M-Theory

A Final Theory of Everything?

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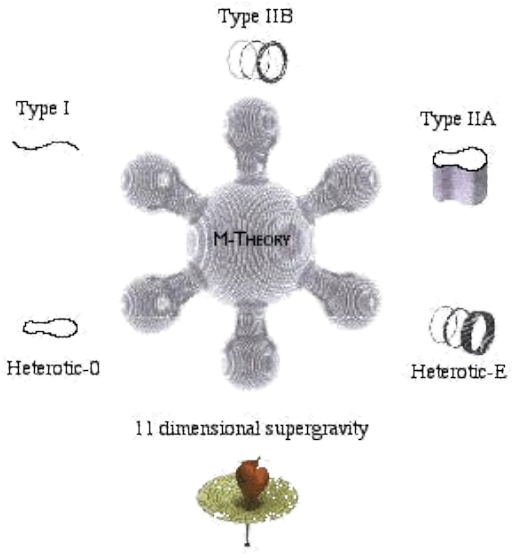
This essay is about M-Theory, an attempt at a Grand Unified Theory of the Universe, a theory to explain everything we see around us, and everything we don't see. Although this theory has withstood nearly thirty years of criticism and rigorous research, and has moved towards verification, it is still in the theoretical stages, mainly due in part to its complexities and highly advanced mathematical foundation, and a final "yes or no" has yet to be reached in the verdict for this candidate for a "theory of everything."

M-Theory is a leading Grand Unification Theory (GUT) that many physicists are pursuing today. M-Theory is a unified version of six other theories, five of which are superstring theories, and the other is a theory of quantum gravity. Supersymmetric String Theory, or Superstring Theory for short, is a theory which makes the broad leap of assuming that the fundamental particles of matter and force are actually incredibly small vibrating strings. Superstring theories also predict the existence of ten spatial dimensions and one temporal dimension, which contradicts the four-dimensional world we can see around us (three spatial and one temporal dimension). Superstring Theory was an attempt by physicists to unite the two pillars of physics, which are mutually incompatible when you attempt to apply them together: Quantum Physics and the Theory of General Relativity.



This Illustrates how the 5 superstring theories and Supergravity theory are the smaller parts that make up the entirety of M-Theory [1]

I. Why Is M-Theory Needed?

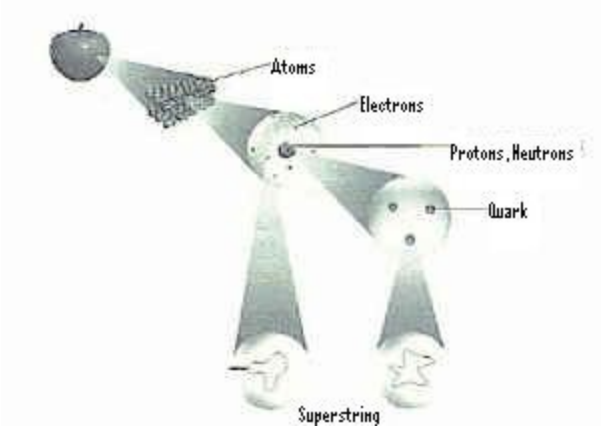
M-Theory is an attempt to create a GUT, and replace the Standard Model of physics. What makes M-Theory a GUT, is the fact that it is considered to be background-independent, which means that the equations will output the observed features of the universe without any specific values from the observed universe input as variables.[4] One of the reasons physicists began working on M-Theory is because there are a number of problems with the Standard Model, which M-Theory addresses and attempts to rectify. The main problems with the Standard Model are as follows: it cannot account for the observed unbalance between matter and antimatter in the known universe, and it contains 29 free parameters that must be determined experimentally, and cannot be determined through the theory itself, which means that it is background dependent, and variables from experiments must be added into it to make it work, and the Standard Model provides no mechanism to explain Cosmic Inflation, which is the exponential expansion of the universe during the Big Bang.[4]

Although throughout the past few decades physicists have made accurate predictions using Quantum Mechanics and General Relativity that match the results from experiments carried out, many physicists are not satisfied with these two theories, because of a fatal flaw that occurs between the two. Although most situations and conditions that scientists wish to understand further only need one of the theories to make predictions, there are certain extreme conditions in the universe,

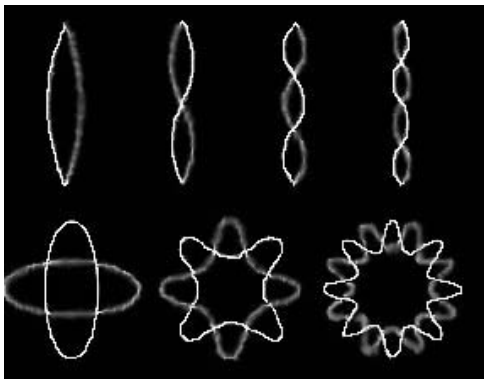
such as black holes, that require the two theories for proper understanding of the mechanics behind the said system, which is where problems arise. On their own, each theory makes accurate predictions that correspond to measure values, but when both are required to work together, physicists have found that the two theories are mutually incompatible.[2] What this means is that when the equations of both theories are used in tandem with one another, they churn out non-sensible numbers and probabilities that are equal to infinity, which makes no sense whatsoever.

