A Theory of Everything

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"If we knew all the laws of Nature, we should need only one fact, or the description of one actual phenomenon, to infer all the particular results at that point. Now we know only a few laws, and our result is vitiated, not, of course, by any confusion or irregularity in Nature, but by our ignorance of essential elements in the calculation. Our notions of law and harmony are commonly confined to those which we detect; but the harmony which results from a far greater number of seemingly conflicting, but really concurring, laws, which we have not detected, is still more wonderful." From Walden by Henry David Thoreau

"One cannot help but be in awe when he contemplates the mysteries of eternity, of life, of the marvelous structure of reality. It is enough if one tries merely to comprehend a little of this mystery every day." Albert Einstein

"But to a sound judgment, the most abstract truth is the most practical. Whenever a true theory appears, it will be its own evidence. Its test is, that it will explain all phenomena." …

"The ancient Greeks called the world χόσμος, *beauty. Such is the constitution of all things, or such the plastic power of the human eye, that the primary forms, as the sky, the mountain, the tree, the animal, give us a delight in and for themselves; a pleasure arising from outline, color, motion, and grouping."* From Nature by Ralph Waldo Emerson

"Kya knew from reading Albert Einstein's books that time is no more fixed than the stars. Time speeds and bends around planets and suns, is different in the mountains than in the valleys, and is part of the same fabric as space, which curves and swells as does the sea. Objects, whether planets or apples, fall or orbit, not because of a gravitational energy, but because they plummet

into the silky folds of spacetime – like into the ripples on a pond – created by those of higher mass.” From Where the Crawdads Sing by Delia Owens

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Key Concepts

The theory of everything described in this paper is a conjecture that starts with a firm conviction that energy, space and time are the *only* real things in the universe. That means that the universe is really nothing more than energy enabled fluctuations in warped space-time. This leads to our perception of all of the quantum particles and the three quantum forces; the electromagnetic force, the strong force, and the weak force. The only real force is gravity.

When we say “the universe” that’s what we’re talking about.

The next step emerges from the realization that the conservation of energy and the law equating energy to mass times the speed of light squared apply at all energy and distance scales and that together they constrain the evolution of the universe and everything in it.

The resulting theory provides an explanation for dark energy, dark matter, particle mass, the quantum characteristics of particles, and the evolution of the universe including its beginning and possible end with no need for extra-dimensional string theory, supersymmetric particles, an inflaton or a graviton.

It also leads to a plausible explanation of why relativistic quantum field theory can be used to explain the way particle physics works and why it makes such accurate predictions even though space-time is continuous. This eliminates the need to formulate a quantum theory of gravity to resolve the apparent inconsistency between general relativity and quantum mechanics. Instead a continuous theory of quantum mechanics does the trick.

Rationale for developing my theory

The equation $E=mc^2$ relates energy (E) and space and time (c^2), the only three things I think are real. That led me to believe that, just like the other relationship that involves energy, space and time as determined by the equations of general relativity, it must play a fundamental role in a theory of everything, a set of physical laws that are true at every scale. So, since observations show that E equals mc^2 in every process we can observe, it must also be true at scales we can’t directly observe. I decided to make that assumption and investigate the consequences.

At the scale of the universe, the amount of energy is fixed. It cannot be created and it cannot be destroyed. That energy is causing the universe to expand. If there was nothing to constrain the effect of this energy, the expansion would just continue unabated, at the same speed it had when inflation started. Since it slowed down, a constraint must exist and I wondered if the requirement that E must always be equal to mc^2 might do the trick.

At the smallest possible scale we can observe, quantum mechanics makes no sense. As Einstein was among the first to realize, it is an incomplete theory. It offers no reason for why individual physical events happen, provides no way to get at objects’ intrinsic properties and has no compelling conceptual foundations. There must be something happening at a smaller scale we can’t observe that leads to our observations of quantum mechanics. I wondered if that something could be fluctuations in the warping of space-time powered by energy and governed by $E=mc^2$.

During my investigation, I realized that my assumption led to observable predictions, namely the effects we see of dark energy and dark matter, as well as providing a possible logical explanation of what lies behind quantum mechanics. So, in the end, my theory not only makes sense to me, it also seems to explain everything we can observe.

It took a while for the implications of these ideas to sink in; to fully realize that everything I'm aware of, from the computer I'm using, to the leaves I'm looking at outside of my window that are waving gently in the breeze, to the breeze itself, to my own hand, to the fingers that are tapping on the keys, even the changes in my brain that are leading to my thoughts are, in reality, just changes in the warping of space-time, changes in the shape of space over time. Kind of amazing I say to myself, but I believe it must be true. In fact, it's the only thing that makes sense to me.

In an epiphany, I realized the significance of the fact that calculus can only be applied to continuous functions. In a theory of everything, that must be true at every scale and, if the universe is changing and it certainly is, space-time has to be continuous at the smallest possible scale if it's possible to describe the universe mathematically. For me, the existence of quanta of space-time makes no sense.

Outline of the Theory's Logic

Assumptions (and their consequences):

1. The only real things in the universe are energy, space and time.
2. In the ultimate reality, space and time (space-time) are manifestations of energy.
3. Energy and space-time are continuous, not quantized.
4. The laws of physics are scale invariant.
5. The warping of space (which involves interactions between energy, space and time) leads to our observations of quantum particles and the three quantum forces.
6. Energy is precisely conserved.
7. $E=mc^2$ applies at the scale of the universe with c being interpreted as the speed of its expansion, and it is the constraint on the evolution of the universe.
8. In the ultimate reality, mass is caused by gravitational interactions at exceedingly small space-time scales rather than by the Higgs field.

Evolution of the universe:

1. Initially there was only energy and its two manifestations, space and time.
2. Before there was any mass in the universe, there was no relationship between these three things so space and time could take on any value and had no meaning.
3. Space-time took on a value that allowed for the creation of the energy fluctuations that we observe as quantum particles and forces.
4. Some of the particles acquired mass because their energy fluctuations propagated at a slower speed than the speed of light and thus it was possible for gravity to accelerate them.
5. From then on, the universe evolved under the constraint that energy is precisely conserved at all scales.
6. In the future, if and when all of the mass in the universe has disappeared having been transformed into pure energy, the process repeats (go back to step #1) and a new universe is born.

The theory provides a possible explanation for:

1. The birth of the universe.
2. The reason for the extremely low entropy at the beginning of the universe.
3. Why some particles have mass and some don't.
4. What caused inflation.
5. The effects ascribed to dark matter.
6. The effects ascribed to dark energy.
7. The possible end of our universe and what would come next.

I. Preface

Some years ago, I bought a book on astronomy and became fascinated with learning about the life cycle of stars. That began what seemed to be an inexorable learning process which subsequently led me to books on atomic physics, galaxies, special and general relativity, cosmology, quantum physics, string theory, quantum gravity and “the theory of everything”. All of these subjects are related by being aspects of theoretical physics.

I’m still fascinated by these same subjects primarily because advances in telescope, satellite and particle accelerator technologies are rapidly improving our ability to know what the universe is made of and to figure out what that new information implies about how it evolved in the past and how it will evolve in the future.

I’m not a physicist. Even though I majored in mathematics in college, I’m not a mathematician either. Cosmology and theoretical physics are my hobbies. I like to think and read about them in my everyday language.

