A Universal Orchestra: String and M-Theory

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Imagine taking the smallest elements and cutting those up into their fundamental pieces, like an atom into its protons, neutrons and electrons. Then slice those up again into their fundamental particles such as quarks. Continue slicing these particles into their smaller and smaller constituents. What is the end result? Surely there is a smallest particle, one so fundamental that it would make up all matter and forces in the universe. But what would that particle be? String Theory, and it's more generalized version called M- Theory, suggests these are miniscule, one-dimensional vibrating strings. The oscillation patterns of these infinitesimally small elements would determine the structure of everything in the universe, from matter to forces. But why strings? Why does the universe need such fundamental particles, and why are physicists so concerned with naming the most fundamental element? To explain this thoroughly, a brief history before M-Theory is necessary.

Physics has come into its heyday within the past several hundred years, beginning with Newton's description of gravity. Newton and his Law of Universal Gravitation seemed to perfectly describe why objects were all attracted to each other, as well as to what physical degree. Indeed, experiments proved his calculations were correct, and his theory on gravity seemed undoubtedly correct and was not challenged by a physicist of any merit for many years. After all, with this much proof, it seemed silly to suggest Newton was anything but completely correct. However in the mid-19th century, with the advent of James Clerk Maxwell's equations on electromagnetism, Newtonian physics was turned on its head. Newton suggested that, if one were to run fast enough, he could catch up to the speed of light. Traveling the same speed of light, one could in theory "hold" what seemed to be nonmoving light, at least relatively. Not so, according to Maxwell. He and his equations suggested that nothing – neither force, energy, or mass could catch up to light (Greene, 2003). How could this be then, considering according to

Newton gravity could work across enormous distances instantaneously? This was the first great conflict in physics. Both theories seemed correct, and experimentation suggested they both were, yet they could not both be.

Einstein would settle part of this dispute with his theory on special relativity. Special relativity suggested that space and time were not universal concepts set in stone throughout the universe; rather, their form and appearance depended on one's state of motion. Therefore a watch traveling much faster than another would actually read *different* than another who was not traveling the same speed. Yet this still left a nagging question: Newton's law on gravitation still suggested light could travel instantaneously, yet Maxwell said *nothing* could travel faster than light. Einstein would solve the rest of these issues with his grand general theory of relativity. With his general theory of relativity, space and time were not only dependant on one's motion, but also space and time can warp and curve in response to matter or energy (Greene, 2003). This warping could transmit the force of gravity from one location to another. Together with these two theories, special and general relativity, physics of the large scale became extremely predictable. However, as in the past, more conflict was introduced, as Einstein's general relativity and another revolutionary theory, quantum mechanics, would prove unable to coexist. One had to be right and one had to be wrong it seemed, but both were proven true with numerous experiments and equations.

Quantum mechanics deals with the physics of very small. At extremely small levels, all relativistic physics breaks down and Einstein's theories make no sense. The physics of the miniscule must therefore be different than that of the large. Yet this doesn't seem to make sense; why would the universe operate on two sets of laws? For the most part, scientists only deal with *either* very large and massive *or* that on the quantum size, so it wasn't as important at the time as to why these two laws which, though completely different, worked so perfectly on their own and so impossibly together. However there are a few cases in the universe in which there is an extremely massive object *and* extremely small. This is that of the singularity at the center of a black hole. In this situation, all conventional ideas of relativity and quantum mechanics break down, thus these theories are virtually useless at predicting and explaining black holes (The Official String Theory Website). Some sort of unifying theory, something dealing with gravity at a quantum level, is needed.

However, M-Theory was a long time in the making, and not even dreamed of yet when relativity and quantum mechanics were first birthed. Einstein realized this and spent nearly thirty years of his life searching for a unified field theory. Aspects of quantum mechanics such as the Heisenberg Uncertainty Principle suggested that in space even gravity at extremely small distances would experience only on average a zero gravitational field. Ideas such as particles and their anti-particle counterparts constantly being created and destroyed by each other suggested at the microscopic level, gravity wasn't smooth and nice as relativity suggested, but rough and violent (Greene, 2003). This is the reason for and basic foundation of M-Theory; that is, a unifying concept which can predict and explain everything, from the big to the small to both at the same time.

