromagnetism and gravity, these pairs manifest as photons and gravitons, respectively.

These transient entities are termed *virtual particles*. Their existence is ephemeral; they momentarily manifest by borrowing energy from nearby space, only to annihilate shortly after, returning the borrowed energy.[136] So, for vacuum fluctuations, we could have virtual photons, virtual gravitons, virtual gluons, etc. (figure 94). [137] But how is the energy of these virtual particles balanced? Since energy conservation is a fundamental principle, one of the particles possesses positive energy and the other particle has negative energy.[138] This concept is illustrated below with a real electron/antielectron pair forming for a short period of time and then annihilating.

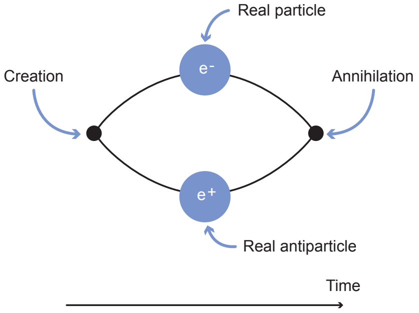
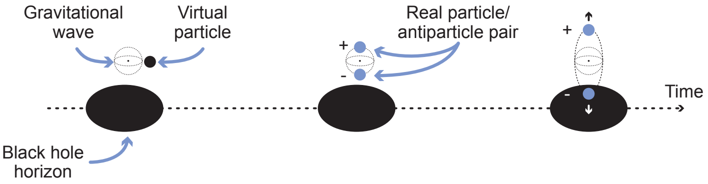


Figure 94. A virtual particle is a particle/antiparticle pair that is created for a short period of time in “empty” space.

Combining virtual particles with black holes leads to Hawking Radiation. To understand this, let's start with a reference frame very near a black hole, like Joe. In this vicinity, particle/antiparticle pairs spontaneously form and annihilate. Given the intense gravitational forces near the black hole, when these pairs form, the gravitational pull can separate them before they have a chance to annihilate. One particle will fly outwards from the hole and one will fly inwards towards the hole.

Recall that virtual particles, on average, possess no net energy. This means one particle of the pair has positive energy, while the other has negative energy. In the intense gravitational environment of a black hole, the negative energy particle can be captured by the black hole, while its positive energy counterpart escapes into space. This process effectively reduces the black hole's mass and energy, as described by Einstein's equation, . Over time, this leads to the black hole losing mass and "evaporating". The dynamics of this phenomenon are depicted in the following illustration.[139]



(a) Virtual particle approaches black hole

(b) Virtual particle splits into two real particles

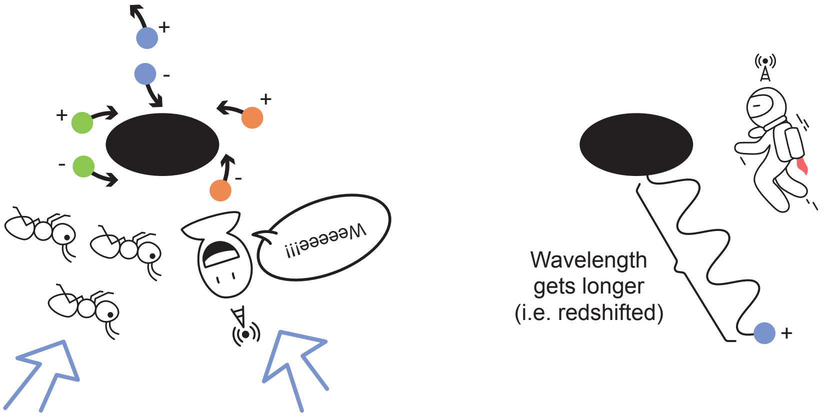
(c) Gravitational wave pulls real particles apart

Figure 95. The evaporation of a black hole.