This paper is a documentation of some of my thoughts about cosmology and a theory of everything. It describes a thought I had about 14 years ago which has stood the test of several years’ thinking and still seems plausible and logical to me. I’ve refined and developed the original thought but the overall concept has remained. I was emboldened to write this paper by a comment many years ago from the physicist Lee Smolin who said that my ideas, when I described them to him in an email, made sense to him. Having read that, I decided to write this paper.

II. Points of Departure

The Importance of Perspective - When I was a boy, my family used to play a game. Somebody would point to a living thing. It could be an animal or a plant, but it was usually an animal - another person, a dog, a cat, an ant, a fly; or sometimes it was a tree, a flower or whatever and we would talk about what the world would appear to be like if we were, in fact, that creature. In other words, we would do our best to actually become the thing we were pointing to. It's not easy to do that and, to some extent, I'm sure we always failed but at least we tried. The game did teach me a good lesson though. It taught me how important perspective is in determining what we think is reality and, perhaps more importantly, it taught me that my perspective is just mine. It's not shared by anybody else, certainly not shared by other animals and definitely not shared by plants. Also, at that age, I began to realize that there's nothing special about my perspective. It's just one perspective among many others with no reason to be special. And, hard for me to imagine at the time but now obvious, all of those perspectives had an equal claim on legitimacy.

Our perspective is, to a large extent, determined by what we can directly sense. Evolution has given us the ability to sense the things that are important for us to be able to sense for our survival. Hence, we have the familiar five senses – sight, hearing, smell, taste and touch. But, equally importantly, evolution did not need to give us the ability to directly sense a lot of things that are equally real, but not particularly important for our survival. We are either the wrong size, or we don't have the needed sensory capability, or we are inside of the thing to be sensed.

Let me give you some examples of aspects of reality that we can't directly sense for these three reasons.

We are simply too big to directly sense a bacterium much less an atom. But bacteria are small enough to sense other bacteria and, from their perspective, other bacteria are part of their perceived reality. You can get even smaller. Some molecules respond to the presence of other molecules and, from their perspective, those other molecules are a part of their perceived reality.

You can get even smaller. In string theory, strings of energy vibrate in different patterns depending upon the structure of the space that they're associated with. It makes sense to think of the energy string, in its perspective, sensing the space which is part of its perceived reality. If we were the size of a string and had its characteristics we would vibrate in the same way. Interestingly enough, you can turn that around and also think of the vibrating energy string as part of the perceived reality of the space in which it resides with the string contributing to the shape of the space. As we'll see later, it's general relativity on a subatomic scale.

The problem of size can also be illustrated by the difficulty of comprehending the enormous size of the observable universe. The tiny part of the universe that we do comprehend is too small to give us the perspective necessary to realize how big it really is. The only way I've been able to get any appreciation of the universe's size is to take it in stages. If I really work at it, I think I can get a feel for the enormous size of our Milky Way galaxy. But to go beyond that, I have to change my perspective to the one that I would have if I were the size of the Milky Way. In a sense, I have to become the Milky Way. Only with that new perspective can I comprehend the size of the universe.

So our size is a major stumbling block to our understanding of the very small and the very big.

Secondly, we don't directly perceive much of reality because we don't have the right sensors in our bodies. Huge numbers of neutrinos pass through our bodies every second, moving at nearly the speed of light. They're really there but we don't perceive them because we have no way to sense their presence. One might say that we lack the right perspective. But, if they were important to our survival, we would have evolved a way to sense them and avoid their ill effects or we would be extinct. Likewise, our perspective doesn't include all of the electromagnetic radiation that surrounds us, only the small part of the spectrum that we call light and heat. Our particular perspective doesn't include the rest because we didn't need to evolve a way to sense it. But it's still really there.

Lastly, it's difficult for us to directly sense the reality of something that we're a part of. When we look at our Milky Way galaxy in the night sky, our eyes and minds don't readily tell us that in reality the galaxy is shaped like a disk. It doesn't look like a disk but in fact it is. The problem is our perspective. We are the right size to see the galaxy and we have eyes to sense the light it emits but we are, in fact, in it. Our perspective makes it hard to see it as it really is. The same problem makes it hard for us to perceive the reality of the universe. We are in *it* too.

So perspective is crucial to perceiving reality and changing perspective allows us to understand different realities. In a sense, the first thing one needs to do to understand some element of reality is discover the right perspective and then, in our minds, get as close to that perspective as we can.

The concept of perspective will become an important tool later in this paper. There, I will extend the concept to include different ways of "looking" at something that doesn't involve a human perceiver or, for that matter, any observer at all. For lack of a better word, when a perspective of something doesn't involve a perceiver, I'll call it a "manifestation" of the thing.

When we don't have and can't get the right perspective, we tend to describe reality by averaging. We can't perceive the reality so we do the best that we can and describe what we *can* perceive, what emerges from the unknown reality. For example, a TV screen is really filled with tiny stationary pixels, but we don't see them when we're watching TV. What we see is a moving picture which we say is really there even though it really isn't.

Some physicists, including the author of this paper, believe, for example, that quantum physics isn't the deepest reality but only an averaged description of some deeper, as yet unknown, reality. Think about the TV. Quantum mechanics is the moving picture that we think is real and something that we'll talk about later is the real stationary pixels.

Some physicists go even further and believe that there is no ultimate reality. In other words, they believe that the universe emerged from, and remains, nothing.

However in this paper, I propose that there *is* an ultimate reality - energy. Space and time, the other two things we believe constitute the entire universe, are real although they're not the ultimate reality. Rather they're what physicists call "exact dualities" of energy. They use this term for two different ways of looking at the same phenomenon. When two things seem different but in fact they're simply two ways of describing the same phenomenon, they're called "exact dualities". I believe that space and time (or space-time) are exact dualities of energy.

So energy, space and time exhibit the deepest of all symmetries. While they can be distinguished, in the ultimate reality they're not different. They're really all the same thing ... the energy of the universe.

The Importance of Relativity – There seems to be a trend in physics to understand reality in terms of relativity. Albert Einstein made the term popular but the concept seems to be spreading. The idea is to assume that reality doesn't incorporate absolutes. Rather the characteristics of things are relative. Another way of saying the same thing is to say, as I did before, that reality depends on one's perspective. Einstein said that the mass, dimensions and the passage of time associated with moving things changes as their relative speed changes. He also realized that the shape of space and the speed of time change in the presence of concentrations of energy. Relativity has been an important tool in gaining a better understanding of reality.

In fact, if you think about the significance of perspective, you might think that everything must be relative. How could it be otherwise?

However, in this paper, I propose that there's one thing that isn't relative … the total energy of the universe. It's the only thing that isn't relative. Put simply, it's not relative because there's nothing else for it to be related to. The concept of relativity makes no sense if something is the entire universe, if there's nothing else for it to be related to.

The Concept of Relativity in General Relativity and String Theory – When he developed his special theory of relativity, Einstein realized that space and time are intimately related. He said that space-time is four-dimensional with three space dimensions and one time dimension. If you change space it also changes time and visa versa. In a sense, space and time are the coordinates of 4-dimensional space-time.

Then, when he later developed the general theory of relativity he realized that energy in any form, including mass, and space-time are also intimately related. Change one and you change the other. As I said before, I prefer to think of space and time as two different manifestations of energy.

According to string theory, energy and space-time are again assumed to be intimately related, this time on the smallest possible scale. Minute energy strings are vibrating in the presence of space-time. Change one and you change the other. When you change the shape of space-time, the energy string vibrates differently and visa versa. Once more, I prefer to think of space and time as manifestations of energy.

