The Great Divide: Unifying Quantum Mechanics and General Relativity

Abstract

For decades, physicists have grappled with the problem of unifying the theories of quantum mechanics and general relativity. Both work exceptionally well within their respective fields; quantum mechanics accurately predicts the behaviors of subatomic particles, while general relativity accurately predicts large-scale structures. However, neither one explains the entire range of physical phenomena. Not only are the two theories incomplete, they are incompatible. When combined, the two theories lead to inconsistencies and contradictions. Take the interactions between gravity and subatomic particles: their behavior can not be fully explained by either theory alone or a combination of the two. Physicists have long searched for a working unified theory, often referred to as "quantum gravity" to no avail. This paper will explore what makes quantum mechanics and general relativity incompatible, where each model breaks down, and how black holes and neutrino particles might provide an answer to quantum gravity.

Section I - Introduction

A unified theory, quantum gravity, offers the potential to provide a consistent framework accurately describing all physical phenomena, from the smallest particles to the largest structures. Such a theory would revolutionize our understanding of the universe to a degree on par with or even greater than Einstein's theory of general relativity. With a single, coherent understanding of the universe, scientists would be able to predict physical phenomena in extreme conditions that neither quantum mechanics nor general relativity can fully explain. Astronomers would better understand black holes and the early moments of the universe following the Big Bang. A unified theory could spur technological breakthroughs in material sciences, energy generation, quantum computing, and, most importantly, space exploration.

If a unified theory could solve the energy concerns constraining space exploration, the possibilities for humankind would be tremendous. The extraordinary amount of fuel rockets consume is the primary obstacle preventing extensive space travel and the establishment of colonies on Mars or the Moon. Currently, we think of energy as a limited resource, but this is not an inherent property of energy. Every second, the Sun outputs enough energy to power humanity for 500,000 years, while fusion promises to provide virtually limitless energy. When humanity eventually figures out how to access unlimited energy, there will be nothing stopping widespread space exploration. Unlimited energy is just one of the many possible impacts of a unified theory of quantum gravity on technology. Even if such a theory did not advance technologies, it would fundamentally revolutionize scientific progress. The theory could explain mysterious phenomena such as dark matter and energy, which constitute an estimated 95% of the known universe.

The contradictory nature of quantum mechanics and general relativity makes developing a unifying theory extremely difficult. Quantum mechanics describes the behavior of subatomic particles, while general relativity describes the behavior of celestial structures, and neither theory works for both domains. Quantum particle properties, such as the uncertainty principle and the quantization of fields, directly contradict general relativity's definition of gravity being a smooth spacetime manifold. In specific extreme environments, such as in black holes, neither theory can accurately predict the behavior of particles or the overall structure. Through gravitational waves, scientists have determined that all accepted physics laws completely break down in black holes, and they have no plausible explanation for the anomalies. Some researchers have suggested that the key to quantum gravity may lay in neutrinos or neutron stars, both demonstrating quantum behavior while interacting with gravity. Others have suggested various well-known theories, including string theory and loop quantum gravity, and less prominent theories, including asymptotic safety and holographic principle. To appreciate and attempt to understand a unifying theory of quantum gravity, one must contrast general relativity and quantum mechanics, observe black holes and gravitational waves, analyze neutrinos and neutron stars, and explore string, loop quantum gravity, asymptotic safety, and holographic principle theories.

Section II - The Fundamentals of Quantum Mechanics - Uncertainty

Quantum mechanics and general relativity differentiate in their scope. Quantum mechanics deals primarily with subatomic particles, describing their behaviors and counterintuitive principles. According to well-established theories and mathematics, the wave function of a particle fully represents the quantum state at a given time, meaning it describes position, momentum, energy, spin, etc. Everything needed to define the quantum state of a specific particle can be found through various extraction methods and manipulations of the wave function. To calculate a wave function in a particular system, solve Schrodinger's equation. This equation describes how a wave function changes or how a quantum state behaves and interacts. Essentially, Schrodinger's equation is analogous to F = ma, where F = ma describes the movement of a system with mass m. If scientists know the mass of an object and its acceleration, they can solve for the force, or if they know the force and the acceleration, they can solve for the mass. Schrodinger's equation represents the same concept but for quantum states instead of classical systems. The wave function is analogous to an object's position vector or specific position at a particular time. If an object is at position x at time t, F = ma describes how the initial position will change based on various factors (mass, force, acceleration). Similarly, Schrodinger's equation dictates how the wave function changes based on different factors (potential energy, Planck's constant, mass, hamiltonian operator). The only aspects that change are the factors - a wave function describes parity, charge, magnetic moment, quantum number, etc., while an object's position vector describes the x, y, and z location in space.

