The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest For… Study Guide

The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest For… by Brian Greene

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Plot Summary

This book is a search for perhaps the oldest question of humanity: Why are we here? In a very literal sense, the book examines the "whys" for the physical properties that surround people in everyday life. These things are mostly taken for granted because they are so commonplace—gravity, for example. Isaac Newton formulated the "how" for gravity, but not the "why," leaving room for Einstein's formulation of special relativity centuries later, and from there the quest for the ultimate theory to explain all: the T.O.E., or "theory of everything." This led physicists to string theory.

The first few chapters provide background information necessary for readers who do not have an intimate understanding of physics. They explain the different forces and elementary particles: protons, electrons, neutrons, quarks, for examples. Then the book moves on to Einstein's theory of special relativity and the discovery of quantum mechanics, preparing the reader for the ultimate comparison to string theory.

Brian Greene takes the reader through string theory's history, patiently explaining important discoveries along the way that are necessary to understand string theory's implications. Much of the book focuses on explaining general relativity, special relativity, and quantum mechanics. This lays the foundation for latter chapters which explain that these independently accurate theories of the very large and very small dissolve into nonsense when they are combined. String theory is the remedy for this disconnect.

The theory proposes that point particles do not exist—instead, all matter is made of extremely tiny vibrating strings. The vibrations make up the elemental "particles," with certain vibrations corresponding to certain particles. Physicists have also confirmed the importance of symmetry in the natural world, using supersymmetry to approximate the important equations in string theory. The strings are a very tiny length, known as the Planck length, and settle the jittery quantum mechanical world by "smearing" out the energies. String theory declares that the fabric of spacetime can tear, contradicting Einstein's original notion, and is capable of encompassing such extremities as black holes into its own fabric. Though hailed as the theory to end all theories, string physicists were embarrassed to find five different ways that string theory could work—essentially, five different theories. However, recent ideas seek to unite the five theories into one overarching theory, known as M-theory. This theory, physicists hope, will be the T.O.E., though they are still possibly years away from discovering the mathematics to reach their conclusions. String theory is also not experimentally testable: physicists are waiting for current technology to catch up with them. However, the theory still has the potential to explain everything: from the Big Bang, to black holes, to the Planck length and beyond, no one can know how far string theory will reach.

Chapter One, Tied Up with String

Chapter One, Tied Up with String Summary and Analysis

Chapter one gives an introduction and background information about developments in physics. Modern physics relies on two major pillars: general relativity and quantum mechanics. However, as they currently stand, the two theories are in direct conflict with one another and cannot both be correct. General relativity concerns the large scale universe, and quantum mechanics concerns the small scale universe: stars, supernovas, and galaxies vs. atoms and electrons. Though usually physicists only deal with either the very large or the very small, sometimes in extreme cases they must use both, such as at the very tiny, yet incredibly massive innermost point of a black hole. Superstring theory not only makes general relativity and quantum mechanics compatible, but makes them dependent upon the other to make sense. According to Einstein's theory of special relativity, space and time are not just frozen backdrops of the universe, but are flexible and their interpretations depend on one's state of motion. In 1915 Einstein announced his theory of general relativity, claiming space and time are directly affected by energy and matter, and can warp and curve. However, when Einstein's theory was applied to the microscopic world, there were glaring inconsistencies and physicists developed quantum mechanics as a framework for the very small. The theories work beautifully separately, but are completely incompatible when combined: this is known as the central problem of modern physics. Physicists want one overlaying structure, one Theory of Everything (T.O.E.) to describe the behavior of the universe, both large and small.

Atoms consist of a nucleus holding protons and neutrons, with electrons in orbit. In 1968 experimenters at the Stanford Linear Accelerator Center found that protons and neutrons, formerly thought to be elemental, were actually made of even smaller particles called quarks. Eventually, six types of quarks are discovered: up, down, charm, strange, top, and bottom quarks. Also discovered were the neutrino, a tiny electrically neutral particle that rarely interacts with other particles, and the muon, identical to the electron except about 200 times heavier. Also discovered were the tau, another heavier version of the electron, and the electron-neutrino, muon-neutrino, and tau-neutrino. Each particle has an antiparticle counterpart of the same mass but opposite electric charge. When matter and antimatter are in contact, they create energy. The matter particles are separated into three groups, known as families.

Physicists have reduced all interactions to four fundamental forces: the gravitational, electromagnetic, weak, and strong force. An object's mass determines how much gravitational force it can exert and feel. The electromagnetic force powers microwaves, as well as lightening storms, and the charge of the its particles determines its strength. The strong and weak forces are only apparent at a microscopic level: the strong force is responsible for keeping atoms "glued" together, and the weak force is responsible for radioactive decay of matter (like uranium). Photons are the smallest bundles of the electromagnetic force, weak gauge bosons are the smallest constituents of the weak force, and gluons are the smallest of the strong force. Physicists believe there is a particle for the gravitational force, the graviton, but its existence has not been confirmed. The electromagnetic force is much, much stronger than the gravitational force, but most things are composed of equal amounts of positive and negative charges that cancel each other out, leaving no room for competition between the forces. Physicists have discovered all these "whats" and "hows" explaining the physical world, but string theory provides a "why."

String theory claims that if the particles could be magnified more than is currently possible, we would see they were made up of tiny one-dimensional loops. Replacing the point-particle theory with loops of vibrating string resolves the conflict between general relativity and quantum mechanics. The loops of string vibrate at different frequencies that determine matter's properties, like mass and force charges. This could be the T.O.E. However, the mathematics of string theory are so complex that no one knows the exact equations of the theory; instead approximate equations are used (and even these, so complicated they are only partially finished).

Chapter Two, Space, Time, and the Eye of the Beholder

Chapter Two, Space, Time, and the Eye of the Beholder Summary and Analysis

In the mid-1800s, James Clerk Maxwell united magnetism and electricity in one mathematical framework, bringing to light the electromagnetic field. He discovered that light was one particular type of electromagnetic wave, and all electromagnetic waves constantly travel at a fixed speed. According to Newton's laws of motion, it would be possibly to catch up with the light eventually: to hold stationary light in one's hand. Einstein took issue with this, and created the framework for special relativity: to understand how the world appears to individuals. Observers in relative motion to each other will have different comprehension of distance and time: space and time are not experienced exactly the same by everyone. Most of the inconsistencies are so small in day-to-day life that they go unnoticed, but they are still present. The example is Slim and Jim, who are drag racing. Slim takes off in the car, and races around the track in 30 seconds according to Jim's stopwatch. However, Jim's stopwatch has recorded a little less: 29.99999999999.52 seconds. The same happens with the length of the car: when measured before he takes off, it is 16 feet. As Jim measure the car while Slim speeds by, it comes to 15.9999999999974 feet; as Slim and Jim's relative velocities grow larger, the difference becomes more apparent. Called "time dilation" or the "Lorentz contraction," these inconsistencies are apparent on a large scale.