Bringing the two supposedly inconsistent theories of general relativity and quantum mechanics together in one Theory of Everything requires that the space-time of the first must be the same as the space-time of the second. There's only one space-time which, as we'll see, is continuous and also can seem to be quantized. With this assumption in mind and a belief that space and time are different manifestations of energy, the idea that the entire universe is one thing becomes apparent. Energy becomes the only reality. In the deepest sense, energy doesn't exist in space-time. It doesn't exist in space. It doesn't exist in time. *It just exists*.

Without space-time, energy can't change because there's nothing else to relate the change to and change has no meaning. However, when space-time emerges, space becomes a manifestation of energy which does change, relative to energy and time. And time becomes a manifestation of energy which also changes, relative to energy and space. We'll see later that $E=mc^2$ can be applied to the entire universe which allows us to state those relationships mathematically for a given amount of mass in the universe.

t [time] = the square root of (m [mass] x s [space] squared / E [energy])
s [space] = the square root of (E [energy] x t [time] squared / m [mass])

In a universe with discernable space-time the existence of energy, space and time are dependent on each other. All three must exist for any one of them to exist. After all, the energy of a particle has 3 components … its rest energy which is fundamentally dependent on the existence of energy; its potential energy which is fundamentally dependent on the existence of space; and its kinetic energy which is fundamentally dependent on the existence of time.

Einstein realized that particles that move at the speed of light, like photons, which have no rest energy or mass, don't experience time. From their perspective, they are "just there". Similar thinking leads to the realization that anything that has no movement relative to anything else doesn't experience time. Everything moves at the speed of light in space-time. Since a photon isn't relative to anything, it can't change. It can't be accelerated because movement has no meaning for such a thing. In a sense, you can think of it as having no mass because it's impossible to accelerate it (see Section IX).

You can also apply that way of thinking about things that can't be accelerated to the universe itself! From its perspective, it is "just there" too. If we were the universe, we would think of ourselves as being just there even though from our perspective we think of the universe as something which evolves, changing in space over time ... perhaps the most extreme example of the significance of a difference in one's perspective.

So we've come full circle. Any entity that can't be accelerated (like a photon or like the universe) just exists. From its perspective it doesn't perceive time so the idea of its changing is meaningless ... to it!

One can easily see that energy, space and time are the only things in the universe that are real and they must be exact dualities of each other. Ultimately the universe is just fluctuating space-time that is being warped in different ways at different places in a mutual dance as a result of energy. All of the observed quantum forces in the universe are caused by fluctuations in the warping of space. You can think of the universe as a continuous energy field with the values of the field continuously fluctuating in response to the curvature of the surrounding space-time ... general relativity writ large and writ small.

This might remind you of string theory. It's similar in a way but there are important differences because unlike string theory, the theory of everything described in this paper doesn't require the existence of eleven space-time dimensions to be described mathematically... only four.

In 1998, physicist Juan Maldacena completed the work that led to a precise mathematical relationship between two perspectives of the universe taken from different vantage points … an "intrinsic" perspective involving the bulk physics of strings moving on a stack of branes and an "extrinsic" perspective involving the boundary physics of strings moving through a region of curved space-time bounded by a stack of branes. When he worked through the logic of the mathematics, Maldacena arrived at what's been called "a thoroughly bizarre conclusion". He discovered that a particular nongravitational, point particle quantum field theory in four space-time dimensions (which is what the first perspective equates to) describes the same physics as a string theory, including gravity, with strings moving through a particular swath of ten space-time dimensions (which is the second perspective).

String theory physicists believe that strings and branes must vibrate in a space-time shape with eleven dimensions that's a member of a huge collection of possible shapes called Calabi-Yau shapes. The enormous number of such shapes makes the task of selecting the one that's the exact shape of space-time in our universe seem almost impossible. There are simply too many possibilities. As a result, physicists are becoming increasingly doubtful that such a task can ever be accomplished. But I suspect that in reality the hypothesized extra dimensions that string theory requires don't exist. If that's true, it would enormously reduce the number of possible space-time shapes that energy can dance in, and greatly simplify the calculations.

But even if string theorists are right and there are really eleven space-time dimensions, Maldacena has provided a self-contained, precise mathematical dictionary which physicists can use to determine all of the details of this “holographic” realization of physical law. They now have a way to calculate precisely the energy string vibration that would be required to produce the quantum state of any particle that we can observe. It will be immensely complex, particularly if there are eleven dimensions, but in principle physicists can now use his equations to determine the single space-time shape that results in the observed quantum states of all of the particles in our universe. They will have found the Holy Grail … the Calabi-Yau shape of space-time.

If and when that’s accomplished, it will be a breakthrough. Even though we’ll never be able to make observations at the unimaginably tiny scale of ultimate reality, we would know precisely how the dance between energy and space-time is choreographed in our universe at that scale. It will take a while to get there but when that happens, we will be well on our way to fully validating a true theory of everything.

To complete the description of this theory, in the next section of this paper we will take up the question of the shape of space-time on the largest possible scale … the scale of the entire universe.

As we do that it will be helpful to think about quantum fields, particles and forces as though they are real even though we speculate that there’s a deeper, more fundamental reality. Quantum physics is very successful at explaining and predicting what we can observe. Making the assumption that it describes reality provides a unifying link between the physics of what we can’t observe (the unimaginably small) and what we can (the relatively large like, for example, the quantum scale). It leads us in the right direction as we try to discover a complete theory of everything; one that brings general relativity and quantum mechanics together under one set of physical laws that determine how energy and space-time interact on all energy and distance scales. So I’ll make that assumption in the rest of this paper. Let’s assume that both quantum mechanics and general relativity are right and see if we can find a path to the ultimate Holy Grail of physics, a theory of everything.

III. Cosmic Mathematics

The Universal Constraint - For nearly a century, cosmologists applied the equations of general relativity to the whole universe and found a variety of solutions that were tested by observations. Those solutions that predicted the big bang prevailed.

However, one can gain an even better understanding of how the universe evolves by starting with general relativity and then assuming that energy is precisely conserved and applying Einstein’s other famous equation, $E=mc^2$ (energy equals mass times the speed of light squared), to determine the structure and evolution of the universe and everything in it.

When $E=mc^2$ is applied to the universe itself and c is interpreted as a velocity determined by dividing distance by time, it’s apparent that the equation relates the only things in the universe that are real; energy, space and time. Specifically, the total amount of energy in the universe is proportional, by a factor equal to the amount of mass in the universe, to the square of the speed of its expansion. It should be noted that, according to special relativity, this equation is only valid for an object at rest. For a moving object it must be modified by a factor equal to the square root of 1 minus the square of the speed of the object divided by the speed of light squared. However, in this case since there’s no frame of reference for the universe, $E=mc^2$ is valid without modifications.

The assumption that $E=mc^2$ can be applied to the universe as well as to everything in it is fundamental to the theory described in this paper.

If you rewrite the equation as $E/m=(s/t)^2$, you can see that the speed of the universe's expansion depends on the ratio of its mass to its energy. Since energy can't be created or destroyed, the amount of energy in the universe can't change and the value of that ratio, in turn, depends on how much mass there is in the universe … the more mass, the slower the expansion. It might be helpful to think of that critical ratio as the density of mass in the energy of the universe.