One other key difference: classical mechanics (f = ma) is deterministic, and quantum mechanics is probabilistic. If one knows an object's force, mass, acceleration, and initial position, one can determine precisely where an object will end up based on how much time has passed. In quantum mechanics, despite knowing everything about a particle's current state and the variables, solving Scrodingers's equation based on time only produces a probability of a particle having a particular quantum state. Physicists do not understand why but have determined the probabilistic nature through extensive experimentation. Physicists cannot simultaneously determine specific pairs of physical properties, such as position and momentum, so increasing one measurement's accuracy decreases the other's. Known as the Heisenberg Uncertainty Principle, this represents another fundamental property of quantum mechanics. To determine whether two states, for example, position (m) and momentum (p), follow the Heisenberg Uncertainty Principle, first analyze their relations using Fourier transforms, commutation, and operators. Operators are generic mathematical functions that act on an element in space to produce a different component in the same or different space. For example, take a vector that exists in 2D space (x,y). Imagine a vector to just be a line that has magnitude (length) and direction; the vector $\begin{bmatrix} 2 \\ 3 \end{bmatrix}$ is just a line drawn from (0,0) to the point (2,3), with an arrow at (2,3) pointing northeast. In linear algebra, an operator acts on a vector to transform it, so the matrix $\begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}$ is an operator. When applied to the vector $\begin{bmatrix} 2 \\ 3 \end{bmatrix}$, the result is defined as $\begin{bmatrix} 2*2+1*3 \\ 2*1+3*2 \end{bmatrix}$ or $\begin{bmatrix} 7 \\ 8 \end{bmatrix}$, which is another vector defined in 2D space. All the operator did was transform the vector into another vector in the same space. To change spaces, the operator would need to have three rows, which would subsequently result in a third row in the final vector, making it go from 2D to 3D (rows correspond to dimensions). In quantum mechanics, operators are associated with physical attributes, such as position, momentum, or energy. For two physical properties to commute, their respective operators must commute; if operator m corresponds to position and operator p corresponds to momentum, then mp-pm=0 for them to commute. If mp-pm does not equal 0, then position and momentum are non-commuting operators and position momentum depend on each other. In terms of the wavefunction, which describes all of the quantum states of a particle, this means measuring the position fundamentally changes momentum. To extract information about a particle's position, physicists apply the position operator to the wave function. If w represents the wave function and x is the position operator, the function becomes x*w=x*w. It is a simple multiplication because in classical mechanics, an object's position is simply its position, or x, in this case. In classical mechanics, position is a definite variable representing the location of a particle. In quantum mechanics, position is defined by the position operator acting on a wave function to provide the probability of finding a particle at a given location.

Another analogy is in probability. To find the expected value of a probability density function, a mathematician multiples a value by the probability of that value occurring and then adds up all of the results for every possible value. For example, if someone rolled a dice, to find the expected value of a roll, mathematicians would multiply 1 (a possible value) by its probability (⅙), 2*(⅙), and so on until 6. Summing all of those results would give the expected value of 3.5. In quantum mechanics, the wave function is the probability, and x is all the possible values. If scientists were evaluating a particle's position in all dimensions (x, y, and z, or equivalently, x1, x2, and x3), they would simply multiple x1*wavefunction + x2*wavefunction + x3*wavefunction. Extensive experimentation confirmed initial postulations, which describes how physicists determine operators; they derive them from classical mechanics and test them to see whether the mathematics and predictions worked as expected. As a vector, the position operator has something called an eigenvalue and an eigenvector. When physicists measured a quantum particle's position, the value was an eigenvalue of the position operator. An eigenvalue is a number defined as λ in the equation $Av = \lambda v$, where v is the eigenvector and A is any matrix. Since the position operator is a matrix, A, and the measured value was its eigenvalue λ, v must be the waveform function. Due to the nature of the position operator, there can only be one eigenvector associated with all possible eigenvalues: $\delta(x-x0)$, where x0 is the measured position or eigenvalue. Applying the Fourier transform, which converts from the time domain into the frequency domain, results in a uniform momentum distribution. A uniform distribution means that all possible values are equally likely, implying the particle has an equal probability of having any momentum value. The momentum has maximum uncertainty. To summarize, measuring a physical property collapses the corresponding portion of the wave function into a specific eigenvector. Non-commuting property pairs, determined through their commutation relationship, are related through mathematical equations. Solving these mathematical equations with the collapsed wave function results in highly uncertain states for the non-measured property. Other pairs of physical properties, such as energy and time or angular momentum components, follow the same logic and hold uncertainty. In explaining the Heisenberg uncertainty principle, the collapse of the wave function was mentioned but not adequately explained. The wave function describes all quantum states, but it can not be measured; the act of measuring and interfering with the quantum states collapses the wave function and forces the particle into a specific state. Without interference, the particle remains in a superposition of states.