The theory of special relativity is structured from the properties of light, and the principle of relativity. The principle of relativity states that whenever speed or velocity are examined, one must know exactly who or what is doing the measuring. The concept of motion is relative, and the only way to speak about an object's motion is to compare it with another object. There is no "absolute" notion of force-free motion, or motion with no other accelerating force: it is always relative. When a force is involved, it changes speed or velocity, and alters the observer's perspective. Constant-velocity motion cannot be felt by the observer, they require an outside accelerating force to feel in motion; again, motion is relative.

Light and its properties of motion are also essential to special relativity: it travels at a constant speed of 670 million miles per hour regardless of comparison to other objects. Einstein's discovery of light's constant speed discredited Newtonian physics, and proved one can never "catch up" with light.

Speed measures how far an object travels in a duration of time, while distance measures how much space there is between two points. The constant speed of light means there is no such thing as a "universal clock"; observers in relative motion will not agree that events occur at exactly the same time. Even clocks moving relative to each other will tick at different rates; as a clock speeds up in comparison to a stationary clock, it ticks slower and slower the faster it moves. Time elapses more slowly for an individual in motion than for one who is motionless. The difference is too minute for everyday existence, but physicists have observed the passage of time slowing for muons, a type of subatomic particle. They deteriorate in about two millionths of a second, but at 99.5 percent of light speed their life expectancy is increased 10 times; time elapses more slowly for these muons than the ones at rest, and it is as if they exist in slow motion. Just as time has an effect on motion, motion has an effect on space. Motion moves an object through both space and time, and Einstein named time as the fourth dimension of the universe, adding it to the three spatial dimensions. As per Einstein, objects can share one fixed speed between the dimensions of space and time, and the speed of an object through space is a reflection of how much its motion through time is diverted. Einstein showed that energy and mass are convertible currencies with his formula E=mc2, or energy equals mass times the speed of light squared.

Chapter 3, Of Warps and Ripples

Chapter 3, Of Warps and Ripples Summary and Analysis

Through special relativity, Einstein proved that nothing can outrun light, which overturned Newton's universal theory of gravity. Isaac Newton was born in 1642, and revolutionized physics by applying mathematics to physical pursuits. Newton discovered that everything exerts a gravitational force on everything else, dependent upon the amount of matter an object has, and how close or far away the two objects are. The closer and more massive an object, the more gravitational force they have; the less massive and father away, the smaller the gravitational force. Newton created a formula for gravity, where "the gravitational force between two bodies is proportional to the square of the distance between them" (p.55). However, much of the theory of special relativity depends on the speed of light and the fact that nothing can surpass it. With Newton's theory of gravity, if two objects with a gravitational relationship change in mass or distance, they will feel it instantaneously. This is impossible according to special relativity, where nothing can travel faster than the speed of light—not even gravity. Newton described how objects act under the influence of gravity, but did not explain what gravity actually is. Einstein was not only interested in individuals undergoing constant-velocity motion, but also individuals in accelerated motion. He discovered that gravity and accelerated motion are intertwined—the force of gravity and the force of accelerated motion are indistinguishable when the individual has no vantage point. This is called the equivalence principle.

Accelerated motion curves and warps space and time, although the disturbances in everyday life are so minute that people do not notice. Gravity, Einstein declared, is the warping of space and time, and the presence of mass causes the spatial fabric around it to warp; space responds to objects in and around it. Therefore, gravity is communicated by the warping of space. The more massive an object, the greater the warping of space, and the greater the gravitational influence it deploys.

Objects move through spacetime taking the shortest paths possible, and warp the space around them three-dimensionally. The warping of space will travel outward three-dimensionally from the massive body, at exactly the speed of light—not instantaneously, as Newton claimed. According to Einstein and general relativity, nothing can travel faster than the speed of light. Einstein's theory was tested experimentally by observing starlight bending around the sun during a solar eclipse. He calculated the angle the starlight would bend, and on November 6, 1919, his theory of general relativity was confirmed by the Royal Astronomical Society.

German astronomer Karl Schwarzschild discovered black holes in 1916, objects so dense and massive that not even light can escape after passing the black hole's event horizon. Black holes slow the passage of time considerably, and though they are invisible to telescopes, are extremely massive and can be observed according to their effect on the objects around them.

American astronomer Edwin Hubble used Einstein's equations to discover that the fabric of the universe is not staying still: it is either expanding or shrinking. The universe began as a incredibly dense point, then erupted outwards in the Big Bang to eventually form the cosmos we know today. General relativity, though revolutionary, is completely incompatible with another theory: quantum mechanics. This constitutes the central problem of modern physics.

Chapter 4, Microscopic Weirdness

Chapter 4, Microscopic Weirdness Summary and Analysis

"Quantum mechanics is a conceptual framework for understanding the microscopic properties of the universe," (p. 86). The universe behaves entirely different on an ultra-microscopic scale than it does on the everyday scale. Quantum mechanics began with a problem: when physicists were calculating the total energy inside an oven, they kept concluding that the energy was infinite. Max Planck discovered the electromagnetic waves generated by the oven must have a whole number of peaks and troughs that fit perfectly within the oven's surfaces. Waves are described in wavelength, frequency, and amplitude. Physicists found that the waves, regardless of wavelength, carry the same amount of energy. Though requiring the waves be whole numbers specifies the rules, it still leaves an infinite number of waves possible, therefore, an infinite amount of energy. Max Planck solved the problem by declaring that fractions of energy were impossible and the energy of a wave is determined by its frequency; the minimum energy a wave can have is proportional to its frequency. A larger frequency and shorter wavelength means a larger minimum energy, and shorter frequency and longer wavelengths mean a smaller minimum energy. This revelation—that minimum energies are lumped together—cured the problem of the oven's infinite energy. The principle is known as Planck's constant: the proportionality factor between waves and energy.

Planck, though he solved the problem, did not specify why minimum energies lump together. Einstein explained this phenomenon with the photoelectric effect. When light shines on certain metals, they emit electrons. Einstein proposed that light is made up of tiny particles of light called photons—the tiniest lumps of light possible, or light's quanta. "The frequency of the light determines the speed of the ejected electrons, and the total intensity of the light determines the number of ejected electrons," (p. 97).