Now, all that was from Joe's reference frame, somewhere near the black hole. What would Misty see as she awaits for a signal from Joe? If Misty was at a safe distance from the black hole, then she primarily observes the particles that manage to escape the black hole's gravitational pull. These escaping particles, carrying positive energy, would appear redshifted to her due to their journey from the intense gravitational field.

Misty's perspective is often termed the *accelerated viewpoint*. To maintain her position and not be pulled into the black hole, she'd need to counteract the gravitational pull, perhaps with powerful thrusters. The contrasting observations of Joe and Misty are depicted in the following illustration (figure 96). Joe sees the effects of vacuum fluctuations, while Misty only sees the particles that make it out of the black hole's gravitational grasp with a longer wavelength.

For instance, the wavelength emitted by a black hole twice as large as our sun would be around 9 km–much larger than our ordinary radio waves!



(a) Falling viewpoint **(b)** Accelerated viewpoint

Figure 96. The falling viewpoint sees virtual particles, while the accelerate viewpoint does not.

All in all, Hawking calculated that the black hole will keep evaporating until it's spin has come to a halt. From there, the evaporation accelerates until the black hole diminishes to a minuscule size, at which point it undergoes a cataclysmic explosion. Kip Thorne provides a vivid illustration:

> *A hole that has recently formed by stellar implosion (and that thus has a mass larger than about 2 Suns) has a very low temperature: less than degrees above absolute zero (0.03 microkelvin). Therefore, the evaporation at first is very slow; so slow that the hole will require longer than* 10^{67} *years (*10^{57} *times the present age of the Universe) to shrink appreciably. However, as the hole shrinks and heats up, it will radiate more strongly and its evaporation will quicken. Finally, when the hole's mass has been reduced to somewhere between a thousand tons and 100 million tons (we are not sure where), and its horizon has shrunk to a fraction the size of an atomic nucleus, the hole will be so extremely hot (between a trillion and 100,000 trillion degrees) that it will explode violently, in a fraction of a second.*[140]

But what remains after a black hole has entirely evaporated? The answer remains elusive. One intriguing possibility is the emergence of a *naked singularity*—a singularity devoid of an event horizon, making it observable from the external universe. That said, Roger Penrose, renowned for integrating topology into physics, conjectured that "no imploding object can ever form a naked singularity; if a singularity is formed, it must be clothed in a horizon so that we in the external Universe cannot see it."

Kip Thorne and John Preskill famously wagered with Stephen Hawking on the possibility of a naked singularity's existence. While they believed in its feasibility, Hawking disagreed. Yet, a mere four months later, Hawking's own research indicated that a fully evaporated black hole might leave behind such a singularity. Ironically, it appeared Hawking had disproven his own stance. However, in a twist of wit, Hawking pointed out that the bet's terms specified the impossibility of naked singularities under the rules of general relativity. Since Hawking radiation emerges from quantum mechanics, he hadn't technically lost. A cheeky move by the brilliant physicist.[141]

Bonus Chapter V:

Galaxies: Life in Death

The final stop on our bonus chapters comes at taking a look at how galaxies form. Many galaxies form after the collapse of a black hole and are a natural continuation of our conversation. We'll start by building general sense of how galaxies form in general. Then, we'll take a closer look at the giant black hole centering most galaxies. Finally, we'll briefly discuss the solar system.

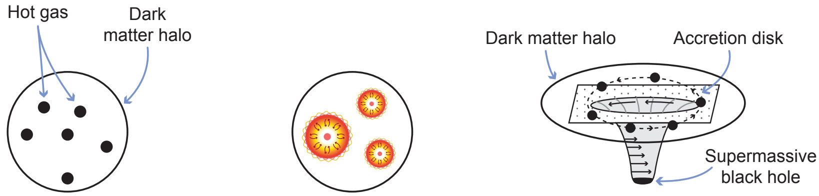
DARK MATTER AND GALAXY FORMATION

True structure formation, including the emergence of nebulas and stars, began approximately 50,000 years after the Big Bang when the universe transitioned to being matter-dominated. This transition is logical since matter domination allows gravity to pull matter together, facilitating the formation of cosmic structures.[142]