The famous double-slit experiment demonstrated this superposition of states. When scientists fired electrons through a pair of slits onto a flat wall filled with detectors, they noticed several important characteristics. When the electrons were left alone and not measured before entering the slits, they produced a wave interference pattern on the back wall, implying wave behavior. To double-check, scientists tried observing the electrons before they entered the slit. When observed, the electrons formed singular slit patterns, consistent with expected particle behavior but completely different than the wave interference pattern of the unobserved particles. Subatomic particles appeared to demonstrate properties of waves when unobserved and properties of particles when observed. Even more odd was when the scientists sent a singular particle through one of the slits and observed a wave interference pattern identical to when a particle was sent through each slit, suggesting the single particle was somehow traveling through both slits at the same time. This property is called superposition and needs to be better understood. All physicists know is that the wave function collapses into a specific eigenstate of the observed physical attribute.

The principles governing superposition lead to another important quality: entanglement. When a pair of subatomic particles interact, their independent wave functions cease to exist, and a new, combined wave function arises. If the two entangled particles are separated while maintaining a superposition of states, interacting and measuring one particle instantaneously influences the state of the other, no matter the distance. Entanglement occurs because of Conservation Laws, which state that entangled particles' total energy, momentum, and angular momentum must add up to the original value. Since both particles are in a superposition of states and must add up to a singular value, measuring one collapses both wave functions. For example, imagine two particles having a total spin of zero, meaning one must be up and one must be down. When the particles are separated but not observed, they exist in a superposition of up and down spins. If the first particle is measured to be spinning upwards, that forces the second particle to be down, implying information teleportation. Various experiments conducted to test entanglement have confirmed this very counterintuitive result.