In the early 1800s, physicist Thomas Young conducted the double-slit experiment and discovered, through the experiment, that light behaves as a wave and not a particle. Einstein discovered that light actually is made of particles—photons—but it has properties of both waves and particles. In 1923 Prince Louis de Broglie used mathematics in quantum mechanics to imply that the wave-particle duality applied to matter as well as light. This was experimentally confirmed by Clinton Davisson and Lester Germer, who declared that electrons exhibit the wave-particle duality as well, though the resulting wavelengths are too small for notice in everyday living. In 1926, German physicist Max Born suggested that electron waves "must be interpreted from the standpoint of probability" because of the wave nature of matter (p. 105). If an electron wave hits something, then it will ripple out akin to a wave of water, leaving a number of possibilities as to its location. Erwin Schrodinger determined an equation to govern the shape and evolution of probability waves, later called wave functions.

Richard Feynman argued that, during the double-slit experiment, electrons cover every possible trajectory at the same time. The electron reaches its locations by choosing one path out of the infinity of paths possible: all other paths cancel each other out. Werner Heisenberg amplified this idea by the discovery of the uncertainty principle: that there are some features of the universe, especially on a small scale, that cannot be known with complete precision. Tiny particles can sometimes "borrow" energy to do what is impossible according to classical physics. This is known as quantum tunneling.

Chapter 5, The Need for a New Theory, General Relativity vs. Quantum Mechanics

Chapter 5, The Need for a New Theory, General Relativity vs. Quantum Mechanics Summary and Analysis

Since quantum mechanics governs the very small, and general relativity the very large, in most situations one uses either one theory or the other, but not both. However, in some situations—like the central point of a black hole which is both very small and very massive—both theories are needed. However, when combined, the theories are completely incompatible. Quantum mechanics states that, on a microscopic level, energy and momentum are uncertain: they are constantly fluctuating, borrowing, and creating energy, though on average it all cancels each other out, leaving empty space looking serene. This is the major problem in uniting quantum mechanics and general relativity. To attempt solving this problem, physicists developed quantum electrodynamics, and ultimately quantum field theory. This lead to quantum chromodynamics, studying the strong force, and quantum electroweak theory, studying the weak force. In extreme energy and temperature situations, the weak force and electromagnetic force dissolve into one another, then separate out as the temperature drops again. This is known as symmetry breaking.

The strong and weak forces, just like light, have smallest constituents that are their messenger particles, called gluons and weak gauge bosons, respectively. These messenger particles impart the forces they constitute. Gluons keep subatomic particles stuck together, and weak gauge bosons are responsible for radioactive decay. Physicists predict the existence of the graviton, the smallest constituent of gravity, but it has not yet been officially discovered.

Just as spatial curvature indicates gravitational field, quantum fluctuations appear as distortions of the surrounding space, especially when the space becomes increasingly smaller. Called quantum foam, this is the major problem between the two theories: the equations of general relativity cannot account for the violent fluctuations in quantum mechanics. These fluctuations occur at the Planck length, a millionth or a billionth of a billionth of a billionth of a centimeter. Superstring theory resolved many of these conflicts.

Chapter 6, Nothing but Music, The Essentials of Superstring Theory

Chapter 6, Nothing but Music, The Essentials of Superstring Theory Summary and Analysis

Superstring theory suggests the microscopic world is awash with tiny strings "whose vibrational patterns orchestrate the evolution of the cosmos" (p. 135). These are one-dimensional filaments that are the absolute smallest building blocks in nature. Replacing point-particles with strings solves the mathematical discrepancies encountered between quantum mechanics and general relativity. Michael Green and John Schwarz published a paper in 1984 claiming that string theory encompassed the four forces of matter as well, thus beginning the first superstring revolution. The equations of string theory are so difficult that only approximate equations have been deduced thus far. Though string theory is compelling, we do not yet know if it is correct: the Planck length is so small that no one has been able to directly observe activity at that level.

Strings emit vibrational patterns known as resonances, and these vibrational patterns give rise to different masses and force charges—they make up the elementary particles. The greater the amplitude and shorter the wavelength, the greater energy the string emits; the mass of the elementary particle, including messenger particles, is determined by the string's vibration. Heavier particles are a string that vibrate with more energy, lighter particles require less energy. The particles are different because their strings vibrate in different resonance patterns. The string are extremely tense: one thousand billion billion billion billion tons, called the Planck tension.

The energy of a vibrating string is determined by the tension in the string and the exact way it vibrates. The typical energy of a vibrating string is called the Planck energy and the typical mass of a vibrating string is called the Planck mass. Strings can vibrate in an infinite number of different ways.

String theory resolves the conflict between quantum mechanics and gravity by "smearing" the incredible forces present at the very short distances in the microscopic world. Strings, unlike point particles, spread out the the violent quantum interactions, thus smoothing out the sub-Planck-level distances.

In the mid-1990s, physicists discovered that string theory included other objects as well, not just strings.

Chapter Seven, The Super in Superstring

Chapter Seven, The Super in Superstring Summary and Analysis

Much in physics depends on symmetry, and mathematically physicists have found that some messenger particles and matter particles could have the greatest possible symmetry, or be called supersymmetric. Physicists' research relies on a stable universe that obeys the fixed universal laws—-laws that do not depend on when or where you use them. These are called symmetries of nature, which "treats every moment in time and every location in space identically," or symmetrically. Symmetries have a direct link to motion, time, or space.

In 1925, electrons were discovered to have certain magnetic properties, including a rotational motion, or spin. Like the earth, electrons both revolve and rotate—-they spin at one fixed rate. All matter particles have a spin equal to the electron, known as "spin-1/2," the quantum mechanical measure of how fast the particles rotate. Gravitational force was included in quantum mechanics because of the discovery of a vibrational pattern that matched the theorized graviton.

With the inclusion of spin, physicists realized there was one more symmetry of the laws of nature that was mathematically viable: supersymmetry. When particles' spins differ by half a unit, they must come in pairs, known as superpartners. Though initially supersymmetry was thought by many physicists to be much too delicate to actually be applicable in the universe, bosons and fermions even out some of the problems with the theory, thus stabilizing the supersymmetric standard model. Physicists have also found evidence for grand unification, theories that merge the three nongravitational forces into one theoretical framework. Though the strengths in the forces do not quite agree at small distance scales, when supersymmetry is applied, the mismatch disappears.