The matter we're familiar with, encompassing protons, neutrons, and electrons, is termed *baryonic matter,* and it is part of the Standard Model. However, there's another elusive form of matter known as "dark matter". While its exact nature remains a mystery due to its non-interaction with light, it significantly outweighs baryonic matter. In the observable universe, dark matter accounts for about 23% of the energy density, baryonic matter for 4%, and the enigmatic dark energy, driving the universe's expansion, comprises the remaining 73%.[143]

In the most general sense, galaxy formation goes as follows. First, dark matter acts as gravitational seeds that bring hot gas together (figure 97-a).

These seeds are often called *dark matter halos*. The hot cloud of gas then cools down to a certain temperature that allows stars formation (figure 97-b). It is theorized that the first generation of stars were much more massive than typical stars. Therefore, when they collapsed, they form *supermassive black holes*. These black holes then form a giant accretion disk, which eventually become galaxies. Namely, the gas in the accretion disk turns into stars, planets, and other cosmological objects. (figure 97-c).[144]



(a) Dark matter halo accumulates hot gas

(b) Hot gas cools, allowing star formation within dark matter halo

(c) Large star collapses into supermassive black holes within dark matter halo

Figure 97. High level overview of how an individual galactic system forms.

However, the universe's intricacies mean that this process isn't uniform. Galaxies and their associated dark matter halos don't exist in isolation. For example, smaller galactic structures can merge to create larger systems, a phenomenon termed the *bottom-up* approach. This merging can occur at any stage, whether it's dark matter halos, gas clouds, or even fully-formed galaxies (figure 98-a). Conversely, larger galactic structures can fragment, leading to the creation of smaller galaxies. In this *top-down* scenario, a massive dark matter halo, resembling a cosmic "pancake", disintegrates into smaller galaxies (figure 98-b).[145]

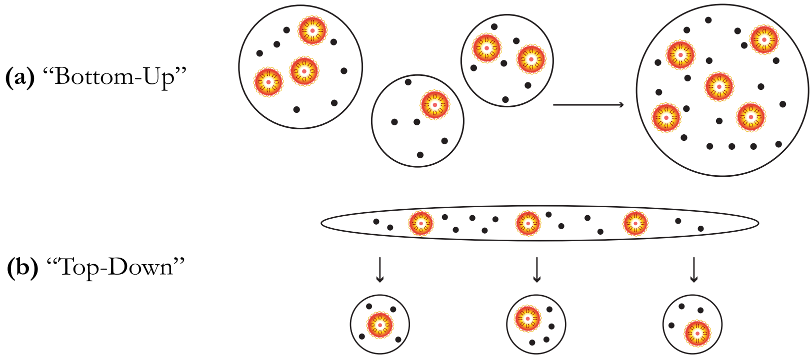


Figure 98. (a) Smaller galactic structures merging together. **(b)** Larger galactic structures breaking down into smaller ones.

Galaxies manifest in a myriad of shapes and sizes. Broadly, they are categorized into three primary types: elliptical, spiral, and irregular. Their sizes can range dramatically, from dwarf galaxies, home to as few as 100 million stars, to colossal galaxies boasting over a trillion stars. Elliptical galaxies can range in shape from nearly circular to highly elongated (figure 99-a). Dominated by older stars, they rarely engage in active star formation. In contrast, spiral galaxies comprise a large fraction of all the galaxies in the local universe and are actively forming stars (figure 99-b). Our very own Milky Way is a prime example of a spiral galaxy. Irregular galaxies don't conform to the typical structures, lacking a pronounced bulge or a rotationally symmetric disk (figure 99-c).[146] They are most commonly found in the early universe.

(a) ESO 325-G004 by ESA/Hubble

(b) NGC 5457 by ESA/Hubble

(c) NGC 1427A by ESA/Hubble

Figure 99. **(a)** Elliptical galaxy. **(b)** Spiral galaxy. **(c)** Irregular galaxy.