Section III - The Fundamentals General Relativity

General relativity deals with large-scale cosmology. According to Einstein, the principle founder of the theory, gravity is a geometric property of both space and time. Combined, the three dimensions of space and the fourth dimension of time create a continuum referred to as spacetime. Events can be described by three spatial coordinates and one temporal coordinate. Gravity is not a force but the warping and bending of spacetime caused by celestial bodies. To determine the curvature of spacetime, Einstein developed his field equations based on the distribution of matter and energy within a specific space. Solving the equations produced a mathematical object called the metric tensor, which is practically used to calculate distances, angles, and volumes within curved spacetime. Geodesics, or straight paths in curved spacetime, often appear curved to outside observers. The effect can be seen through gravitational lensing, where light seems to bend around strong gravitational objects. Equivalence principles state that, locally, the effects of gravity are indistinguishable from acceleration, resulting in three distinct results. Weak equivalence principle states the trajectory of a freely falling test particle is independent of both mass and internal structure: all objects fall at the same rate in a gravitational field regardless of composition. In a vacuum, a feather and a hammer will fall at the same rate. Einstein's Equivalence Principle states that the outcome of any local non-gravitational experiment in a freely falling reference frame is independent of velocity and location. A human freely falling from a building experiences the same laws of physics as an astronaut in deep space far from any gravitational source. The two scenarios are indistinguishable. In fact, according to equivalence, the freely falling object is actually at an inertial frame of reference (state of rest), and the world rushing past is the one accelerating upwards. Strong equivalence principle states that the laws of physics, including both gravitational and non gravitational, are the same in locally inertial frames, regardless of whether gravitational fields are present. The force an astronaut feels in an accelerating rocket is not similar to gravity but, for all intents and purposes, identical. In the example of a freely falling object, an outside observer standing still in reference to the Earth cannot distinguish between the Earth accelerating upwards or feeling gravity, which means the Earth accelerates upwards. According to Einstein's geodesic equation, in a uniform gravitational field, the second derivative of position with respect to time equals acceleration minus the curvature of spacetime multiplied by velocity through time squared. Essentially, if acceleration and the curvature of spacetime multiplied by velocity are equivalent, an observer will be accelerating without moving. Everything on Earth, from buildings to cars to people, must accelerate upwards to stand still. Inside the accelerating rocket, to the astronaut, loose objects appear to accelerate toward the floor of the rocket; there appears to be gravity. To an outside observer in an initial state of reference, not feeling any force, the rocket accelerates upwards. Similarly, to an observer in an inertial state of reference on Earth, such as free falling, the Earth appears to accelerate upwards. In this context, objects traveling along geodesic paths with no acting forces have an inertial reference state; in general relativity, they are at rest. Using this definition, the speed of light (c) must remain constant and independent of any particular reference frame. For example, scientist A travels in a rocket at half the speed of light (.5c), and scientist B remains stationary on the ground. Both scientists will measure the speed of light inside the rocket to be c. If instead of light, the scientists measured the speed of a bullet shot inside of the rocket, assuming a bullet travels at .1c, scientist A will observe the speed as .1c while scientist B will observe the speed as .6c. After one year, the bullet has traveled .1 light-years (ly) from scientists and .6 ly from scientist B. Distance is relative. In comparison, since light speed must remain constant, the total distance light travels can not change based on a particular frame of reference. After one year, light has traveled one light year from both observers. The apparent contradiction only became plausible once scientists realized that speed has two components: distance and time. If distance remains constant, then time must be changing. Similar principles were applied to strong gravitational fields, indicating that time slows down with increasing velocity or gravitational fields.

Section IV - The Breakdown: Black Holes

Black Holes illustrate the contradiction between quantum mechanics and general relativity. The wave function describing quantum particles suggests the universe operates on probabilities, and precise predictions are inherently impossible. Physicists can calculate the likelihood of specific outcomes with the wave function. Still, it is fundamentally impossible to predict quantum states with certainty, irrespective of future advancements in technology and knowledge. On the other hand, with general relativity, scientists can make precise predictions about the motions and interactions of celestial objects without accounting for their quantum particles. Inexplicably, quantum properties disappear on the macro scale. According to general relativity, spacetime is a smooth, continuous fabric, where gravity is not a force but a geometric shape affecting the various curvatures of spacetime. At the quantum level, superposition implies a fragmented nature of states, where particles exist in multiple states at once. Scientists do not understand how a continuous fabric can emerge from non-continuous states. Furthermore, the Heisenberg Uncertainty Principle fails to conform with general relativity, even though differential operators, eigenvalues, and eigenvectors describe quantity changes in spacetime. In general relativity, the metric tensor often appears as an operator, with the corresponding eigenvalues representing the compression and stretching of time, spatial, or angular geometry and the corresponding eigenvectors representing the specific directions. In spite of the mathematical similarities, the end conclusions are vastly different. Detecting a particular property in quantum mechanics innately leads to uncertainty for non-commuting property, while in general relativity, measuring properties leads to certainty. Quantum properties constantly fluctuate between various states, and by definition, a collapse of the wave function impacts the related properties, thrusting probabilities into higher degrees of uncertainty. In contrast, objects described by general relativity are stable and exist in a singular state independently of detection. For example, measuring the mass of an object allows precise calculations for the gravitational field produced by the object. Mass and gravity are directly related and not measuring, rather than measuring, leads to uncertainty. Similar mathematical processes produce complete opposite results in quantum mechanics and general relativity.