The first string theory concept was called the bosonic string theory, and required that the vibrational patterns of the bosonic strings were whole numbers—-this was a problem, as it did not include fermionic vibrational patterns. With the inclusion of fermionic patterns, research eventually culminated in supersymmetric quantum field theory, which avoids all the vibrational problems and still merges general relativity and quantum mechanics.

However, in 1985, physicists realized that supersymmetry could be integrated into string theory five different ways! These theories are the Type I theory, Type IIA theory, Type IIB theory, the Heterotic type O(32) theory, and the Heterotic type E8 times E8 theory. This was very troublesome for physicists, who want one T.O.E. But these five theories may be five ways of describing the same, "umbrella" theory.

Chapter Eight, More Dimensions than Meet the Eye

Chapter Eight, More Dimensions than Meet the Eye Summary and Analysis

In 1919, Theodor Kaluza suggested to Einstein that the universe may contain more than just the three apparent dimensions: "the spatial fabric of our universe may have both extended and curled-up dimensions" (p. 188). In other words, in addition to the three large, extended dimensions, there are tiny, curled-up dimensions that are relevant on the quantum mechanic level, perhaps as small as the Planck length. This theory is known as the Kaluza-Klein Theory. In the search for equations to solidify his theory, Kaluza united Maxwell's theory of light with Einstein's theory of gravity by suggesting both are carried by ripples in space: gravity carried by the three known dimensions, and electromagnetism by the new, curled-up dimensions. In the mid-1970s, Kaluza's theory was upgraded to include even more forces and dimensions, though the major problems in the theory were not resolved until the incorporation of string theory into the mix.

String theory actually requires extra spatial dimensions, and in more dimensions, there are more ways for a string to vibrate. For string theory to resolve the conflict between quantum mechanics and general relativity, it requires 10 dimensions—9 spatial and 1 time—to prevent the negative and infinite answers physicists' equations kept yielding. An event like the Big Bang may have stretched out the three dimensions we experience daily, while others remained small. It is also possible that the curled-up dimensions are time dimensions, though that would require an overhaul of how we currently think of time—-as only going one direction. The curled-up spatial dimensions effect the strings' vibrational patterns, and are therefore directly responsible for forces, charges, and much of what appears to us as "natural" in our commonly experienced world. So, the actual shape of the curled-up dimensions is of utmost importance. A six-dimensional geometric shape fit the restrictive equations of the theory, and this shape is known as the Calabi-Yau space.

Chapter Nine: The Smoking Gun, Experimental Signatures

Chapter Nine: The Smoking Gun, Experimental Signatures Summary and Analysis

String theory actually predicts gravity—if it was not apparent in the world around us, physicists would be able to deduce its existence using string theory. Though it is perhaps the most promising theory in the history of physics, the current inability of string theory to be experimentally tested is a big setback. Traditionalists in physics want theories to be experimentally testable, as experimentation has been the way to test theories for the last few centuries. These objects theoretically existing at the Planck length are about 17 times smaller than the current limit of magnification.

The elementary particles fall into three family groups which possibly correspond to specific holes in the Calabi-Yau shapes, according to their string vibrations. The three family groups are a reflection of the geometric shape of the Calabi-Yau, and the corresponding extra dimensions. However, the equations are still too difficult and complicated to deduce exactly what the shape is. Physicists calculate the approximate shapes using the perturbation theory, which is a way of finding a ballpark figure then working backwards to find the details. Working this way, some Calabi-Yau spaces can be found that fulfill the vibration requirements and have an appropriate number of curled-up dimensions.

Still, string theory is highly symmetric, and makes the prediction that superparticles will come in pairs, or, have superpartners. These superpartners have not been observed, but physicists think they are actually too heavy to show up in a particle accelerator.

Chapter Ten, Quantum Geometry

Chapter Ten, Quantum Geometry Summary and Analysis

When working with scales as small at the Planck length, a new kind of geometry must emerge called quantum geometry: a modification of Riemannian geometry, which is the basis of general relativity. Riemannian geometry examined warped shapes, stating the greater the stretching, the greater the variation from the distance on a flat shapes. In other words, there is curvature. In mathematics, spacetime's curvature reflects the distorted distance relations between its points. As an object gets smaller—closer the the actual physical idea of a point—the mathematics more closely aligns with the physics.

As discovered by Edwin Hubble, the universe is still expanding from the Big Bang. If the average matter density exceeds the critical density, then the universe's gravitational force will cause expansion to stop and reverse. Astronomers note the visible matter in the universe is much, much less than that critical density, but there is also evidence of dark matter in the universe. This dark matter does not give off light so it is invisible, and does not undergo the nuclear fusion that keeps the stars in the universe active. No one knows exactly how much of this dark matter exists, which means we are also not entirely sure how close to the critical density we actually are. When and if that collapse occurs, string theory claims the universe and all its matter cannot be squeezed smaller than the Planck length: instead, it will bounce back out again, and the process starts over.

As an extended object, a string not only oscillates and vibrates, but can wrap around in the curled-up space dimensions, called a winding mode of motion. Wrapped strings have a minimum mass determined by the size of the circular dimension, while unwrapped strings can be massless. So, the energy of a string comes from both its vibration and its winding energy. The number of times a string wraps around the circular dimension (curled-up dimension) is called its winding number. Winding energies come in multiples of 10, while vibrational energies come in multiples of smaller numbers (1/10). These radii are inversely proportional, but because of the smallness and the properties of the basic particles, there is essentially no way to distinguish between the two: they are physically identical.

Some Calabi-Yau spaces are physically equivalent but geometrically different: these are knows as mirror-manifolds, or mirror pairs. String theory was thus discovered to have mirror symmetry. This means some of the extremely difficult equations applied to string theory could instead be accomplished using the mirror perspective—often much easier.

Chapter Eleven, Tearing the Fabric of Space

Chapter Eleven, Tearing the Fabric of Space Summary and Analysis

According to the theory of relativity, the fabric of space cannot tear. However, according to string theory, it could be possible: in extreme situations, like the incredibly dense central point of a black hole, the fabric of space may actually puncture. Some physicists theorize there may be "bridges" possible in space that go from one region to another, otherwise called wormholes. In 1987, Shing-Tung Yau and Gang Tian found, using a mathematical procedure, that certain Calabi-Yau shapes could be changed into others by rupturing the surface, then quickly repairing it. Brian Greene, Paul Aspinwall, and David Morrison converged on the Massachusetts Institute for Advanced Study to examine the possibilities of tearing space, or space-tearing flop-transitions. They examined the issue using mirror symmetry: often, the mirror of an object could be used and the equations were less difficult to solve. Morrison and Greene had to work together using both their fields, math and physics, while Aspinwall put together a computer program to run the equations once they were finished. They found, conclusively, that space-tearing flop transitions are part of string theory, as is mirror symmetry. The strings provide a protective barrier, shielding the outside world from the potentially disastrous tear. The tearing processes, officially named topology-changing transitions, could also occur in everyday three-dimensional space.

