Maya Benyas
The Frontiers of Physics
Paul McCullough
11 July 2019

String Theory

Two of the most studied areas of theoretical physics are relativity and quantum physics. Relativity succeeds in explaining the fabric of space-time, and quantum physics describes the nature of particles and their interactions, yet what remains is how to mesh these concepts together into one single theory. The main issue with developing a way to relate these concepts is taking into account the presence of gravity, which throws a wrench into the very makeup of the universe. By the current laws of physics, gravity and the three other forces are independent of each other. String theory, however, is one, and perhaps the most successful, grand unification theory that has been proposed, encompassing all four fundamental forces: the strong, weak, electromagnetic and gravitational forces. The first three are easily related, but the gravitational force appears slightly disconnected from the others, requiring a separate explanation. In fact, the very goal of string theory is to bridge the gap between gravity and quantum mechanics, which consists of the strong, weak and electromagnetic forces (Siegel, *Forbes.com*).

String theory, like many other "theories of everything," proposes an idea for what the framework of the universe looks like, how gravity affects that framework, and how all matter interacts. What makes string theory stand out from others, nevertheless, is that it is represented in one dimension. The three-dimensional world, in fact, is too complicated and unnecessary to explain the four fundamental forces, hence the use of only one dimension in string theory (Siegel, *Forbes.com*). String theory states that everything in the universe is composed of one-dimensional strings, either with loose ends or closed ends, that vibrate, thus creating different types of particles. Previously, it was believed that the smallest particles in the universe were those such as protons, neutrons, etc. This was later proved wrong when scientists discovered that particles could be further split by smashing them together at very high velocities, creating quarks and other

Figure 1: Strings of String Theory

fundamental particles, which may or may not be the last subdivisions of matter. String theory is hinged on the idea that all matter, even tiny particles like quarks, is composed of strings, making strings the most fundamental subdivisions in the universe (Greene 327). The idea of representing particles as strings solves many problems, one such issue being that particles are zero-dimensional and point-like with no actual size, while strings are one-dimensional, with a length of approximately 10^{-35} meters (which is about 100 billion billion times smaller than an atomic nucleus) (349). The vibrations of these strings, which all vibrate in unique manners, determine the properties of all particles, such as mass and charge (Mann, *Livescience.com*). Just as the strings on a cello vibrate to produce different frequencies and tones, the strings in string theory also vibrate with standing wave patterns to produce different vibrations corresponding to different particles. For example, strings that vibrate faster are heavier particles, and strings that have less frenetic vibrations are lighter particles. By assigning unique properties to every particle based on string vibrations, while maintaining a single "species" of string to describe all particles, string theory takes a huge step toward the unification of the universe (376).

This one-dimensional model of the universe indeed appears much simpler than the three-dimensional one; the movements of particles in more than one direction in fact do not play a role in string theory, as long as their momentum is taken into account. Yet, the concept of string theory still puzzles many physicists, as the theory itself requires a universe of eleven dimensions, currently undetectable to the eye. The 11D world exists due to the nature of the strings themselves; they have surfaces, allowing for the curvature of space-time throughout the universe (Siegel, *Forbes.com*). The cosmological world in general is warped, shaped by the effects of the gravitational force. In one sense, this phenomenon can be explained by the strings of string theory, since, with their one-dimensional shapes, the strings themselves curve and vibrate in and around all massive bodies. An image of the curvature of space-time is shown at the right.