The range of time transcends time itself and the scope of space transcends space itself, but before there was any mass in the universe, space and time weren't constrained by being related to energy and they could have taken on any values. Before the beginning of the universe, energy, space and time existed but with nothing for them to be related to, they couldn't be meaningfully measured. Energy was evenly distributed throughout space and time. But it could propagate in waves and those waves could fluctuate   When gravity led to the creation of the first mass in the universe (see Section IX), space and time had definable, measurable values. In a sense, they became real. They could have come into existence with any initial values as long as those values were compatible with the value of energy – i.e. as long as the square of the speed of the universe's expansion had been equal to the fixed amount of energy in the universe divided by the total amount of mass in the universe. But in any case, it was when the first particle became massive that space and time became real.

Now that space and time existed, some of the particles that were created from the energy of the vacuum, from the energy of space-time itself, acquired mass because space-time was so severely warped at that time. This warping led to those particles being accelerated in the strong gravitational field (see Section IX). As a result more massive particles were created as a result of the relationship between energy, space and time. The evolution of the universe from that moment on has been and will always be determined solely by the requirement that as long as there's any mass in the universe, E must equal $m(s/t)^2$.

Now let's consider the entropy of the universe. Entropy is a measure of the degree to which a system is ordered. The more ordered a system is the less entropy it has. The Second Law of Thermodynamics says that over time the total entropy of a closed system will increase. Over time, all such systems become more disordered. When the second law is applied to the universe observations imply that it must have come into existence with incredibly low entropy. Physicists have struggled to find a reasonable explanation for this. But picture the universe as just energy in warped space-time and think about what it would look like when the first particle acquired mass. When space-time became real, energy was evenly distributed and the shape of space-time was the same throughout the universe except where that one massive particle created a slight additional warping. What could be more ordered than that? So we can easily see why the theory described in this paper provides a simple explanation for the exceedingly low entropy of the universe at its beginning.

Now let's consider symmetry. Before the Big Bang there was only energy and without space or time it couldn't propagate. The universe's symmetry was perfect. But when space and time came into existence, waves of energy were created which *could* propagate. As particles were acquiring mass the perfect symmetry of the universe was broken. Later on there were further symmetry breaks as the temperature of the universe dropped. The rest is history.

In the beginning, mass wasn't created at exactly the same time and as particles began to become massive there was relatively little of it. In a way, you can think of the universe as a quantum particle. Because it had so little mass at that time the universe's Compton wave-length, which sets the scale of quantum effects and is inversely proportional to mass, was huge and the velocity of the expansion of the universe was very fast. But the portion of the universe's energy in the form of mass was increasing quickly and, even though the universe expanded very rapidly during what's called the inflation period, the speed of its expansion quickly slowed down.

Right now we're at a time in the history of the universe when mass is being converted into energy. The ratio of mass to energy is decreasing and as a result the expansion of the universe is accelerating. In reality, the force of "dark energy" simply results from the fact that the evolution of space and time is constrained by $E=mc^2$. However, over time the rate of this acceleration will decrease because the expansion of the universe will make the distribution of its energy more dilute. As energy becomes more evenly distributed there will be fewer of the concentrations of energy that are favorable to the conversion of mass to energy. Consequently the universe's mass-energy ratio will decrease more slowly and the acceleration of the speed of the increase in the distance between objects in the universe will slow down.

So we can see that all of the universe's characteristics are explained by the constraint on the evolution of space-time imposed by $E=mc^2$. Everything we can observe, including the effects of quantum mechanics and general relativity, happens if we make that assumption. So it seems we've arrived at a theory of quantum cosmology although at the end of Section VII, we'll see that in reality there's no need for such a theory because space-time is continuous.

But this same equation, $E=mc^2$, constrains the warping of space-time in all gravitationally bound entities in the universe – our solar system, other stellar systems, galaxies and clusters of galaxies, for example – as well as in the universe itself. Those constraints on the manifestations of energy apply in all space-times regardless of their size. When the ratio of the entity's mass to its total energy decreases, it causes an acceleration effect which, according to the insight which led to the general theory of relativity, can't be distinguished from the effects of the warping of space which we call a gravitational field.

The magnitude of those effects in any particular entity depends on how rapidly its mass/energy ratio is changing. Consequently, the acceleration and perceived gravitational effects, while exceedingly small in the entire universe, are significantly larger in places where energy densities are relatively high, for example in galaxies and particularly near the center of galaxies where the ratio is changing relatively rapidly. In the case of galaxies and clusters of galaxies, it's common for a significant amount of mass to be converted into energy in stars, as neutron stars are formed or as matter collapses into black holes. As a result, gravitational effects are seen that astronomers have said result from "dark matter". But, in reality, there is no *dark matter*.

Instead the gravitational effects we observe are caused by a decrease in the proportion of the gravitationally bound entity's total energy that's in the form of massive particles, not by dark matter. This decrease permeates the entity with a small additional warping of space. Near the center of the entity, this additional effect is so small compared to the curvature predicted by general relativity that it's not noticed. But farther from the center and closer to the edge of the entity, the effect causes an appreciable proportion of the total space-time curvature and it is definitely noticed. This is exactly what astronomers have observed in galaxies and clusters of galaxies leading physicists to assume the existence of dark matter. More about this in Section V.

This table summarizes the effects of the constraint on the evolution of space-time imposed by the requirement that E must always be equal mc^2 in the universe and everything in it. The predictions of those effects shown in bold in the table are consistent with all astronomical observations.

Event in the universe	**Time from the beginning of our universe**	**In the universe as a whole**					**Inside of gravitationally bound entities in the universe**		
		Speed of the expansion of the universe	**Curvature of space**	**Gravity**	**Amount of mass**	**% of energy in form of mass**	**Curvature of space**	**Gravity**	**% of energy in form of mass**
Before there was any mass	Time isn't measureable	Space isn't measureable			None	0	There was no gravitational field and no gravitationally bound entities		0
When mass first exists and inflation starts	10^{-35} seconds	**Very fast but slowing down rapidly**	Spherical	Attractive	Increasing very fast	Increasing	Not applicable	Not applicable	Not applicable
When inflation stops	10^{-33} seconds	**Staying about the same**	Spherical	Attractive	Essentially Unchanging	Unchanging	**Spherical**	**Attractive**	Unchanging
When first stars form	100 million years	**Slowing down**	Spherical	Attractive	Starting to decrease	Decreasing	**Spherical**	**Attractive**	Decreasing
When acceleration starts	7 billion years	**Starting to accelerate**	Hyperbolic	Repulsive	Decreasing	Decreasing	**Spherical**	**Attractive**	Decreasing
Now	**13.8 billion years**	**Accelerating**	**Hyperbolic**	**Repulsive**	Decreasing more slowly	Decreasing	**Spherical**	**Attractive**	Decreasing
In the future		Accelerating but at a slower rate	Hyperbolic	Repulsive	Decreasing even more slowly	Decreasing	Spherical	Attractive	Decreasing
If protons can decay and there's no mass	*~ 100 billion years*	*Spacetime no longer exists. The universe is only energy. This is the same condition that existed before there was any mass in our universe and another universe will be created. Go back to the top of the chart. This new universe will have the same laws of physics but they will have different starting values leading to a different history.*							

Note that the conjectured theory described in this paper requires the existence of a solution to Einstein's field equations of general relativity that includes the modifications required by the assumption that $E=mc^2$ constrains the evolution of the universe and everything in it. That solution must also be in accordance with astronomical observations that imply that the universe had a beginning, expanded exponentially shortly thereafter, continued to expand at varying speeds, and is currently accelerating. Those equations must also reduce to Einstein's equations of general relativity when gravity is weak. If it turns out that such a solution doesn't exist, then this "theory of everything" is wrong. While I hope someone will eventually find such a solution there's certainly a very real possibility that it doesn't exist. Time will tell, so stay tuned … and readers who are really good at solving Einstein's equations, please let me know if you have any thoughts about this or come up with something!