Chapter Twelve, Beyond Strings, In Search of M-Theory

Chapter Twelve, Beyond Strings, In Search of M-Theory Summary and Analysis

The discovery of five different versions of string theory is an embarrassment for physicists: they want one unified theory. String theory is still new, so the five theories may be a result of how physicists are analyzing the data, or they may actually be branches of a larger, overarching theory: M-theory. M-theory requires 11 different dimensions, ten space and one time. It contains not only vibrating strings, but other shapes as well: two dimensional membranes and three dimensional "blobs," among others. M-theory is even newer than string theory and so-called because it is a mystery.

The methods of research are limited because physicists have to use perturbation theory, or approximate answers. Strings interact by joining and splitting, and must "borrow" energy to momentarily burst into existence as two separate strings. However, they must just as quickly repay that borrowed energy, and recombine as one string. These are virtual string pairs. There is a number that predicts the likelihood of a string splitting into pairs, called the string coupling constant, that has not been determined yet by physicists. The answer may require a nonperturbative approach, which has yet to be discovered.

Edward Witten pointed out the duality in string theory, that the five different theories are ways of describing one umbrella theory. Supersymmetry is a key in finding how the theories relate, and Witten discovered symmetric relationships between two of the theories and their coupling constants. The two theories can actually transform into one another, known as strong-weak duality: the strong coupling constant of one theory appears identical to the weak-coupling properties of another. Physicists were trying to incorporate gravity, or supergravity, into their new theories as well, and realized they needed yet another dimension, for a total of eleven.

Chapter Thirteen, Black Holes, A String/M Theory Perspective

Chapter Thirteen, Black Holes, A String/M Theory Perspective Summary and Analysis

Initially, black holes all appeared alike to researchers. Black holes spin at certain rates and can carry electric charge and it has been speculated that they could be large elementary particles. However, black holes are so massive that they cannot be understood in terms of quantum mechanics, and must be studied using general relativity (not including the ultra tiny central point of a black hole). Some physicists theorize that the extreme interior of a black hole is actually a rip in spacetime, previously thought impossible.

Calabi-Yau spaces can come in different "branes," or dimensions: a one-brane is one dimensional, two-brane is two-dimensional, etc. When a three-dimensional Calabi-Yau space collapses, it reinflates as a two-dimensional Calabi-Yau space. With all these interactions, the Calabi-Yau space can transform itself into other shapes all together. Greene and Morrison published a paper on this space-tearing topology, stating that the collapse of a Calabi-Yau space can result in a spatial tear.

These space-tearing transitions, later named conifold transitions, do not cause the catastrophic breakdown of spacetime as physicists originally thought. The three-brane within a Calabi-Yau space wraps around the tear, effectively providing a shield. When black holes are as small as the Planck length, they can undergo phase transition. These tiny black holes are made of strings just as elementary particles are made of strings, and the shape of the Calabi-Yau space determines whether the string becomes elementary particles or black holes.

Black hole entropy is the measure of randomness or disorder inside a black hole. The second law of thermodynamics declares that the entropy of a system always increases, or, that "everything tends to greater disorder." Jacob Bekenstein proposed that the event horizon of a black hole was the precise measure of its entropy, or disorder. In 1974 Stephen Hawking discovered that black holes have a nonzero temperature, and actually emit radiation on a quantum mechanical level—-they glow. Hawking could calculate the entropy of a black hole by using a combination of quantum mechanics and general relativity, but it took string theory to identify microscopic constituents of black holes. These are called extremal black holes: they have electric charge, and the minimal possible mass.

Black holes may be a final phase in the life of a star as well; after billions of years, the star can no longer support its gravitational field and collapses in on itself. Time itself may stop at the heart of a black hole, where there may be a tear in spacetime—-this could connect to another universe on the other side of the tear, though this is currently more in the realm of science fiction than science.

Chapter Fourteen, Reflections on Cosmology

Chapter Fourteen, Reflections on Cosmology Summary and Analysis

The standard model of cosmology existed before string theory. It is based on Einstein's equations, and recognizes that the universe began with an enormous explosion, the Big Bang. The next three minutes after the Big Bang were when most of the hydrogen and helium neuclei formed, in a period called primordial nucleosynthesis. After a billion years or so, stars, galaxies, and planets began to form. Scientists see remnants of the Big Bang in cosmic background radiation, which is microwave radiation still expanding from the initial Bang. NASA's Cosmic Background Explorer confirmed that the universe is permeated with microwave radiation whose temperature is about 2.7 degrees above zero. The entire universe was condensed to the Planck length before the Big Bang at an incredible density and temperature. In the extreme moments after the Big Bang, the universe underwent symmetry breaking where the three non-gravitational forces expanded to their current size. In the extreme pressure of the universe before the Big Bang, all the forces melded together.

The horizon problem is one of the major issues in modern cosmology. The cosmic background temperature is the same in all directions, though the different points in the universe are separated by vast distances. The cosmological model had to be modified to an inflationary viewpoint: in the first moment of expansion, the first trillionth of a trillionth of a trillionth of a second, the universe expanded by a greater percentage than it has in the 15 billion years afterward. Before the expansion, the matter of the universe was close together for long enough to establish a common temperature.

String theory influences the cosmological model in three ways: it implies that the universe has a smallest possible size, it has a small radius/large radius duality, and it has more than four spacetime dimensions. At the Planck length, or the smallest possible size, Robert Bradenberger and Cumrun Vafa discovered that the universe is at its maximum temperature. There may also be a prehistory to the Big Bang, where a small three-dimensial space existed in an infinite cold expanse, then some instability caused the space to expand.

The universe may be part of a larger cosmological expanse known as a multiverse, with multiple universes where our entire understanding of physics may not be applicable. This theory is in the very farthest reaches of physics.