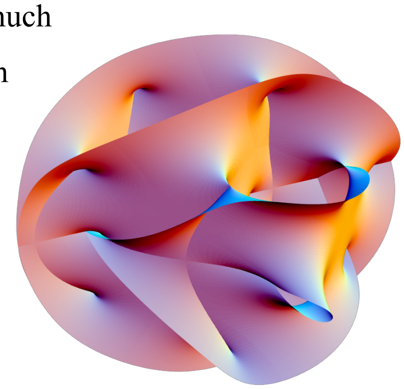

Figure 2: Dimensions of String Theory

This proposed theory of the universe seems vast, with infinite applications throughout space, but it has one main goal: to unify gravity with particles. Through the use of one-dimensional "strings" as opposed to zero-dimensional particles, string theory yields a more realistic number of dimensions, leading to a better theory of quantum gravity. In the center of a

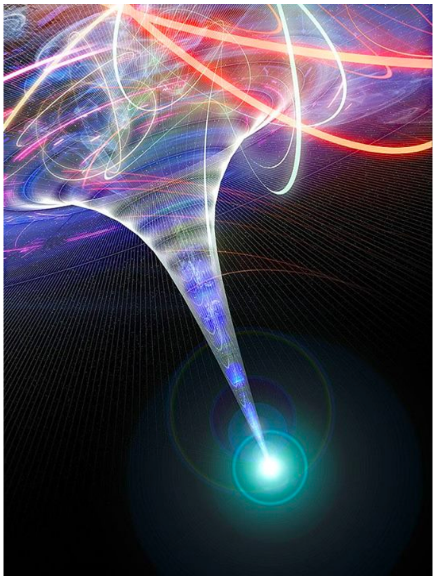

Figure 3: Singularity of a Black Hole

black hole, there is a single point at which space-time curves infinitely, known as the singularity of a black hole. At this point, Einstein's equations and the current laws of physics stop working and gravity becomes infinite. On the other hand, the complex equations of string theory still work in this paradox, surpassing Einstein's Theory of General Relativity. In essence, General Relativity creates infinities which string theory can make disappear; in fact, these infinities are only produced because particles were considered points previously, and now string theory uses strings. The singularities of black holes serve as significant evidence for string theory's usefulness in explaining quantum gravity ("Quantum Gravity: Why String Theory").

String theory has developed two distinct variants: bosonic and supersymmetric string theory. Bosonic string theory, the original proposal, focused on bosons, or particles that control forces (ie. electromagnetism, gravity, etc.). Researchers found a problem with this theory, however; every vibrational pattern determined in bosonic string theory had either spin-0, spin-1, spin-2, etc. This presents an issue because particles of matter (ie. electrons and quarks), have spin-½, a fractional amount. Soon, nevertheless, a researcher named Pierre Ramond of the University of Florida, modified the equations of string theory to fit fractional vibrations as well (355). As a result of this modification, a new development arose. Scientists found that there was a certain symmetry between particles with different spins, specifically by a difference of ½. For instance, a vibrational pattern with spin-½ always has a partner with spin-0, and a pattern with spin-1 is always associated with one of spin-½. The association of these vibrational patterns has been termed supersymmetry, leading to another variant of string theory: supersymmetric string theory, also known as superstring theory (Jones, *Thoughtco.com*).

Superstring theory incorporates both fermions (particles that make up matter, such as quarks and leptons) and bosons. The new, modified version of string theory contains five distinct subgroups, each with their own conditions and vibrational patterns: Type I, Type IIA, Type IIB, Type Heterotic-O (HO), and Type Heterotic-E (HE). With these five unique models of how the universe works, scientists first believed that experimental data could be sorted and organized easily according to the variants of string theory. Despite this, the existence of five separate configurations of the universe only served to complicate the relationship between quantum mechanics and general relativity (377). Therefore, it was an unexpected surprise in the scientific world when, in 1995, Edward Witten discovered a way to tie all five string theories together into a single theory, one fundamental physical model. According to Witten, the five superstring theories all fit under the umbrella of this master theory, dubbed M-Theory, which can be mathematically analyzed in five different ways to produce the five theories (379).