By far and large, the most interesting thing about galaxies are the mysterious dark matter halos. You might wonder: *how do we know these halos exist?* When physicists observe a galaxy, they anticipate its rotation to behave in a certain manner based on its visible mass distribution. Specifically, the outer layers of the galaxy should rotate more slowly than the inner layers. Yet, galaxies present a counterintuitive behavior: the rotational speed remains consistent as one moves outward from the center. The prevailing hypothesis is that an enveloping dark matter halo stabilizes the galaxy's rotation. For perspective, visible matter in the Milky Way weighs in at around $M_\odot$, while dark matter's mass comes in at around $10^{12}\ M_\odot$. Dark matter evidently outweighs regular matter by a significant margin![147]

This dark matter puzzle is depicted in the graph of the Messier 33 galaxy below. The y-axis represents velocity, and the x-axis indicates distance from the galaxy's center. The expected velocity, based on visible matter distribution, is shown by the grey dashed line. In contrast, the observed velocity is represented by the solid line. Notably, the galaxy's speed remains consistent as one moves farther from its center. The inner values of the solid line, derived from starlight observations, are marked in yellow. The outer observations, sourced from hydrogen atom light, are in blue. Dark matter remains a captivating enigma!

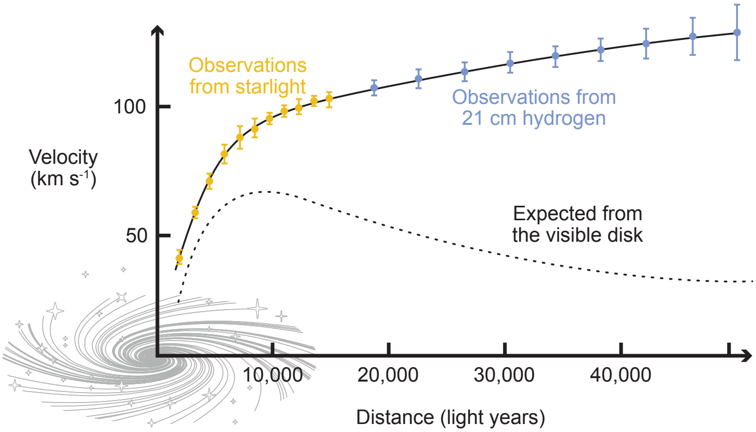


Figure 100. The unexpected rotation of galaxies, as illustrated here, is a primary reason physicists postulate the existence of dark matter.

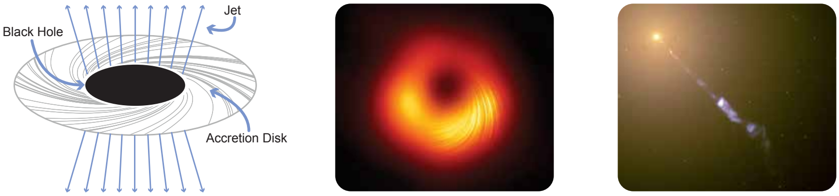
QUASARS

Around 3.5 billion years after the Big Bang was when there was the highest peak of star, black hole, and galaxy formation in our universe's history.[148] For these reasons, it is often dubbed *cosmic noon*.

Many galaxies, as previously mentioned, harbor supermassive black holes at their cores, playing a pivotal role in their formation. In fact, nearly all sizable spherical and elliptical galaxies boast a supermassive black hole at their heart.[149] These black holes engage with the surrounding gas, giving rise to what's termed an Active Galactic Nuclei (AGN). An AGN is a compact region at a galaxy's center that emits an astonishingly bright light, often outshining its entire host galaxy, sometimes by a factor reaching into the thousands! While there are various types of AGNs, this section will spotlight the most captivating and potent of them all: quasars.[150]