Chapter Fifteen, Prospects

Chapter Fifteen, Prospects Summary and Analysis

The major lesson physicists have learned in the past studies is how closely the laws of physics are related to symmetry. Part of the reason string theory is so attractive is that symmetry—including supersymmetry—are encompassed in its structure. In the context of string theory the symmetries are consequences, not ideas forced into the theory. Moving forward in string theory, physicists are focused on finding the principle of inevitability, or the essential underlying framework that makes the theory tick.

The fabric of spacetime is made of the vibrating strings, known as a coherent state of strings, though the strings themselves do not take part in the fabric unless they vibrate. If they do not, there is no notion of time or space—the string simply is. In M-theory, the zero-brane gives physicists an idea of this domain: below the Planck scale, conventional notions of time and space do not apply, and regular geometry is replaced by non-commutative geometry. In this geometric state, conventional notions of distance do not apply. Further investigation must be approached from a quantum-mechanical standpoint, since M-theory and quantum mechanics are inherently quantum-mechanical symmetries.

String theory incorporates both gravity and quantum mechanics, has naturally occurring symmetry, and has no adjustable parameters. Much of the theory cannot be experimentally tested, but its predictions are theoretically sound. It has generated the most excitement in the physics community since Einstein, and is a hugely important candidate in the explanation of the universe.

Characters

Albert Einstein

Born in Germany on March 14th, 1879, Albert Einstein discovered the theory of special relativity, then the theory of general relativity, thus changing the face of physics forever. While working in a patent office, he overturned Newtonian physics and became the father of modern physics. He discovered, through general relativity, that space and time communicate gravity through curvature: the first time anyone proved that space was curved, not flat and static. His famous formula, E=mc squared, examined and explained the relationship between mass and energy. He received the 1922 Nobel Prize in physics for his discovery of the Photoelectric effect, and made many other major contributions to modern physics. Much of string theory is based on his original ideas, though the conflict between general relativity and quantum mechanics persisted for many years. Einstein also predicted the expansion of the universe, though this idea was so radical that he modified his equations to show the universe was still static and unchanging. This view was proved wrong a few years later, and Einstein classified his blunder as one of the biggest mistakes of his career. Though his equations required the fabric of spacetime could not be ripped or torn, string theory proved years later that it could.

Isaac Newton

Born January 4, 1643, Isaac Newton famously discovered gravity. He used mathematics to examine physical properties, and even invented mathematics not previously in existence to finish his equations. His theory of gravity declared that absolutely everything exerts a force on absolutely everything else, and the strength of the force depends on the objects' mass and their distance apart. His theory was able to describe the motion of the cosmos and was revolutionary for the time, but is incompatible with special relativity. Newton's theory does not take into account how long the objects have been in each other's presence, and states they would immediately feel a change in their gravitational attraction. This would require the forces to be faster than the speed of light—-impossible, according to special relativity. Though Newton was obviously brilliant, his theory was proved incorrect by Einstein, and the classical Newtonian view of physics ended.

Max Planck

Planck discovered quantum mechanics, and solved the infinite-energy paradox by discovering that electromagnetic waves have a minimum energy denomination, and they cannot have fractional values. He was also the first person to read Einstein's theory of special relativity, and knew instantly that the face of physics had been changed. He continued to specify many properties of quantum physics, including the Planck energy, Planck length, Planck mass, Planck's constant, Planck tension, and Planck time.

Karl Schwarzschild

Schwarzchild discovered black holes. He took Einstein's theory of general relativity and found that when the mass of a star is concentrated to a small enough point, the time warp does not allow anything to escape, not even light. The force of gravity is so strong around a black hole that time slows down considerably.

Richard Feynman

Feynman was awarded the Nobel Prize in Physics for his discovery of quantum electrodynamics.

Werner Heisenberg

Heisenberg discovered the uncertainty principle, the idea that the exact locations of quanta in the universe simply cannot be known. Instead, one must use probability to determine where is the likeliest spot for the quanta to be based on the situation.

Edward Witten

Perhaps the greatest living physicist, Witten has made numerous contributions to string theory, including work on symmetry, super symmetry, mirror symmetry, duality, and flop transitions. He also announced the possibility of M-theory at a physics conference—the overarching theory combining the five string theory possibilities.

Brian Greene

Greene is the author of "The Elegant Universe," as well as "The Fabric of the Cosmos," another physics book meant to be accessible for the general public. He is a leading researcher in string theory and has done extensive work on mirror symmetry, flop-transitions, and Calabi-Yau shapes.

Paul Aspinwall

Worked with Brian Greene and David Morrison in the discovery of space-tearing flop-transitions. He designed the computer program that allowed them to calculate their results.

David Morrison

A mathematician who worked with Brian Greene and Paul Aspinwall in the discovery of space-tearing flop-transitions. Morrison and Greene worked together, teaching each other the mathematical and physical concepts necessary to complete their research.

Shing-Tung Yau

Discovered that certain Calabi-Yau shapes could be transformed into others by puncturing the shape's surface, then sewing up the hole using a certain mathematical procedure.

Victor Batyrev

A mathematician whose discoveries in mirror symmetry greatly influenced the research on flop-tearing transitions, thus contributing to Greene, Aspinwall, and Morrison's work.

Stephen Hawking

A theoretical physicist famous for his work on black holes and quantum gravity. He discovered that black holes are not completely black; they emit radiation, or glow.

Alan Connes

Developed noncommutative geometry for zero-branes smaller than the Planck scale.

Robert Bradenberger

Worked with Cumrun Vafa to establish some of the important qualities of string theory as applied to cosmology.

Cumrun Vafa

Worked with Robert Bradenberger to establish some of the important qualities of string theory as applied to cosmology.

Objects/Places

Superstring

A superstring is a tiny, one-dimensional string whose vibrational patterns make up everything in existence.

Institute for Advanced Study

Located in Princeton, this institute is the premier place for physicists to research. Einstein worked here, as did Greene, Aspinwall, and Morrison when they discovered flop-transitions.

Antimatter

Has the same gravitational properties as matter, but an opposite electric charge and force charge.

Atom

Composed of a nucleus and electrons. The atom is the fundamental building block of everything.

Black Hole

A point in space with huge gravitational force. Even light may not be able to escape after crossing a black hold's event horizon.

Dimension

A direction in space or spacetime. The three most familiar dimensions are left-right, up-down, and back-forth.

Calabi-Yau Space

A six-dimensional shape with curled-up spatial dimensions.

Graviton

The smallest possible bit of gravitational force.

Nucleus

Core of an atom made up of protons and neutrons.

Proton

Constituent of an atom's nucleus that has a positive charge.

Electron

Orbits the nucleus of an atom and has a negative charge.