The main motive for the development of string theory was to explain how gravity is intertwined with the rest of the universe, at which no previous theory had succeeded. While researching string theory, scientists found that its quantum mechanical equations demonstrated an interesting hypothetical effect of particle collisions. They predicted that in high-energy collisions, an unknown spin-2 particle with a mass of 0 is produced (341). While studying this case, another issue arose that puzzled many scientists. A key difference between quantum mechanics and gravity lies in the presence of particles. According to string theory, strings throughout space vibrate, join, split and stretch in different ways to create unique particles, each with its own function. For example, in quantum mechanics, the electromagnetic force occurs as a result of photons, and the strongforce is carried out by gluons, but the gravitational force has no correlation to any one particle. In an attempt to connect the two fields of study, the gravitational force was assigned a hypothetical particle that, if proven correct, functions by transmitting the force. Scientists experimentally determined that these hypothetical particles, named gravitons, had two definite properties: they must be spin-2 and massless. Noting a correlation between the missing particle and the graviton, scientist John Schwarz and his colleague, Joël Scherk, linked the two together by declaring the hypothetical graviton the missing particle. Just how certain vibrating strings produce electrons, quarks and other subatomic particles, other vibrating strings make up the graviton (Mann, *Livescience.com*).

The relevance of string theory is infinite when it comes to applications throughout space. One idea that string theory proposes is that there are around 10^{500} multi-verses, to which we may be able to travel using wormholes. Nevertheless, some studies have shown that not a single one of these multi-verses is ours, due to a lack of dark energy, which is necessary in our universe (Mann, *Livescience.com*). Another future application is the use of string theory to create time machines. String theory is not only a theory of the framework of space, but it is also a theory of time. Space and time are always interconnected, as stated by Einstein's Theories of Relativity. In string theory, space-time can warp due to the flexible strands that make up the framework of the universe. This framework can be compared to a piece of paper, folded to represent the curvature of space-time. In the image at the right, space-time has been folded to create a wormhole between two universes, one on each side of the paper. In turn, the wormhole can act as a time machine, a theory that would not exist without string theory (FloatingUniversity).

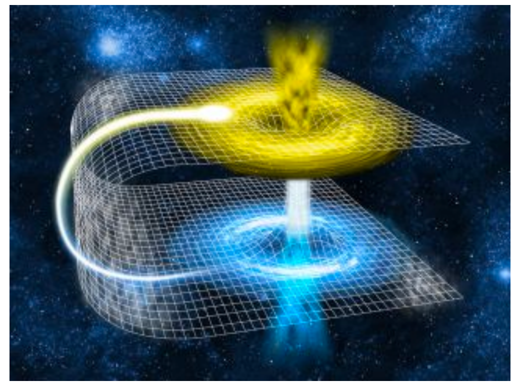

Figure 4: Wormhole Between Two Universes

String theory is currently the best model of the universe that explains both gravity and quantum mechanics. Nonetheless, much of the research that has been conducted on string theory today is math without physics, calculations without observation (Mann, *Livescience.com*). Still, this is the first step to making progress in a field that was only recently introduced to the scientific world, and that will continue to grow over the years.

Works Cited

FloatingUniversity, director. *String Theory, by Michio Kaku*. *YouTube*, YouTube, 7 Dec. 2011, www.youtube.com/watch?v=kYAdwS5MFjQ.

Greene, Brian. *The Fabric of The Cosmos*. Vintage, 2004.

Jones, Andrew Zimmerman. "String Theory: The Mathematics of Moving Beyond Current Physics." *ThoughtCo*, ThoughtCo, 2 Mar. 2019, www.thoughtco.com/what-is-string-theory-2699363.

Mann, Adam. "What Is String Theory?" *LiveScience*, Purch, 20 Mar. 2019, www.livescience.com/65033-what-is-string-theory.html.

"Quantum Gravity: Why String Theory." *Quantum Gravity | Why String Theory*, whystringtheory.com/research/quantum-gravity/.

Siegel, Ethan. "What Every Layperson Should Know About String Theory." *Forbes*, Forbes Magazine, 26 Nov. 2016, www.forbes.com/sites/startswithabang/2016/11/25/what-every-layperson-should-know-about-string-theory/#396ac3675a53.