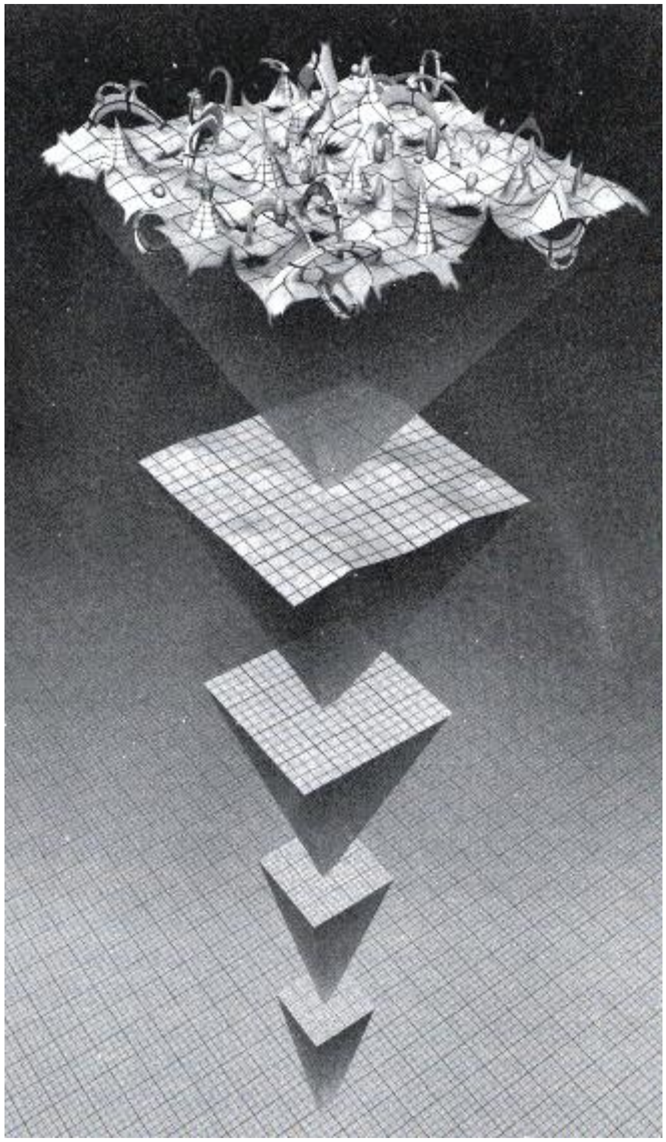

Fig. 1 Empty space experiencing quantum fluctuations as a result of the uncertainty principle (http://abyss.uoregon.edu/~js/ast123/lectures/lec17.html)

The first attempt to find a unifying theory was known as the Standard Model. This was designed within the framework called Quantum Field Theory, and tools used by this model were able to be consistent with Quantum Mechanics and special relativity. The Standard Model was able to describe three of four of the known interactions: electromagnetism, and the strong and weak nuclear forces. However it still could not describe gravity. The problem was that when rules of Quantum Field Theory are applied to general relativity, the results of which make no sense, such as forces between two gravitons becoming infinity and probabilities going to infinity (The Official String Theory Website). Finally, beginning in the 1960s but not becoming significant to physics until the 1980s came the advent of String Theory, and eventually the even more generalized, unifying M-Theory.

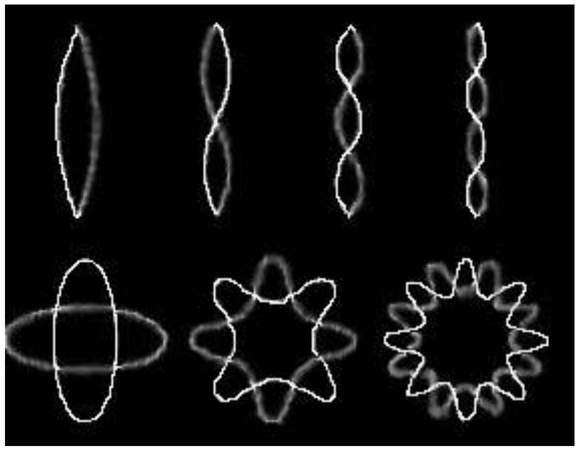

Fig. 1 Top: Open strings. Bottom: Closed strings (http://pdgusers.lbl.gov/~pslii/uabackup/final_frontier/stringxtradimension/4300100.html)

According to string theory, all particles, forces, and everything in the universe is made up of tiny strings. These strings can be closed like loops, or open like a shoestring. As these strings travel across space, they trace a sheet or tube depending on whether they are open or closed. These strings are free to vibrate, and their various vibrational modes represent the myriad of particle types, such as electrons, quarks, muons, neutrinos, etc, and also can represent different masses of particles or spins of particles. Most importantly, these strings can also describe the elusive graviton, which has proved problematic to even the most encompassing theories before string theory. Moreover, it was hoped this elegant theory could provide the long sought after "Theory of Everything" (Cambridge) Only time could tell whether this would turn out to be the theory that described everything.

String theory would mature as various inconsistencies and inadequacies needed to be accounted for. For example, the original string theory only described bosons, which were particles that carried force, such as the photon carrying electromagnetic force, and the graviton, which carried gravitational force. It did not describe fermions, which made up matter such as the electron and quark. The idea of supersymmetry would lead to the evolution of superstring theory, the next installment in the ever-maturing theory of tiny strings (Cambridge).