Photon

The smallest possible big of light.

Wormhole

A possible rift in the fabric of spacetime leading to another point in the universe.

Themes

Theory of Everything

Physicists are driven to explain the natural world around us. String theorists are attempting to find the T.O.E., or Theory of Everything. It is both a literal and esoteric search; they are using modern advances in science to attempt to answer perhaps the oldest question of humanity, the question "why are we here." In the search for the theory of everything, physicists study both the very large and very small. These worlds are nowhere near as familiar as the world we live in. In fact, they can be bizarre and completely contradictory to what we find "normal." However, by studying these extreme corners of the universe, physicists hope to unlock the key to the many answers man has sought since the beginning. The amazing ability of scientists to analyze and explain the physical phenomena surrounding them will continue to evolve as the questions get more and more complex and they are bound to do so the closer one gets to an answer.

The theory of everything may be contained within string theory, within M-theory, within an as-yet-undiscovered theory, or it may be impossible to discover. String theorists are optimistic about string theory because of its inherent abilities to encompass everything: gravity, symmetry, quantum mechanics, general relativity, etc. It is an extremely far-reaching theory; possibly so far-reaching that the real, true implications of the theory are not yet apparent. Yes, string theory may be the absolute and final answer to the cosmos. However, It is also possible that every smaller level of quanta leads to a yet smaller level and finding one answer leads to twenty more questions. However, whether with string theory or not, physicists will continue to strive toward the theory of everything: the idea that the world around us, the everyday, the unimaginably tiny, and the colossal, are explained by one brilliant, elegant, overarching design.

The Malleability of Science

Theories are just that: theories. Without experimental testing, scientists can only theorize the possible results, and it is very possible for the theories to be wrong. Even Isaac Newton, a brilliant mathematician and revolutionary physicist, was proved wrong by Einstein. When Einstein's theory of special relativity came along, Newton's view of gravity was seen as incorrect, though it had persisted for two hundred years in the scientific canon. Even Einstein, when he modified his equations to omit the notion that space was forever expanding, was proven wrong and went back to modify his theory. String theory is poised for a breakthrough, but as Greene point out, only time will tell if the theory is correct or yet another detour in the annals of science. Already string theory is being combined with another, more mysterious M-theory, and may be unrecognizable to future physicists in its original form.

Science moves forward at a sometimes breakneck speed, sometimes so fast that even scientists have to slow down and reexamine their agendas. The world of a string theorist is still full of questions, and though string theory could be the T.O.E., it could still be wrong. The theory must wait on technology to catch up with it; only through data that has been experimentally tested can the theory be proved and that technology could be decades away. Science proceeds in fits and starts and no doubt the answers to string theory hover tantalizingly in the future, whether they are affirming or negating the theory. String theorists know their field is sometimes tenuous, but continue to search for the ultimate truth, realizing it is possible they could all be dead wrong.

The Elegant (Symmetrical) Universe

Brian Greene compares the vibrations of the fundamental string to a huge cosmic symphony, the strings' vibrations giving rise to elementary particles, which make up everything in our world. The idea that everything in the universe is symmetrical is an unexpected and beautiful notion; no longer is the universe an entirely random place, but on some level, there is some form of order. Physicists have discovered that symmetry is essential to string theory, and plays a major role in quantum mechanics. This concept of positive and negative, of yin and yang, is somewhat comforting when taken in the huge expanse of the universe, not to mention very helpful for physicists mathematically and conceptually. The aesthetics of symmetry are very attractive to physicists: if you are going to find the ultimate theory of everything, it should be something beautiful and elegant; sleek and streamlined. String theory provides that framework, and gives string theorists a arresting framework to work from.

By uniting general relativity and quantum mechanics, string theory has paved the way for more discovery. If it can continue to easily string theories together as it has thus far, perhaps the theory can go even farther and deeper into the fabric of the cosmos. It is an oddly romantic idea that physicists can think of a theory as beautiful, but it is a different aesthetic than the normal idea of "beautiful." String theorists are constantly surrounded by the mysteries of the universe; some have been solved, some are being worked out, some have not been dreamed of yet. However, the idea that all of these many processes are orderly and play by the certain rules is monumentally profound, that the universe around us operates using symmetry.

Style

Perspective

The perspective changes throughout the book as the author makes use of explanatory examples, history, and his own experiences. The books covers a wide range within its subject matter, taking it from Isaac Newton in the 1700s to Einstein's 1900 theory of relativity to present day (and beyond). It moves into first person as Greene reaches the more recent development in string theory, in which he plays an important part. He gives a first-person account of his background, experiences, and discoveries with string theory, then slowly phases out of the very direct first person perspective in subsequent chapters, returning to slightly more detached first and second person perspectives in the beginning of the book.

Greene is a celebrated physicist, and is active in researching string theory as well as teaching string theory. His quest to write a string theory book that is accessible to the masses is fully realized and he seems excited simply to share the possibilities of the theory with his audience. He seems to be a teacher at heart, and the thrill of imparting knowledge to a potential student runs through the text. The reader begins to think like Greene, to understand the implications of the theory he is teaching. The flow and plot of the book becomes as interesting and suspenseful as any bestselling thriller. Supplied with the basics in the first chapters, one is ready to fully appreciate the insights and epiphanies in the latter chapters. Greene fills his lecture with information right until the final chapter, like a professor who knows class is almost through, but who is on a role and loathe to stop. The professor's enthusiasm is imbued in the text, and the reader gains a definite appreciation for his viewpoint.

Tone

The book is very conversational, almost as if the reader is attending a lecture given by Brian Greene. It is obvious that Greene is an expert on the subject matter, but he works to make his knowledge accessible for his less-equipped audience. The book is geared toward people without an intimate understanding of physical and mathematical theory and processes, and Greene's conversational tone enhances the feel of being in a lecture hall. He is never condescending toward the reader, and takes extra time to explain more complicated points. Excitement builds as the book approaches the latter chapters containing the more recent developments of string theory and it is apparent that Greene and the physicist community are anxiously awaiting the next breakthrough. Greene's tone is akin to a patient teacher: he has a full understanding of the subject matter, and is enthusiastic about sharing his knowledge.

While parts of the text seem to teeter on a breakthrough along with the scientists being written about, others are technical explanations and diagrams to inform the amateur. The book is never snobbish, but there is a definitely a slight deflation when the author must go over fundamental concepts to hang onto his readers. These moments disappear when a major discovery approaches and are entirely absent in the final pages of the book, where even the author is amazed at the implications of string theory as well as the ability of humanity to expose them. The work is sometimes complex, but always enthusiastic in explaining the mysteries, revelations, and basic ins-and-outs of string theory.