What exactly is a quasar? In essence, a quasar is an astoundingly luminous celestial body, thought to be powered by a supermassive black hole, ranging from millions to billions of times the mass of our Sun, and characterized by two immense jets emanating from it.[151]

To break it down, as the supermassive black hole takes shape, its surrounding accretion disk begins to heat up. As the gas from this disk gets consumed by the black hole, the black hole's spin accelerates, eventually reaching its peak rotational speed—the speed of light During this dynamic process, the black hole releases potent jets in opposite directions, which can span distances exceeding a million light-years.[152] The conceptual representation of a quasar in space can be seen in figure 101-a. Additionally, figure 101-b showcases an actual image of a supermassive black hole at the heart of the M87 galaxy, situated 55 million light-years away. When observed from a greater distance, as in figure 101-c, the prodigious jet is unmistakably evident.



(a) Representation of a supermassive black hole

(b) Black hole at the center of galaxy M87 by Event Horizon Telesecope Team

(c) Galaxy M87 producing a jet by Hubble Telescope Team

Figure 101. A supermassive blackhole that accumulates an accretion disk and produces a powerful jet.

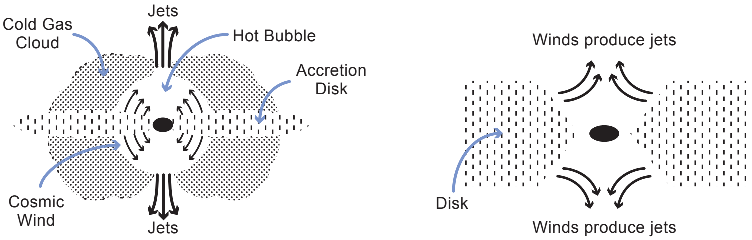
A logical follow-up question is: *how exactly are these jets formed?* There are several theories, and the true mechanism might be a blend of them. These theories, proposed by luminaries, like Roger Blandford, Martin Rees, Donald Lynden-Bell, and Roman Znajek, are outlined below (figure 102):

1. **Gas Cloud Interaction** (figure 102-a): A large, cold gas cloud surrounds the accretion disk near the black hole's center. As the gas from this disk nears the black hole, it heats up, generating cosmic winds, which create a hot gas bubble within the cold gas cloud. This hot gas then blows out from the top and bottom of the larger agas cloud, forming two orifices from which the jets emerge.

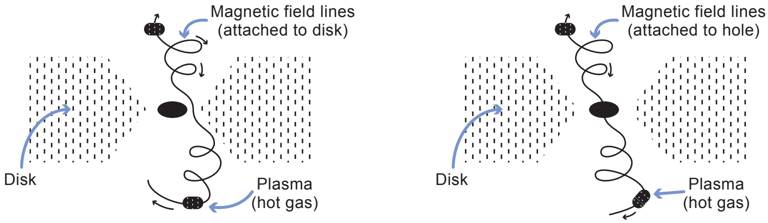
2. **Whirlpool Effect** (figure 102-b): The accretion disk becomes intensely hot, causing its internal pressure to rise. This makes the disk expand and thicken. The gas's orbital motion in the disk creates a vortex, reminiscent of water draining in a whirlpool. The two funnel-like faces of this vortex then expel strong winds, leading to jet formation.

3. Magnetic Field Lines (figure 102-c): The spinning gas of the disk produces magnetic field lines that spiral upwards and downwards. The hot ionized gas (plasma) from the disk sticks to these magnetic lines, moving along them without crossing. As the plasma travels along these lines, it gets propelled upwards or downwards, forming the two distinct jets.