The Famous Incompatibility – So $E=mc^2$ places a constraint on the evolution of the universe and its gravitationally bound entities. But how can a quantum field theory of particles combined with a non-quantum field theory of space-time result in a theory of everything in which $E=mc^2$ applies on all space-time scales? In other words, how can quantum physics – in particular, quantum field theory – be incorporated into classical Einsteinian gravity?

It's interesting to note that the canonical approach to quantizing general relativity breaks down spacetime into two distinct parts: space and time. Just as described in this paper, general relativity stops being a theory about spacetime as one invisible whole and becomes a theory of how space evolves in time. In 1967, Bryce DeWitt showed that it was possible to introduce quantum physics into this picture by finding an equation that can be used to calculate the *probabilities* of a given geometry of space as it evolved in time. Perhaps this is a clue to the way classical Einsteinian gravity can lead to the uncertainties at the scale of quantum mechanics. At least it's something to think about.

There's no shortage of suggestions and a lot of proposals about ways to make general relativity and quantum mechanics compatible. Let's consider some of them.

I've already mentioned string theory which predicts the existence of the graviton. Then there's all of the work by physicists to try to resolve the incompatibility by developing a theory of quantum gravity, particularly loop quantum gravity. But perhaps the most straightforward approach is to augment the gravitational field predicted by the general theory of relativity. There are many proposals for the nature of the required modification to the gravitational field … Nonsymmetric Gravitation Theory (NGT), Jordan-Brans-Dicke gravity, Milgrom's Modified Newtonian Dynamics (MOND), Bekenstein's relativistic version of MOND, Manheim's conformal gravity, five-dimensional modifications of gravity and Moffat's Modified Gravity Theory (MOG), among others.

All of these proposals involve modifying the general theory of relativity. The theory proposed in this paper also requires such a modification so that E will equal mc^2 on all space-time scales.

It's also interesting to note that the Spin (11,3) Lie group seems to provide a complete mathematical description of a universe and everything in it whose evolution is constrained by the requirement that E must equal mc^2 on all space-time scales. If that's the case, in principle all of the consequences of that constraint could be precisely calculated and the theory described in this paper would be testable and could be confirmed by observations. If any of those observations aren't predicted by the theory, it would either be completely wrong or it would require modifications.

An article entitled *The Universe's Hidden Geometry* written by A. Garrett Lisi and James Owen Weatherall was published in the December, 2010 edition of Scientific American magazine. After describing how two mathematical constructs called Spin (1,3) and Spin (10) Lie groups can be used to describe gravity and the Standard Model of particle physics respectively, the article says:

“Now it is just a matter of putting the pieces together. With gravity described by Spin (1,3) and the favored Grand Unified Theory based on Spin (10), it is natural to combine them using a single Lie group, Spin (11,3), yielding a Gravitational Grand Unified Theory … It brings us close to a Theory of Everything.

“The Spin (11,3) Lie group allows for blocks of 64 fermions and, amazingly, predicts their spin, electroweak and strong charges perfectly. It also automatically includes a set of Higgs bosons and the gravitational frame; *in fact they are unified as “frame-Higgs” generators in Spin (11,3).* The curvature of the Spin (11,3) fiber bundle correctly describes the dynamics of gravity, the other forces and the Higgs. *It even includes a cosmological constant that explains cosmic dark energy.* Everything falls into place.

“Skeptics objected that such a theory should be impossible. It appears to violate a theorem in particle physics, the Colemen-Mandula theorem, which forbids combining gravity with the other forces in a single Lie group. But the theorem has an important loophole: it applies only when space-time exists. *In the Spin (11,3) theory (and in E8 theory), gravity is unified with the other forces only before the full Lie group symmetry is broken, and when that is true, space-time does not yet exist. Our universe begins when the symmetry breaks: the frame-Higgs field becomes nonzero, singling out a specific direction in the unifying Lie group. At this instant, gravity becomes an independent force, and space-time comes into existence with a bang.* Thus, the theorem is always satisfied. The dawn of time was the breaking of perfect symmetry.” (Italics mine)

They’re right! Everything *does* fall into place ... the equivalence of the Higgs field and gravity, the cause of the acceleration of the expansion of the universe and the reason for the emergence of space-time … exactly as described in this paper! The full Lie group symmetry is broken when the first particle in the universe acquires mass.

IV. Dark Energy

In the late 1990's astronomers who were trying to determine the rate of the slowdown of the expansion of the universe discovered, much to their surprise, that the expansion seemed to be speeding up instead. Since that time, this acceleration has been confirmed by a variety of observations and methods. So, right now, the universe is not only getting bigger but it's getting bigger faster. The unanswered question is "Why"? What's causing the acceleration?

There must be some kind of energy, with negative pressure, that's counterbalancing the gravitational effects of all of the matter and energy in the universe that should be causing the universe's expansion to slow down. Physicists have a name for that energy, calling it dark energy, but they have no idea what it is.

However, they *can* figure out what some of its characteristics must be. For example, they know that about 68% of all of the energy in the universe must be in the form of dark energy. It's the dominant form of energy. Dark matter contributes about 27% of the universe's energy and baryonic matter, the only kind they can see and understand, makes up the remaining 4.9%. While dark energy must be pervasive, they're not sure whether its density is constant, a la Einstein's hypothesized cosmological constant, or if it changes over time. If its density is in fact changing, it's called quintessence

The dark energy that's causing the universe's expansion to accelerate pervades all of space. In essence it's a characteristic of space-time itself. If in reality space-time wasn't continuous but was quantized, as many physicists believe it is, it would mean that it would undergo quantum "jitters" at Planck scale distances. It's possible to calculate the energy that those jitters would generate and in fact physicists have done that. It turns out that the result makes no sense. They calculate that the energy in space-time would be at least 10^{100} times greater than is actually observed. Something is obviously terribly wrong! But note that space-time is assumed to be continuous in the theory described in this paper. Since continuous space-time doesn't have any quantum characteristics it doesn't have any quantum jitters and dark energy must be due to something else. Perhaps the repulsive force is due to the effects of gravity, the only real force in the universe.

To understand how gravity can cause the acceleration in the expansion of distances between objects in the universe, it's important to focus on my assumption that gravity is the only force in the universe that's real. Recall that there are only three real things in the universe --- warped space and "warped" time and unevenly distributed energy. Warping results in a variety of different shapes of space-time at different places in the universe. Until the universe was about 7 billion years old the shape of space-time was spherical and gravity was attractive. But right now in the universe as a whole, outside of gravitationally bound entities, outside of clusters of galaxies, the shape of space-time is hyperbolic and gravity is repulsive.

In the previous section of this paper, we saw that the velocity of the expansion of the universe is determined by the constraint on the evolution of space-time imposed by the requirement that E must always be equal to mc^2. As the portion of the universe's energy that's in the form of massive particles changes, the speed of its expansion must also change in a way that satisfies the equation that relates energy to space and time.