Beyond these differences exists another direct contrast between entanglement and locality. Locality, a critical principle in relativity, means an event at a specific location in spacetime can only be influenced by the immediate surroundings. The speed of causation must be at or below the speed of light since the speed of light remains constant. No matter how fast an object travels, light will still appear to travel at speed c, making light the speed limit of the universe. Yet entangled particles instantly transfer information, violating the laws in spacetime. Quantum mechanics ignores spacetime altogether. In general relativity, time is fundamentally intertwined within the three spatial dimensions and can be influenced by the curves present in spacetime. According to the Schrodinger and wave functions that govern quantum mechanics, time is just an input that is entirely independent of any quantum state. There are no considerations in any quantum formulas that account for time dilation. Most of the time, scientists ignore the contradiction between general relativity and quantum mechanics. Quantum mechanics accurately describes the subatomic level, while general relativity accurately explains the macro. They rarely ever intersect, especially on Earth. In deep space, however, extreme environments, such as black holes, completely break down both models.

Black holes violate quantum mechanics and general relativity principles, revealing a gaping hole in our scientific knowledge. Regions in spacetime where a gravitational pull prevents anything, even light, from escaping are referred to as black holes. They primarily form when massive stars or gas clouds collapse from their gravity and implode, forming a densely concentrated area. To understand why stars collapse, consider nuclear fusion. Stars produce energy and light through a combination of extreme gravity and extreme heat forcing oppositely charged particles together. The resulting force from fusion pushes the star outwards, directly opposing the star's gravity pulling it inwards. As the fuel for fusion runs out, gravity becomes the dominant force and causes the star to collapse in on itself. The implosion can create a singularity and a black hole if it is massive enough. While general relativity assumes and predicts the existence of singularities, none of the postulates explain what occurs. All known laws of physics cease to exist, and general relativity provides no alternative solutions. In terms of quantum mechanics, both the wave functions and Schrodinger's equations do not even consider gravity. Another result of the extreme gravity in black holes is the information paradox. The equations defining motion in a quantum system are time reversible; given the wave function at a specific time, a physicist can derive the function at any past or future time. The wave function is reversible because it evolves according to a unitary time operator with a defined inverse. If information could be arbitrarily created or destroyed, the unitary time operator would not be defined for all time t, which violates basic mathematical concepts. Thus, information about a system can never be destroyed. Yet general relativity predicts information to be lost forever inside of a black hole. Once anything - matter, subatomic particles, even light- reaches the event horizon of a black hole, it can never escape. Any information is trapped forever within a black hole. By itself, this would not suggest the destruction of information, just the trapping of it. However, this assumes black hole exists forever, which the quantum vacuum theory contradicts. Classical physics defines a vacuum as a region of space devoid of matter and energy, while quantum physics defines a vacuum as the lowest possible energy state of a quantum field. The energy can never be zero because of the Heisenberg Uncertainty Principle, which states that specific pairs of physical properties can not be known precisely.

In Section II, position and momentum were the primary examples; this time, it will be energy and time. The Heisenberg Uncertainty Principle can be written out as E*tħ2, where delta E represents fluctuations in energy, delta t represents fluctuations in time, and h represents Planck's constant. Plank's constant is defined as the smallest possible action a quantum system can take; it is the integral of kinetic energy (T) minus potential energy (V), also known as the Lagrange equation, over a specific period. It essentially sums up all the possible paths a system can take from one point to another that requires the least amount of total motion possible weighted by a phase factor. The energy in a quantum vacuum is never zero but constantly fluctuating. Computational mathematics can be confusing, so one should think of the equations intuitively instead. Delta E means small energy changes. If this were ever zero, that would imply Plank's constant is also zero. If Planck's is zero, then the uncertainty principle would not hold - the only way to make the equation E*tħ2 work with h being 0 would be either delta E or delta t being zero. If either of them must be zero, one value is always certain since delta means small changes. If energy or time is not changing by any amount, it is certain. As explained in Section

II, the properties can not be certain because they are non-commute. The end result of energy constantly fluctuating and never being zero means even in a vacuum, energy exists. The constant fluctuation implies that, at some point, the energy at a specific point becomes more significant than the average energy of the entire vacuum, creating virtual particle-antiparticle pairs. Not much is known about these pairs because they exist briefly and can not be directly observed. However, scientists know they exist because of their effect on observable phenomena, such as the Casimir effect. Typically, because the particles have opposite properties (charge, spin, etc), they annihilate each other immediately after forming. Near an event horizon, however, the intense gravitational field can pull one of the particles into the black hole while the other one escapes. According to the principles of conservation of energy, stability of matter, and thermodynamics, the particle escaping must have positive energy, and the particle falling into the black hole must have negative energy, effectively decreasing the energy and size of a black hole. The fluctuations are inherently random, implying that when the black hole eventually evaporates, all information contained inside would have been effectively destroyed. Again, general relativity predicts a behavior that directly contradicts quantum mechanics.