Symmetry in physics has a slightly different meaning than the everyday connotation. Symmetry in physics means for example that a force or particle will behave under the same conditions the exact same way, no matter when or where in the universe. More simply, that laws of the physical world do not change over time. Gravity behaves the same now as it did since the beginning of time. The type of symmetry that string theory incorporates, known as supersymmetry, suggests that all particles are paired, such that all matter particles have a force partner, and vice versa. Supersymmetry produced a problem in the standard model however, as it was discovered that *none* of the currently known force and matter particles were pairs with one another; rather, that these particles all had yet unknown, undiscovered partners. These partners were named the “selectron” for the electron, “sneutrinos” for the neutrino, “squarks” for the quark, “photinos” for the photon, “gluinos” for the gluon, and so on. It does seem that the lack of evidence for superpartners seemed damning for supersymmetry theories, yet their existence does fix a lot of issues for string theory and even the standard model. So despite there being little factual evidence, supersymmetry is still regarded as probable in theoretical physics (Greene, 2003).

All together, there are five current string theories. Three of which are superstring theories (involving supersymmetry), and two of which combine the best of Bosonic string theories (does not involve supersymmetry) and superstring theory to produce what are known as Heterotic string theory. This seems extremely problematic for proponents of the string theorists, as if string theory hopes to prove to be the Theory of Everything, how can there be five versions? Shouldn't there just be the one? Certainly there can't be five theories of everything. When relativity and Quantum Mechanics was birthed, there was not this issue of different versions, so clearly there has to be some solution or string theory must be incorrect. Furthermore, another problem is that physicists have trouble finding what equations power string theory, as well as what the solutions to these equations were. String theorists had to use approximate equations for approximate solutions – clearly not the most ideal situation (Greene, 2003). What resulted was M-Theory, a theory with encompassed all string theories and showed that it wasn't that with the five string theories, four must be wrong and only one correct, but rather that each is correct, depending on how and where each are observed (Cambridge).

As for the quantitative aspect of string theory, the key to the physics of string theory lie with their movement across space. As a string moves in spacetime, it sweeps out a surface known as the "string worldsheet." Interestingly, in order to make these strings and their oscillations consistent with Quantum Mechanics and special relativity, it is necessary for the number of dimensions be extended and restricted to 10 dimensions. Most important for string theory is that it predicts the graviton, a feat that previous theories were unable to do. If the string is closed moving through spacetime, of the spectrum of oscillations it produces, included is a particle with spin, yet zero mass. This can be nothing else but the graviton. Furthermore, a closed string traveling through spacetime feels curvatures caused by gravity. To be consistent with quantum theory, this curved space it feels must be a solution to Einstein's equations. So therefore string theory actually predicts gravity; moreover, it predicts Einstein's equations will be obeyed (The Official String Theory Website). In this way it seems relativity and mechanics can finally be united.

As previously mentioned, for the various forms of string theory and M-theory to be correct, extra dimensions are required, which seems strange. However without these extra dimensions, results from string theory calculations yield negative probabilities. These extra dimensions were decided to be one of two forms: either extremely large and therefore unobservable, or extremely small and wrapped up. For the latter, the dimensions are wrapped up in tiny, unobservable loops. This is known as Kaluza Klein compactification. The other option is for the dimensions to be extremely large, but all matter and gravity is confined to the three dimensional subspace. Most accept the idea of tiny dimensions rather than the large ones. These tiny dimensions are wrapped up in mathematical shapes called Calabi- Yau manifolds (Greene, 2003). Originally, only one extra dimension was predicted, but it proved inadequate and was later extended to more dimensions in order to derive other forces such as the graviton. Ten dimensions were required for the separate string theories to work first, four being the conventional spacetime we are familiar with, and six being the tiny rolled up dimensions. However with the need for the unification of the five string theories leading to M-theory, one more dimension was added, for a total of eleven. It might seem strangely convenient that, in order for string theory to work, physicists “discovered” another dimension so calculations would make snese, but truthfully the original formulation of the ten total dimensions was an approximation and later, more correct calculations show there should be indeed eleven total (Greene, 2003).