The universe as a whole has a shape that determines the rate of its expansion. At the beginning of inflation, the curvature of that shape was spherical but only a tiny part of the universe's energy was in the form of mass and the universe expanded rapidly. But as the portion of energy in the form of mass increased as massive particles were being created the expansion slowed down.

Then about 7 billion years after the big bang, the expansion sped up again when the ratio of mass to energy decreased as mass was being converted into energy in the nuclear reactions in stars. The shape of space-time became hyperbolic and the expansion of space-time started to accelerate.

Because the rate of the acceleration depends on the precise ratio of the negative pressure of “dark energy” to its density (i.e. the so-called equation of state) the way in which this energy evolves influences the way in which the expansion rate of the universe changes with time.

Even though dark energy makes up roughly 70 percent of all of the energy in the universe today, its repulsive influence had to be insignificant compared to the gravitational attraction of matter when the universe was much younger or it would have prevented matter from falling together to form stars, galaxies, and clusters. But from the time in the very early universe when the creation of particles with mass stopped until the time when the first stars were born there was no mechanism to change the amount of mass in the universe and as a result the influence of dark energy was indeed insignificant. As a result, during that period gravity was essentially unimpeded as it worked to create the first galaxies and stars.

So the nature of the dark energy which is accelerating the speed of the expansion of the universe isn’t mysterious. It’s simply a necessary consequence of the fact that, in the universe as a whole, E must always be precisely equal to mc^2.

V. Dark Matter

Various research groups are exploring the possibility of a unified dark energy (called "quartessence") in which dark matter and dark energy are different aspects of the same thing. As we've seen, we propose that indeed they are. As was pointed out at the end of Section III, the effects of both dark energy and dark matter are caused by the constraint of $E=mc^2$ on the evolution of space-time. They're both the result of the force of gravity, the warping of space-time.

General relativity tells us that the shape of space-time varies from place to place depending upon the distribution of energy. Since gravity is causing space-time to expand right now, the curvature of space must be negative except in gravitationally bound entities in the universe where concentrations of energy and matter cause positive space-time curvature. The different space-time curvatures produce the gravitational forces that result in all of the observations attributed to both dark energy and dark matter.

Now let's consider dark matter. In any gravitationally bound entity a tiny change in the proportion of its energy that's contained in massive particles results in a subtle but significant additional gravitational force beyond that predicted by general relativity. Throughout the entity, like the force predicted by general relativity, the force of this additional gravitational field decreases exponentially in proportion to the square of the distance from the entity's gravitational center. However, this change in the strength of the entity's gravitational field is such that the effects of $E=mc^2$ become increasingly significant and noticeable as you move away from the center. This can explain the difference between the predicted and observed concentration of dark matter at the center of galaxies, the so called core-cusp problem. The density of dark matter in the core of a galaxy is less than what is predicted by computer modelling. Astronomers have investigated the gravitational effects of the hypothetical dark matter that they assume is really there and they've concluded that those effects are increasingly large the farther you are from the center of the entity, like for example in a galaxy. The total effect predicted by the theory described in this paper fits in nicely with the assumed inverse square distribution of the hypothetical dark matter in spiral galaxies, like ours, that's needed to account for the flat rotation curve of the velocities of its stars.

So dark matter isn't really matter at all and it's not mysterious either. It's due to gravitational forces and simply another necessary consequence of the fact that in any gravitationally bound entity in the universe, as in the universe itself, E must always be precisely equal to mc^2.

VI. The Consequences of $E=mc^2$

If my idea is right the only real things in the universe are energy, space and time and space and time are just manifestations of energy, the consequences are profound.

Recall that energy is the ultimate reality and that space and time are manifestations of it. In that sense, energy is the only real thing in the universe.

Energy can't be relative since there's nothing else for it to relate to. It can't change. Energy is conserved. It just ***IS***.

Another way of saying the same thing is that the energy of the universe has always and will always exist in all of the space of the universe. As time and space change, energy continues to exist and never changes in spite of the changes in its manifestations.

In this sense, the universe itself just ***IS***. In reality, it's not changing either. Einstein's intuition told him that the universe was unchanging. He apparently never suspected the significance of $E=mc^2$ even though he discovered that relationship and spent most of his life searching for a theory of everything. There's no evidence that it ever occurred to him to apply his equation to the universe and to try to discover the implications of doing that.

Since, in the ultimate reality, energy has no spatial or temporal or characteristics, it makes no sense to ask if the universe has quantum or continuous characteristics. And, unfortunately, the fact that the universe is only energy isn't detectable either since there's no way to detect something that's everything. Since, in reality, energy has nothing else to react with, it is, in principle, impossible for scientists to detect the fact that space-time is really a manifestation of energy. So my assumption about what's real has to be based on circumstantial evidence. However, the evidence for that idea of what's real is convincing to me and forces us to consider the possibility that it might be correct ... or at least is heading in the right direction.

VII. The Mysteries of Quantum Mechanics

Quantum mechanics and general relativity are both proven theories. They've both been tested many times by carefully designed and implemented experiments. To great precision, neither has ever failed a test. A theory of everything must include both of them but they seem to be inconsistent because they make different assumptions about the nature of space-time; quantum mechanics assuming it, like everything else, is quantized, and general relativity assuming it is continuous. The fact that general relativity is based on relationships between real things (energy, space and time) and also includes energy in the form of mass whereas quantum theory requires the existence of mass which isn't an element of the ultimate reality, just energy, is a clue that the apparent inconsistency in the nature of space should be decided in favor of the former. To put it more fundamentally, general relativity describes relationships between real things whereas, although quantum physics seems to be real, general relativity underlies it.

Once you get over the formidable hurdle of believing that space and time aren't just the arena in which everything takes place but they're real things that are malleable and change in response to their energy environment, general relativity makes sense. In fact, it makes so much sense that it seems almost inevitable. Quantum mechanics is different in this respect. In some ways, it makes no sense at all. All of the efforts to interpret the meaning of quantum mechanics in ways that make sense to us seem somewhat bizarre.

But when you realize the significance of the constraints imposed by ensuring that E equals mc^2 on all scales and the fact that energy and space-time are the only real things in the universe, that weirdness disappears. The key to understanding what quantum mechanics really is is to recognize that there's a deeper reality that underlies it. The reality of fluctuating warped space-time as described earlier in this paper.

So, what does that say about the nature of quantum mechanics? First of all, we think quantum mechanics is real because the quantum scale is the smallest scale we can observe and do experiments on. But the basic reason it makes no sense to us is because it's not really real as we think it is. What's really real is what's described in this paper. That does make perfect sense but it happens at a scale that's so small that we can't directly observe it. But fortunately we can see its consequences – quantum mechanics.

Let me give you a few examples of how the mysteries of quantum mechanics can be resolved.

Quantum theory includes the superposition principle which says that if a physical system may be in one of many configurations—arrangements of particles or fields—then the most general state is a combination of all of these possibilities. Famously, Schrodinger's cat is simultaneously dead and alive. That seems like nonsense. But when you realize that the universe is really only energy and appreciate the significance of $E=mc^2$, it makes perfect sense. The dead cat and the live cat are both, like everything else, just energized fluctuations in space-time. We perceive them as different because they involve different fluctuations, not because they're really different. So the fact that the cat is both dead and alive is no longer mysterious or surprising. In fact, it would be surprising if it wasn't true. You and I are really dead and alive too. As we now know, everything is made up of the same thing, fluctuating space-time. And since it has been shown that changes in those fluctuations occur probabilistically the quantum superposition principle makes sense.