II. Predictions of M- Theory

M-Theory claims that all the things we see around us, all the matter that makes up the earth, the sun, a house, is made up of tiny strings, that vibrate in different ways to create the particles we know as electrons, quarks, photons, everything around is us one giant cosmic symphony of vibrating strings. Much as a violin string vibrates and creates different notes when played, different vibrations on a superstring causes it to take the form of the particles of matter and forces we see around us, such as an electron and the quarks that make up protons and neutrons.[5]



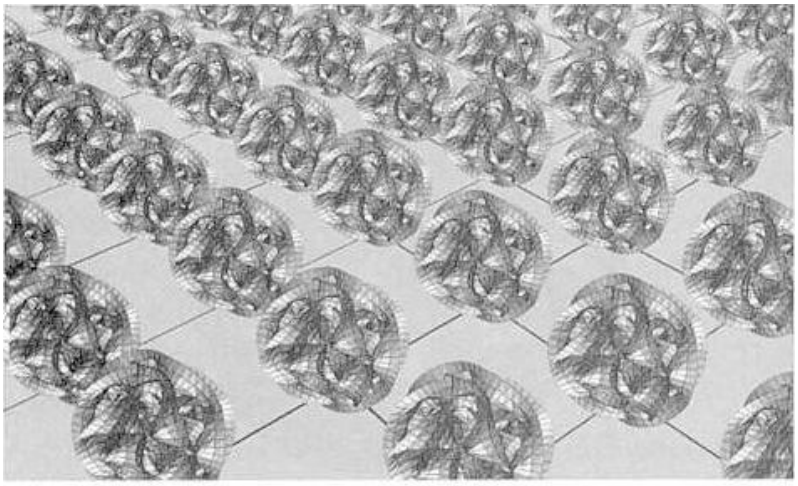
Superstrings make up all the objects we see around us [2]



Vibrating Superstring [2]

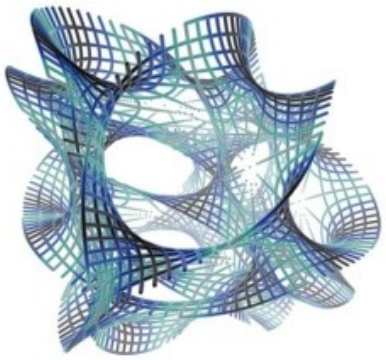
A major feature that puts M-Theory apart from theories like general relativity and quantum mechanics are some of the predictions it makes about the universe, some of which are completely foreign to our everyday experience of the world. One such prediction is the necessary existence of eleven dimensions, ten spatial dimensions, and one temporal (time) dimension. From our perspective, we live in a four dimensional universe, three spatial and one temporal dimension, but the mathematics behind M-Theory predicts eleven. String theorists' explanations for

why we don't observe these seven other spatial dimensions is that they are curled up and are incredibly small, smaller even than the smallest particles of matter that we have discovered thus far. These curled up dimensions have unique shapes, which have been theorized and modeled, and are known as Calabi-Yau Manifolds.[6] The geometry behind these multidimensional objects, some having as many as six dimensions is difficult to imagine, as humans are only used to 3 spatial dimensions, and this six dimensional geometry is also difficult to module even with the aid of supercomputers, because of the inherit complexity of the object, and there are many different possible shapes for these objects to take on.



According to string theory, the universe has extra dimensions curled up into a Calabi-Yau shape.

Calabi-Yau Shapes [2]



Calabi-Yau Shape [3]

III. The Evidence For and Aga inst M- Theory

One of the major weaknesses in M-Theory is its inability to provide exact answers, because the equations are too complicated even for the world's fastest supercomputers, the equations used by physicists are approximations of the actual equations, and therefore, the results are also approximations. [7] This has led to many opponents of M-Theory to claim that it is not an actual theory, because it is all approximations and rough estimates. M-Theory uses Perturbation Theory, which is a mathematical method of describing a complicated system, such as the superstrings and higher dimensions, in terms of a more simplified system, in order to gain a further understanding of the complex system. [8]

Another major weakness in M-Theory is the problem of many of its predictions cannot be verified with today's current technologies, such as using particle accelerators to search for higher dimensions and superstrings, because the predicted energy levels are much higher than anything currently built or under

construction. At the same time, this does not technically discredit the theory, because so long as M-Theory's equations do not predict anything that has been experimentally been proven wrong, and so as long as its predictions agree with the observed properties of the universe, M-Theory is still a possibility for a grand unifying theory.