Lastly, the Bekenstein-Hawking Entropy formula for black holes provides a mechanism for black holes to have entropy and temperature, characteristics not described by general relativity. The formula was proposed as a solution to the apparent violation of entropy in black holes; if matter containing entropy fell into a black hole, the overall entropy of the universe would decrease. Entropy refers to the amount of disorder in a system, and the second law of thermodynamics states it can not decrease in an isolated system. Entropy can also be associated with information: a system with a high degree of entropy can exist in many various states and inherently contains more information. For example, a gas spread out over a large container can take many different shapes than a gas compressed into a tiny corner and requires more information to describe correctly. Essentially, higher entropy means more information.

Bekenstein noticed that the event horizon area of black holes was following the second law of thermodynamics and was not decreasing. He proposed that a black hole had entropy proportional to the location of the event horizon and that matter continuing information beyond the states characterizing a black hole (mass, charge, and angular momentum) that were previously thought to be lost were instead increasing the event horizon and thus the entropy of a black hole. Hence, entropy and the second law of thermodynamics are conserved. However, this meant black holes had both entropy and temperature, which had not been a prediction of general relativity. The theory also failed to solve the information paradox; Hawking radiation from the event horizon is due to random fluctuations and does not convey information from matter lost to a black hole. Information is still being lost.

Section V - Neutrinos: The Ghost Particles

While extreme environments such as black holes involving extreme gravity and subatomic particles can provide valuable information about the fallacies of quantum mechanics and general relativity, they may not be the most suitable conditions for developing a unifying quantum gravity theory. Neutrinos, or quantum particles that interact with gravity, provide a potentially more straightforward and manageable pathway to understanding quantum gravity. The tiny particles that only interact through weak nuclear forces and gravity were recently found to have mass, violating the predictions of the Standard Model. The Standard Model of particle physics, which describes the electromagnetic, weak, and strong nuclear interactions, is a specific quantum field theory. According to general relativity, mass and energy are not just related but fundamentally the same thing. By understanding the mechanisms behind neutrino mass and why quantum-based models failed to describe them accurately, physicists can improve our models. They can connect quantum mechanics and general relativity. Due to their small size, neutrinos can travel through some of the most extreme gravitational fields, such as those near black holes or neutron stars. Researchers can study the impacts of gravitational fields on neutrinos to better understand how gravity operates at a quantum level. Neutrinos also oscillate between different flavors, or species of neutrinos, as they travel. Explaining their ability to change states, from electron to muon to tau neutrinos, requires a complicated quantum mechanical expression, involving superposition and, more importantly, interference. Studying how these oscillations interact with gravitational fields can prove instrumental to determining the nature of quantum gravity. Furthermore, several modern theories suggest neutrinos could be related to dark matter. Dark matter, which makes up 27% of the known universe, is practically invisible due to a lack of interaction with the electromagnetic spectrum. Scientists know it exists only because of gravitational effects. Some physicists have argued for the existence of sterile neutrinos, or neutrinos, that do not interact via weak nuclear forces as electrons, muons, and tau neutrinos do. These hypothetical neutrinos would have masses within the keV, the ideal mass for producing the gravitational effects scientists observed in dark matter. They could have been made through various mechanisms, such as the Dodelson-Widrow or Shi-fuller mechanism in the universe's early days. Neutrinos also played a critical role in the formation of the early universe, where both gravity and quantum mechanics heavily influenced the environment. They were some of the first particles to decouple or stop interacting at thermal equilibrium with other quantum particles (quarks, gluons, photons), creating the Cosmic Neutrino Background (CvB). Cosmic backgrounds are analogous to a fossil record of the universe. They are remnants from the initial stages of the universe and carry important information about the conditions of the universe at the time of their formation. A more well-known cosmic background is the Cosmic Microwave Background (CMB), which formed 380,000 years after the Big Bang when protons and electrons first began combining into neutral hydrogen atoms. The process allowed photons, or light packets, to decouple from matter and travel throughout the universe, making the CMB the oldest observable light. The CvB, however, was created only one second after the Big Bang. By analyzing the CvB, physicists gained the ability to study the universe right after its conception and understand the role neutrinos played in forming the early universe. Neutrinos are notoriously difficult to detect due to them rarely interacting with matter, but following the Big Bang, the extreme gravitational and thermal conditions amplified their interactions and made them more accessible to observe. Since neutrinos are quantum particles and heavily interact with gravity, studying the CvB would provide scientists with valuable information relating quantum mechanics to general relativity. Neutrinos are produced mainly from high-energy astrophysical events and celestial bodies, such as supernovas, gamma-ray bursts, and neutron stars. They can travel close to the speed of light, and since they rarely interact with any forces or bodies, physicists can have an undisturbed view of these extreme environments. Neutrinos are unique as they are an abundant quantum particle that interacts with gravity and weak nuclear forces. Their lack of interaction with matter makes them ideal candidates to study. However, it also makes them extremely difficult to observe. Observing neutrinos takes time and a massive amount of detection material. Still, studying neutrinos holds immense promise and may prove instrumental in creating a universal quantum gravity theory.