Quantum mechanics also says that quantum entities are simultaneously waves and particles. It depends, says the theory, on how they're observed. That also sounds like nonsense. How can something be two different things at the same time? But we now know that particles are in fact waves … not probability waves, but waves of energy. Wave/particle duality makes perfect sense with that in mind.

One of the strangest aspects of quantum mechanics is called decoherence. Take an electron, for example. According to quantum theory, its position in the future depends on a probability wave that determines the likelihood of finding it any place it could possibly be. But when you observe the electron to find out where it is, it always responds by “snapping to attention” and coalescing at one definite location. The probability wave collapses to a specific spot. The mathematics of quantum theory says that such a collapse can’t possibly happen but experiments show that it does. How can that be? Physicists have come up with a lot of ingenious explanations but none of them make much sense.

But remember that electrons aren’t the ultimate reality. The only reality is fluctuating space-time. Both the electron itself and the particles that make up the detector doing the observing are both really just waves of fluctuating space-time (which, at the deepest level of reality, are just energy), like everything else, and when waves collide or intersect it produces an interference pattern. Both waves contribute to creating a new wave pattern with peaks and valleys. We can’t directly observe what’s really happening but we *can* measure the position of the electron. Just like the original pattern of energy fluctuations told us where the electron was, the new pattern tells us where it *is now.* So in reality there indeed *is* a wave going through the two slits in the famous experiment but it’s a wave of energy, not a probability wave and an energy wave doesn’t need to collapse when it’s observed. With this new understanding, decoherence is no longer mysterious and the explanation is simple. Decoherence doesn’t really happen but, at the level we can observe, we think it does. In fact, at that scale it must happen. Anything else would be a puzzle.

Using the principles of quantum mechanics, scientists have designed precise experiments to show that it must exhibit non-locality. Somehow entangled quantum particles, even if they’re astronomically far apart, are related and appear to be able to communicate with each other instantaneously. That makes no sense, we say. It violates the assumption that nothing, including information, can travel faster than the speed of light. But again, the theory of everything described in this paper comes to the rescue. In reality, both particles are just energy, as we know, and in reality energy doesn’t reside in space or time. The instantaneous “communication” between two separated particles which made no sense to Einstein does make sense to us.

What about the uncertainty principle? Why is it that the more you know about a quantum particle’s position, for example, the less you can know about its momentum? The answer is that the more you constrain the “value” of either space or time the more freedom the other one has. Since both are manifestations of the same thing, energy, they have to be consistent. Fixing one gives the other one more freedom while still maintaining the required consistency. Constraining the “value” of time makes the “value” of space fuzzy and visa versa so it’s impossible to determine both of them at the same time with any precision. In reality, that makes the reason for the uncertainty principle easy to understand.

And, finally, what explains perhaps the biggest mystery of all about quantum mechanics? How can quantum field theory, which underlies quantum mechanics, work in a universe of warped continuous space-time that’s in a dance with fluctuating concentrations of energy? The answer lies with the curvature of space-time at extremely small distances … at the Planck scale, roughly as many times smaller than a proton than a proton is smaller than a human. Since gravity responds directly to energy its power is proportional to energy squared. At Planck scale distances and energies the force of gravity is so strong that it overwhelms the other three forces and becomes the dominant force. In fact, at that scale gravity is revealed as the only real force. The curvature of space-time is so severe that the energy fields that we can observe exhibit quantum characteristics even though space-time itself is continuous.

So Einstein’s assumption that space-time is continuous is right while, at the same time, quantum mechanical theory works very well at the scales we can investigate. In reality, it’s the force of gravity, the curvature of space-time, which makes both of these seemly inconsistent concepts compatible.

Fortunately, we can now see that there’s no requirement for a so-called quantum theory of gravity to resolve the apparent inconsistency between general relativity and quantum mechanics because there’s no such thing. Physicists had been looking in the wrong direction. It turns out that a continuous theory of quantum mechanics does the trick.

VIII. What Are You?

At this point in this paper, I can't resist the temptation to get personal. If you ask a scientist what we really are, she might say that we're concentrations of energy. But since we live in a universe comprised of only one thing, energy, the complete answer is that we're all the same even though we think we're all different. In reality we're all simply just energized changing warped space-time. It's wrong to think that we're all made of energy. It's equally wrong to think that we're all part of the universe's energy. We're not even really an averaged description of the relationship between energy and its two manifestations, space and time. In reality, we **are** energy as evidenced by its two manifestations space and time. The fact that everything in the universe is one unchanging entity isn't easy to comprehend. It's not intuitive and that way of thinking about things isn't easy to get comfortable with. However, not only is the assumption that the only real thing in the universe is energy plausible and logical but, if it's true, it explains many aspects of the current thinking in theoretical physics that are mysterious or just don't make sense.

IX. Is Mass Caused by Gravity?

We've seen that mass plays a role in the universe that's so fundamental that it's hard to imagine what the universe would be like without it. If none of the particles in the universe had any mass, there'd be no measureable space or time. In fact, there'd be no universe as we know it. The only reality would be energy. But with no space or time, no space-time, that energy would simply exist. It would be real but it couldn't change, it couldn't concentrate so it couldn't be used for any purpose other than its own existence. So, in a sense, the existence of mass is responsible for the existence of the universe. That means that if we can figure out why particles have mass, we've figured out why there's a universe that we can exist in. Personally, I can't think of a more important question. Why do particles have mass? Why do I exist?

Most physicists believe that particle mass results from interactions with ubiquitous Higgs particles, creating the Higgs field. But I wonder if it's possible that, in reality, a particle's mass is really caused by something else … the universal gravitational field that's described in this paper. Perhaps the very strong gravitational field at tiny distances and very high energies gives mass to those particles which, as we mentioned earlier, are really waves of energy whose propagation can be accelerated.

There are two ways to define mass; either as a characteristic of something that makes it resistant to a force or as a characteristic of two things that attract each other (i.e., they both feel the effects of gravity). If you put these two definitions together, it's a clue that it's gravity that causes something (a particle) to be resistant to a force! Or … gravity causes mass!

After all, everything in the universe moves at the same speed in space-time; the universal speed, 299,792,458 meters per second. If an elementary particle doesn't have any mass, like a photon, its movement in space-time is all in the space dimension. From its perspective, it doesn't perceive time. It takes energy to give another type of particle mass by transferring some of its movement through space-time from the space dimension to the time dimension and slow it down. But where does that energy come from? Perhaps instead of interactions with the Higgs field it's really the severe curvature of space, gravity, at very tiny distances that gives particles like quarks, electrons, neutrinos and the Higgs boson their mass.

The thought that led Einstein to the general theory of relativity was the realization that there's no difference between being in a gravitational field and being accelerated. The special theory of relativity says that accelerating particles increase in mass.

At the end of Section II, I mentioned that a quantum particle is really a fluctuating concentration of energy that moves through space like a wave. If gravity causes mass, the speed of the propagation of a particle's energy wave would determine its mass; the faster the wave moves the smaller the particle's mass would be. For example, the energy wave that we perceive as a photon already propagates at the maximum possible speed, the universal space-time speed, the so-called "speed of light". Even though it's in the same gravitational field with every other type of particle, it's impossible for that wave to accelerate so a photon doesn't have any mass. But gravity *can* accelerate other particles whose waves propagate slower than the speed of light so they acquire mass. In fact, a particle's speed determines how much mass it has. The slower the energy wave that we perceive as a particle propagates the more it's possible for gravity to accelerate it, and the more massive the particle will be. The mass of all of the particles of a particular type is the same simply because the energy waves that underlie them all have the same wavelength and the same propagation speed.