Structure

The book in separated into five sections, then fifteen chapters within the sections. Each chapter has smaller sections within its framework to allow the author to discuss and separate different topics that relate to the same ideas. The author makes ample use of examples, both literary and visual, to help the reader along. Each section has any number of anecdotes or diagrams to familiarize readers with the sometimes bizarre aspects of string theory and its constituents. The book's conversational tone allows Greene to interject colloquialisms, such as "to get to the point," or "most importantly." These are helpful for readers to organize and categorize the sometimes overwhelming information. Greene also forewarns readers of more complicated sections, often allowing or advising them to "skip" sections that go into more detail and are not necessary to the overall idea. Each chapter builds on the previous chapter, and the author often refers back to the chapters that introduced the concepts initially if the reader needs a refresher. It moves, like a class, from basic concepts to more complex ones, and guides the reader through each step of the learning process.

Quotes

"It is inconceivable, that inanimate brute matter, should, without the mediation of something else, which is not material, operate upon and affect other matter without mutual contact. That Gravity should be innate, inherent and essential to matter so that one body may act upon another at a distance thro' a vacuum without the mediation of anything else, by and through which their action and force may be conveyed, from one to another, is to me so great an absurdity that I believe no Man who has in philosophical matters a competent faculty of thinking can ever fall into it. Gravity must be cause by an agent acting constantly according to certain laws; but whether this agent be material or immaterial, I have left to the consideration of my readers," (p. 57). Isaac Newton, on the cause of gravity vs. the effect of gravity.

"Mass grips space by telling it how to curve, space grips mass by telling it how to move." (p. 72) John Wheeler, on how gravity affects spacetime.

"There was a time when the newspapers said that only twelve men understood the theory of relativity. I do not believe there ever was such a time. There might have been a time when only one man did because he was the only guy who caught on, before he wrote his paper. But after people read the paper a lot of people understood the theory of relativity in one way or another, certainly more than twelve. On the other hand, I think I can safely say that no one understands quantum mechanics," (p.87). Richard Feynmen, an expert on quantum mechanics.

"God does not play dice with the universe," (p. 107). Albert Einstein, regarding probability in quantum mechanics.

"[Quantum mechanics] describes nature as absurd from the point of view of common sense. And it fully agrees with experiment. So I hope you can accept Nature as She is —-absurd," (p. 111). Richard Feynman, on the apparent absurdity of nature at a microscopic scale.

"The moment you encounter string theory and realize that almost all of the major developments in physics over the last hundred years emerge—and emerge with such elegance—from such a simple starting point, you realize that this incredibly compelling theory is in a class of its own," (p. 139). Michael Green, co-writer of the 1984 landmark paper on string theory.

"It used to be that as we were climbing the mountain of nature the experimentalists would lead the way, we lazy theorists would lag behind. Every once in a while they would kick down an experimental tone which would bounce off our heads. Eventually we would get the idea and we would follow the path that was broken by the experimentalists. Once we joined our friends we would explain to them what the view was and how they got there. That was the old and easy way (at least for theorists) to climb the mountain. We all long for the return of those days. But now we theorists might have to take the lead. This is a much more lonely enterprise," (p. 214). David Gross, on theorists vs. experimentalists and the mysteries of string theory.

"Physicists are more like avant-garde composers, willing to bend traditional rules and brush the edge of acceptability in the search for solutions. Mathematicians are more like classical composers, typically working within a much tighter framework, reluctant to go to the next step until all previous ones have been established with due rigor," (p. 271). Brian Greene, on the differences between physicists and mathematicians.

"Most physicists want to believe that information is not lost, as this would make the world safe and predictable. But I believe that if one takes Einstein's general relativity seriously, one must allow for the possibility that spacetime ties itself in knots and that information gets lost in the folds. Determining whether or not information actually does get lost is one of the major questions in theoretical physics today," (p.343). Stephen Hawking, on whether or not information is lost forever upon crossing a black hole's event horizon.

"I feel we are so close with string theory that—in my moments of greatest optimism—I imagine that any day, the final form of the theory might drop out of the sky and land in someone's lap. But more realistically, I feel that we are now in the process of constructing a much deeper theory than anything we have had before and that well into the twenty-first century, when I am too old to have any useful thought on the subject, younger physicists will have to decide whether we have in fact found the final theory," (p. 373). Edward Witten, on the possibility of string theory being the final theory, or the T.O.E.

"Absolute space, in its own nature, without relation to anything external, remains always similar and immovable. Absolute, true, and mathematical time, of itself, and from its own nature, flows equably without relation to anything external," (p. 377). Isaac Newton, trying to explain the fabric of the universe.

"I think that a reformulation of quantum mechanics which will resolve many of its puzzles is just around the corner. I think many share the view that the recently uncovered dualities point toward a new, more geometrical framework for quantum mechanics, in which space, time, and quantum properties will be inseparably joined together," (p. 382). Cumun Vafa, on the importance of quantum mechanics to the future of string theory/M-theory.

"I believe the logical status of quantum mechanics is going to change in a manner that is similar to the way that the logical statues of gravity changed when Einstein discovered the equivalence principle. This process is far from complete with quantum mechanics, but I think that people will one day look back on our epoch as the period when it began," (p. 382) Edward Witten, on future changes to quantum mechanics and string theory.

"The most incomprehensible thing about the universe is that it is comprehensible," (p. 385) Albert Einstein reflecting on the complexities of the universe.

Topics for Discussion

What is the essential conflict between general relativity and quantum mechanics? How have scientists treated the two separate schools of thought?

How does string theory mend the gap between general relativity and quantum mechanics? Why is this agreement vital to the survival of the theory?

What are the quantum forces and how do they affect the microscopic particles?

Scientists have predicted the existence of the graviton. What led them to the conclusion that a graviton must exist?

Explain the importance of experimentation in confirming a theory. Has experimentation been an option for string theory? Why or why not?

What is the importance of symmetry in quantum theory? In string theory?

What is the "infinity" problem? How was it solved? How is this relevant to quantum mechanics, general relativity, and string theory?

What is a black hole? Is it really "black"? Why are both quantum mechanics and general relativity needed to explain a black hole?

How many dimensions are required for string theory? Explain the idea of dimensions according to string theory.

Are there constituents in the universe smaller than the Planck length? How does the Planck length theoretically contribute to the Big Bang? To the Big Crunch?