This problem of lack of funding has been a major obstacle in finding any experimental proof that supports or discredits M-Theory. And to make matters worse, although the scientific community supports discovering new properties of the universe with experiments, governments have been less supportive than what could be hoped. Back in the 1980's, the Superconducting Super Collider project was proposed in the United States; the SSC was a particle accelerator that, theoretically had a chance of probing the scales of M-Theory, because of it's high energy output, 20TeV (Tera Electron Volt), unfortunately in the early 1990's, the United States Congress cut funding and abandoned the project, instead favoring putting the money into NASA, and more specifically, the International Space Station. This lack of financing for carrying out experiments to verify M-Theory's claims has plagued it since it's creation in the mid 1980's, and continues to make it difficult to scientifically verify some of it's claims even today.

Edward Witten, the founder of M-Theory, claims that one of the strongest pieces of evidence is that Superstring Theory, and in turn M-Theory, predicts the existence of gravity.[8] At first glance, this doesn't seem to be evidence, as theories

such as General Relativity, and Newton's theory of gravity outline and explain the properties of gravity, and their observations from their experiments showed that gravity exists. But here is where the key difference exists, Einstein and Newton's theories explain the properties based off of their observations of the world around us, M-Theory predicts gravity's existence without any input from what is observed from experimental data. No other theories actually predict the existence of gravity without the input from the observations of the world around us. However, many opponents point at that this is a "postdiction" and not a prediction, because there have been theoretical descriptions of gravity before Superstring Theory or M-Theory ever existed, and because of this, many scientists do not see this as strong evidence for the accuracy of M-Theory.[8]

Another conundrum that plagued Superstring Theory was the fact that there are five different Superstring Theories, and all of them have different properties concerning the universe, and string theorists were not sure as to which one was the correct theory. Fortunately, this problem was resolved in the 1990's during the Second String Theory Revolution, in which it was discovered that all the Superstring Theories are different aspects of a single, overlying theory, known as M-Theory. The five Superstring Theories were found to have dualities between each other, which means that each theory is describing the same universe, but simply from different perspectives and in differing ways, and when physicists realized this, they began to work on combing them together.[8] Edward Witten was the physicist who ended up

creating M-Theory, a combination of all five Superstring Theories and of 11-Dimensional Supergravity, and again, the "super" in Supergravity means Supersymmetric Gravity.[2] 11-Dimensional Supergravity helps to unite gravity on the quantum scale, which was the problem between General Relativity and Quantum Mechanics.

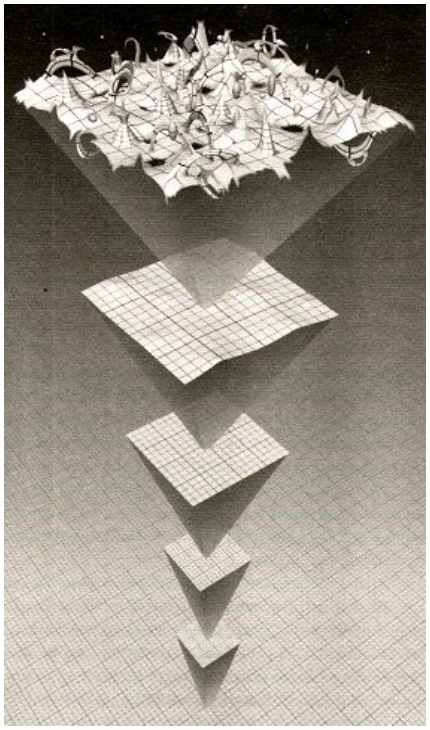
Superstring Theories		
Name	Number of Dimensions	Details
Bosonic	26	Only Bosons, no fermions* Open and Closed Strings Major Flaw: Predicts the existence of a particle with imaginary mass*
Type I	10	Supersymmetry between forces and matter Open and Closed Strings
Type IIA	10	Supersymmetry between forces and matter Closed Strings
Type IIB	10	Supersymmetry between forces and matter Closed Strings
Heterotic-O	10	Supersymmetry between forces and matter Closed Strings
Heterotic-E	10	Supersymmetry between forces and matter Closed Strings
11D Supergravity	11	Combines Supersymmetry and General Relativity p-branes
*Bosons are the force carrying particles, such as the photon (electromagnetism), W and Z bosons (weak nuclear force), gluon (strong nuclear force) and the graviton (theoretical particle for gravity)		
*In this case, the particle is known as a tachyon, and the number value for its mass, when squared, is a negative number		
*p-branes are multidimensional objects that are not made up of anything else		