Section VII - Conclusion

Physicists around the world have been searching for a general theory to bring together quantum mechanics and general relativity. Though both models perform exceptionally well at their respective levels, they are incomplete. Even worse, their respective conclusions directly contradict each other. Quantum mechanics is fundamentally probabilistic; general relativity is fundamentally deterministic. None of the main principles in quantum mechanics, such as entanglement, superposition, or the Heisenberg uncertainty principle, apply even slightly to the macro-level. Quantum mechanics and general relativity are completely separate theories yet must be intertwined in the physical world. Quantum particles are the building blocks of celestial objects, and the behavior of celestial objects impacts quantum particles.

When extreme gravity meets quantum particles, both models become even less reliable, unable to predict phenomena within their respective domains. In black holes, quantum mechanics does not even apply. It fails to consider gravity or the curvature of spacetime, both incredibly important to a black hole's behavior. From gravitational waves and advanced measurement techniques, astrophysicists know both models either fail or have no explanation for the counterintuitive physical properties. The discovery that neutrinos have mass allows physicists to study an abundant quantum particle that experiences gravity in the most extreme environments. They have access to a space 'fossil' of the Big Bang only one second after the event occurred. Extreme environments exacerbate the interactions neutrinos have with gravity, giving scientists an untampered view of a quantum particle fundamentally altered by intense spacetime. Once detection technologies advance enough, humanity could witness the next giant leap in physics.

Our lack of knowledge has not prevented physicists from proposing unifying theories for quantum gravity. One popular theory, string theory, suggests that the fundamental constituents of the universe are not point particles but one-dimensional strings. Vibrations of these strings correspond to different particles. Mathematically, string theory successfully incorporates various aspects of particle physics and general relativity, but its predictions have yet to be verified. To observe the string scale, which parallels the Planck scale in size, requires experimental techniques far beyond our current technology. It also predicts 10-11 dimensions, none of which have been verified, and it lacks accurate predictive power. Loop Quantum Gravity suggests space itself is quantized and consists of tiny, discrete loops. Quantum states are described using spring networks, or graphs with edges and nodes labeled by quantum numbers, and do not require extra dimensions. The theory successfully resolves singularities and has well-defined quantum states but lacks experimental evidence due to limited technology. The same principles apply to Asymptotically Safe Gravity, another mathematically rigorous and logically sound theory that lacks experimental confirmation. Such is often the case with advanced theoretical models; their intricate and complicated mathematical models hinder experimental verification. Scientists may already have a quantum gravity theory that they have not validated or realized.

As physicists and mathematicians develop increasingly complicated theories to explain the contradictory nature of quantum mechanics and general relativity, the search for empirical evidence becomes ever more crucial. Future breakthroughs may provide the tools necessary, but until then, scientists can only speculate and refine our theories based on current knowledge and observations. The quest for quantum gravity and a new astrology revolution continues.