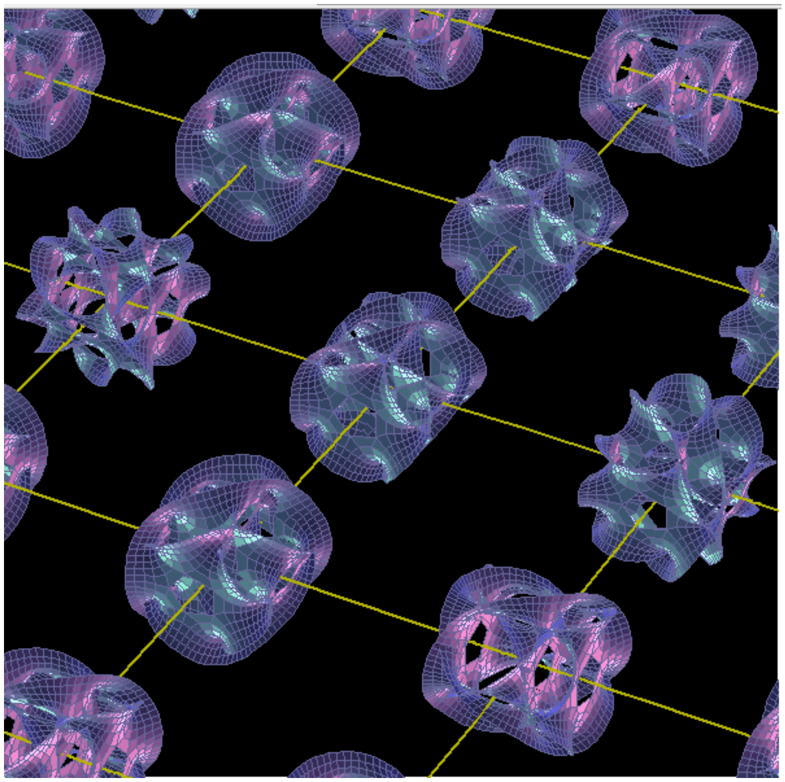

Fig. 1 Virtual representation of various tightly rolled dimensions (http://skepsisfera.blogspot.com/2010/10/about-testing-string-theory-by-analogy.html)

Furthermore, there is one more addition M-theory brings to conventional string theories: there aren't just the tiny one dimensional strings, but rather also two dimensional membranes and even *three*-dimensional blobs, as well as several other types of fundamental ingredients in the universe. Further calculations brought all these new insights together to add to the attempts toward a Theory of Everything. Yet much of M-theory still remains mysterious, and much is left to discover. Physicists refer to theories which seem to be different (such as the various string theories) but seem to describe the same thing dualities (Greene, 2003).

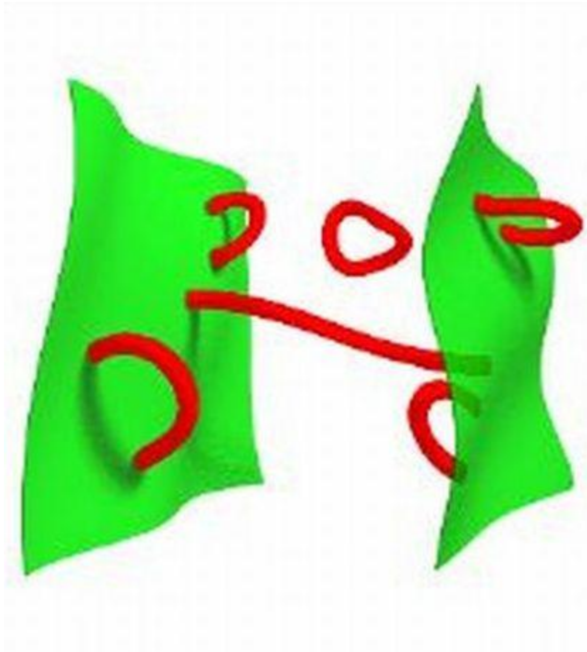

Fig. 3 Strings branching various dimensions
(http://www.damtp.cam.ac.uk/research/hep/research/)

One of the most interesting applications of string and M-theory is to black holes. According to classical physics, black holes should be incapable of growing weaker, as nothing can escape the event horizon. As a result, they should only be able to increase in size from absorbing more matter and energy. Surprisingly, they can in fact grow weaker to an observer. This is arises from Quantum Mechanics and quantum vacuum fluctuations, in which particle and anti-particle pairs are repeatedly created and destroyed. Sometimes, on the edge of an event horizon this process will occur, but before the particles can annihilate each other, one particle will be pulled in while the other is ejected. To an outside observer, it will seem as if the black hole has decreased in size by the mass of the particle ejected. For a certain type of black hole, called the BPS black hole which has both charge and mass, certain string theory calculations will actually match the entropy of these systems. This provides evidence for the plausibility of string theory (The Official String Theory Website).

Ultimately, M-theory may prove to be the unifying theory for the universe. But then again, it may not. M-theory does have several glaring inadequacies, such as its difficulty to be proven and lack of direct evidence. Many suggest however that it’s just too beautiful of a theory mathematically and otherwise to not be true; and without a strong adversary to challenge it, it seems for now to be the best possibility for a Theory of Everything. Only further experimentation will prove if the universe truly does function on an orchestra of tiny, miniscule strings.

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