I created this table myself, to demonstrate how the superstring theories differ from one another[9]

Another feature of M-Theory that has been targeted by opponents of the theory is the superstrings themselves: In M-Theory, the tension on the superstrings is thought to be roughly 10^{39} tons, which compresses them into to roughly 1.6×10^{-35} metres in size. The problem arises from the physics of superstrings, because the energy involved in the vibration of the strings is linked to the tension, the energy required would be massive, and in turn, based off of the equation $E = mc^2$, the mass of the string would be roughly 2.2×10^{-8} kg. This mass is far larger than the most

particles in physics, such as electrons and the massless photons, and would seem to be a fatal flaw that discredits the entire theory. Luckily, the quantum mechanics involved with Superstring Theory and M-Theory come out with the vibrations come out with a negative energy, and cancel out the mass, leaving the strings to be massless objects.

One of M-Theory's strengths is its resolution of the infinites that appeared in probabilities dealing with General Relativity and Quantum Mechanics, specifically with the approach of the Standard Model viewing particles to be zero-dimensional, or point-like. If we assume that particles are point-like, and hence infinitely small, these fundamental particles are affected by the quantum foam that Quantum Mechanics predicts, and hence the probabilities will hit infinity. Quantum foam is the turbulence that takes place at incredibly small distances, roughly 1.6×10^{-35} metres, and they become more extreme as you get smaller, and when a object is infinitely small and has zero-dimensions, it is strongly affected by the turbulence, and this high turbulence causes the infinites to arise. M-Theory solves this problem by using superstrings that can be multidimensional (be it one-dimensional, two-dimensional, etc.) and have finite sizes, which are predicted to be 1.6×10^{-35} metres in size, which means that the quantum foam cannot effect the superstring, so the infinites no longer occur, and the equations yield logical probabilities.



Quantum Foam: The top view of space, which appears rough and turbulent is a highly magnified image of what the turbulence may look like when viewing tiny portions of space [2]

IV. Conclusion

M-Theory is a leading Grand Unified Theory, and many physicists believe that even if it is not a "theory of everything", it will be an important stepping stone in the realm of physics. I personally do not believe there is enough evidence to prove or disprove M-Theory at this time, and only further scientific experimentation and research will be able to determine the validity of M-Theory. Although it rectifies many of the problems that occur in the Standard Model, such as the matter/anti-

matter imbalance and bridges the gap between General Relativity and Quantum Mechanics, there is still very little evidence that supports this theory any more than any other GUT candidate. What makes this theory so difficult to prove is that many of its predictions deal with incredibly small objects that are beyond our capabilities of observing at this point in time.

Also, because M-Theory uses Perturbation Theory, the equations and answers found are all estimates, and simplified properties of an overlying, more complex system, physicists cannot be exactly sure of its predictions or its accuracy, the validity of M-Theory will have to be proven through physical experiments and when advances in technology allow us to fully utilize the equations of M-Theory. Without exact values and exact equations, scientists cannot be sure as to the predictive capabilities of the theory. However, until this happens, M-Theory is just that, a theory, and it still needs many more years of research and experimentation, however, as of right now, it appears to be a very strong candidate for a "theory of everything".

References

[5] Quarks, Leptons and the Big Bang. Jonathan Allday. IOP Publishing, 2002.
[2] The Elegant Universe. Brian Greene. Vintage Books, 2003.
[6] The Fabric of the Cosmos. Brian Greene. Vintage Books, 2004.
[7] The Road to Reality. Roger Penrose. Vintage Books, 2005.
[8] Understanding the Universe: from Quarks to the Cosmos. Don Lincoln. World Scientific Publishing Co., 2004.
http://cfa-www.harvard.edu/~afriedman/AndysWebPage/BSJ/Constants.html
http://en.wikipedia.org/wiki/Calabi-Yau
http://en.wikipedia.org/wiki/M-theory
[4] http://en.wikipedia.org/wiki/Standard_model
http://en.wikipedia.org/wiki/Supergravity#11d:_The_Maximal_SUGRA
[9] http://en.wikipedia.org/wiki/Superstring_Theory
http://lofi.forum.physorg.com/Calabi-Yau-Spaces-Good-Elf_2183.html
http://starlife.stardusts.net/20060609.php
http://universe-review.ca/R15-18-string.htm\
[3] http://www.casimir.rl.ac.uk/zero_point_energy-quantum_fluctuations.htm
[1] http://www.chem.ucla.edu/~ltfang/comments/science/branches.htm
http://www.damtp.cam.ac.uk/user/mbg15/superstrings/superstrings.html
http://www.physics.arizona.edu/physics/news/matters/summer00/guts.html
http://www-pnp.physics.ox.ac.uk/~karagozm/ed_guide/