4. Blandford-Znajek Process (figure 102-d): This mechanism is somewhat akin to the previous one but with a twist. Instead of the magnetic field lines attaching to the gas in the accretion disk, they thread through the black hole itself. While one might wonder how a black hole can possess magnetic field lines given the "No Hair" Conjecture, it's essential to note that this conjecture applies to isolated black holes. In this scenario, the magnetized gas from the accretion disk, as it approaches the black hole, attempts to drag its magnetic field lines along. However, upon reaching the event horizon, these magnetic lines are severed, leaving them protruding from the horizon and threading through the black hole. The black hole's spin then twirls these magnetic lines, flinging the plasma upwards or downwards, thereby producing the impressive jets. The key distinction here is the magnetic field lines are attached to the black hole, instead of the accretion disk, like in the previous process.[153]



(a) Hole in gas cloud **(b)** Winds from disk



(c) Magnetic field lines from disk **(d)** Blandford-Znajek Process

Figure 102. The four ways powerful jets are produced around supermassive black holes.

Quasars captivate our attention due to their unparalleled power, tearing through spacetime in ways unmatched by any other cosmic entity. Take quasar 3C273, for example: it outshines even the most luminous galaxies by a factor of 100. Yet, while a galaxy emits light across a vast expanse of about 100,000 light-years, 3C273 achieves its brilliance within a mere light month![154]

It is theorized that most galaxies have experienced one or more Active Galactic Nuclei (AGN) phases during their existence. However, AGNs have fleeting lifespans, which explains why they constitute only a small fraction of today's galaxy population. But in the universe's earlier days, AGNs were abundant, sculpting the majestic galaxies and stars we admire today, including our own Milky Way.[155]

Zooming out, we find a universe, 3.5 billion years post-Big Bang, in a state of ceaseless expansion, teeming with the birth of stars, quasars, and galaxies (see figure 103). Truly, a mesmerizing cosmic noon.

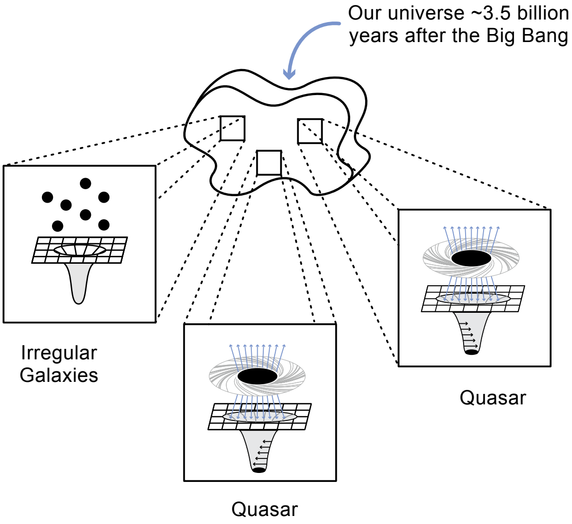


Figure 103. Our universe ~3.5 billion years after the Big Bang indicates the peak formation of stars and galaxies.

OUR SOLAR SYSTEM

Nestled within the vast expanse of the Milky Way, our remarkable solar system finds its home. Situated in the Orion Arm, we're a considerable 26,000 light-years from the galaxy's center.[156] This cosmic neighborhood we've cherished for eons boasts a stellar ensemble: the Sun, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune (figure 104). Accompanying them are dwarf planets like Pluto (forever in our hearts), a myriad of moons, and countless asteroids, comets, and meteoroids.

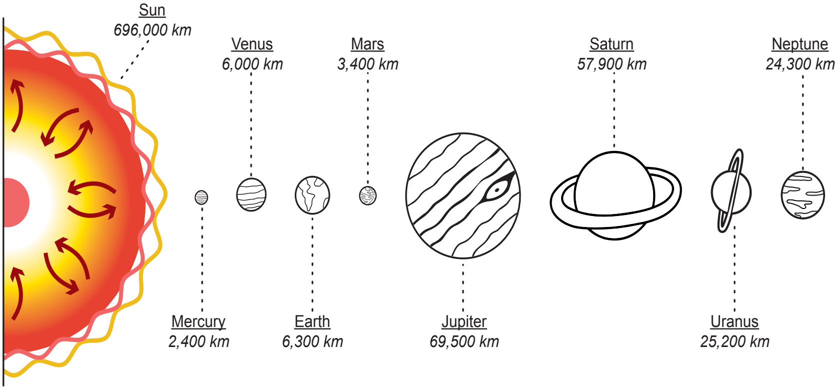


Figure 104. The celestial beings that live in our solar system with their corresponding equatorial radii.

The inner planets, up to Mars, are primarily rocky, because only such materials could endure the intense heat of the nascent solar system. Journeying further out, we encounter the colossal gas giants, Jupiter and Saturn, followed by the icy giants, Neptune and Uranus. Most planets boast their own moons, with the gas giants parading a more extensive entourage than their rocky counterparts.

The Sun's magnetic influence, or the heliosphere, largely defines our solar system's boundaries. Emanating from the Sun, magnetic field lines are propelled by solar winds, creating a protective shield against many harmful galactic cosmic rays. The point where these lines begin interacting with the interstellar medium (the gas-filled space between stars) is termed the termination shock. Beyond this, solar winds decelerate until they reach the heliopause, where they're halted by interstellar winds.[157] For reference, the heliopause lies around 123 astronomical units (1 AU = 150 million km) from the Sun, while Neptune is around 30 AU.[158]

Venturing beyond the planets, our solar system features two vast icy realms. The Kuiper Belt, a donut-shaped region brimming with icy bodies, lies just beyond Neptune. In stark contrast, the Oort Cloud is a vast spherical shell enveloping our solar system. Its inner edge starts around 5,000 AU from the Sun, extending to anywhere between 10,000 to 100,000 AU (figure 105). Home to over a trillion icy entities, the Oort Cloud is a testament to the solar system's grandeur.[159]

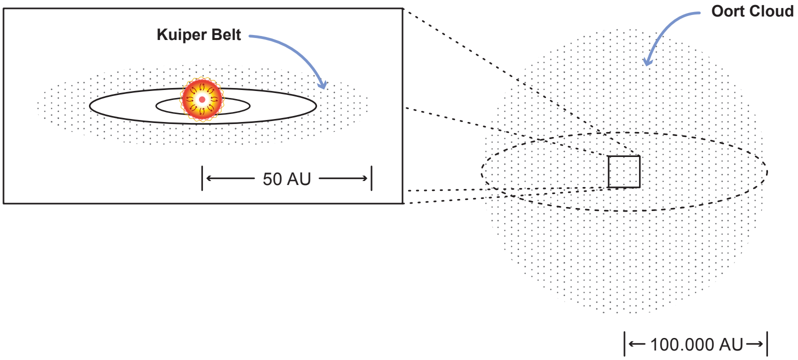


Figure 105. The Kuiper Belt and the Oort Cloud are host to billions of icy objects.

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"Life is but a series of paths."

- Clément Decrop

Inventor and Belgium-born author, Clément Decrop moved to the United States at the age of six with his family. With a degree in Mechanical Engineering from Penn State, Decrop has worked across the globe, including France, Spain, the United Emirates, and then back home in the United States.

The Idea Space: The Science of Awakening Your Non-Self delves into the depths of consciousness by introducing a distinctive solution to Einstein's field equation to describe the mind, accessible to the layperson. In these pages, Decrop guides readers to view their thoughts objectively and identify their impact, helping them discover a happier existence and a deeper understanding of their life's purpose.

As a *Global Educator* since 2018, Clément has shared his wisdom on meditation, sleep, exercise, and nutrition with thousands of eager participants across 40 countries. His innovative spirit led him to collaborate with numerous inventors from Wikipedia's Most Prolific Inventors List, resulting in 130-plus patent disclosures within one year, 50-plus filed, and 25-plus issued as of late 2023.

Outside these professional spheres, Decrop finds joy in the simpler pleasures of life. He's an avid reader—from textbooks on semiconductors and rockets to general fiction—an experimental cook, a global traveler, an enthusiastic coder, and a health & fitness devotee. He lives in Pennsylvania.

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FOR READING!