Note that gravitational acceleration doesn't depend on mass which places gravity on a different footing from any other force in nature. When a particle has acquired mass because of its acceleration in curved space-time that mass doesn’t result in further changes in space-time curvature. Fortunately there’s no annoying, endless feedback process. As a result the mass of all of the particles of a particular kind is the same and a particle’s mass doesn’t change when its space-time environment changes; exactly what’s observed.

X. Epilogue – E=mc^2 and the Mysteries of the Universe

The Hierarchy Problem- Why is Gravity So Weak? –The Standard Model of particle physics is based on the concept of relativistic quantum fields. It assumes that all interactions are caused by a completely random and unpredictable exchange of particles. On the other hand general relativity assumes that the gravitational field isn't quantized and that space-time is continuous. This fundamental difference between these two theories makes incorporating gravity into the Standard Model very difficult, in fact impossible.

General relativity shows that the presence of energy causes space-time to warp. Things that feel the force of gravity are moving in a straight line in warped space. Since they're moving in a straight line their gravitational interactions don't require an exchange of energy in the way the three quantum forces do. So it isn't surprising that at low energies the force of gravity is so much weaker than those other forces because it's not caused by the same kind of process. Of course, at very small space-time scales and at very high energies, the force of gravity increases significantly. At Planck scale distances gravity plays the dominant role. When energy levels are high at very small distances, gravity isn't weak. Taking that perspective helps us to realize that gravity is the ultimate force, the only real force, in the universe.

Extra Dimensions? – There are no "extra" dimensions in addition to the familiar three dimensions of space and the fourth "dimension" of time. The assumption that there are many more dimensions is attractive for two reasons: 1) it can provide a plausible explanation for gravity's weakness compared to the other three forces of the Standard Model of particle physics. But, as we've just seen, the difference in their relative strengths is because the force of gravity results from warped space-time and not from an interchange of particles like the strong, weak and electromagnetic forces, and 2) it seems that string theory requires extra dimensions to work. Since extra dimensions don't exist, string theory is either wrong or formulated in the wrong way. But string theory's assumption that reality is made up of minute forms of energy vibrating in space is on the right track and physicists will have to figure out how that can happen in three-dimensional space. When they do that they should be able to calculate the properties of quantum forces and particles.

Is Space-time Continuous or Quantized? – In all likelihood space-time is continuous but that hasn't been definitely established yet even though recently there has been strong observational evidence of that possibility.

General relativity and quantum mechanics are incompatible. General relativity states a relation between energy in any form and space-time. For that reason it's fundamental and so far it's been proven by experiment and observations. On the other hand, even though quantum mechanics isn't fundamental because it requires the existence of mass, it's been proven by experiments too. But these two theories seem to be inconsistent.

Such a discrepancy between a generic quantized-space theory (that assumes a quantized space-time) and general relativity (that assumes continuous space-time) simply means that both theories have been regarded as "effective theories", valid only in their own regimes. General relativity applies on very large scales, whereas a quantum theory usually is "impossibly tough to solve" when extended to large scales. Conversely, general relativity seems to have serious divergences when analyzed at the quantum scale, where quantum theory applies very well. An important fact is that both have to converge into Newtonian physics at intermediate scales ("our" scale).

In a “theory of everything” there can only be one fundamental structure of space-time. It has to be the same at every distance scale from the very largest (the universe) to the very smallest (the Planck scale). In the theory described in this paper, modified general relativity applies on all scales and space-time must be continuous on all scales including the Planck scale. Thus in reality, space-time must somehow be both continuous *and* yet somehow seem to be divided into chunks in our quantum experiments ... the only possibility that permits general relativity and quantum mechanics to peacefully coexist.

Recent observations made by NASA’s Fermi Gamma-Ray Space Telescope of a race between gamma rays of differing energies and wavelengths spit in a burst from an exploding star when the universe was half its present age indicate that Einstein was right when he proclaimed that the speed of light is constant and independent of its color, or energy; its direction; or how you yourself are moving relative to others. This result is consistent with an assumption that space-time is really continuous and comes close to proving it. Future observations by the telescope might close the case.

Further evidence came in 2019 when radio astronomers using the Event Horizon Telescope announced that they had been able to capture an image of the unobservable: a black hole, a cosmic abyss so deep and dense that not even light can escape it. The image was calculated from radio waves and is strong observational evidence that space-time is continuous for two reasons. One of them is theoretical and the other physical and they corroborate each other.

The theoretical reason is that the astronomers were able to calculate the shape of the disc precisely and it’s shape is what would be predicted by General Relativity under conditions of very strong gravity. Since GR requires continuous space-time that is strong evidence that that’s the case.

The second reason is completely separate from the first and it’s physical. Think of the radio photograph. The black hole is in a galaxy 57 million light years away and the picture was taken from a telescope effectively the size of the earth, approximately 1/14 of a light second. Think about the incredibly thin isosceles triangle that depicts the path of the radio waves. It’s hard to imagine how the picture could be so sharp if space were not continuous. If space-time were quantized, made up of chunks, those quanta would be magnified as the radio waves travelled from the black hole to the earth and the image would be fuzzy. But it’s not.

How Did the Universe Begin? What Came Before? – As mentioned in Section III, at the beginning of the universe there was no mass and the only reality was energy. Space and time were unconstrained and didn’t have definite values. Since they couldn’t be measured they weren’t real. There was only energy. But when the first massive particle was created, space and time became real and the universe came into measureable existence.

What Caused Inflation and Why did it Stop? – As also mentioned in Section III, the early universe expanded very rapidly as the propagation rate of energy waves that could be accelerated by the universal gravitational field increased and the particles they were associated with acquired mass. At that time, the ratio of all of the mass in the universe to its energy was increasing rapidly. Initially the ratio was small so the universe expanded very rapidly. But the pace of the ratio’s increase quickly slowed down and, because of the constraint on the evolution of the universe imposed by $E=mc^2$, the speed of the universe’s expansion slowed down too. By the end of inflation, much of the energy in the gravitational field that caused the rapid expansion of space-time had become locked into matter.

Why Is There So Much More Matter than Anti-matter? - In the very early universe, CP violation must have created more matter than anti-matter when particles whose interactions were mediated by the electroweak force, for example B mesons, were decaying back and forth with their anti-particles. They decayed from their anti-matter state to their matter state more rapidly than they decayed in the other direction. This difference in their decay rates resulted from the fact that the two states had different speeds in space-time. Since, as we saw earlier, the speed of a particle's energy wave determined how much it could accelerate in space-time, the two B meson states had different masses. The very high energies at that time exacerbated the difference in the speeds of their two energy waves, and thus in their masses and their decay times. The resulting CP violation led to a preponderance of matter in the universe explaining why we find it made up primarily of matter, which allows, I must say fortunately, for us to exist

How Will the Universe End? What Will Come Afterwards? – The universe would end if and when there's no mass left in it because all of its massive particles have disappeared and their energy has been converted back into energy. That's the same condition that existed before our universe began when the only reality was energy. As we've seen, under those conditions, energy, space and time aren't mathematically related and, once again, space and time will be unconstrained and able to take on any values. Another universe would begin but it will undoubtedly have different starting values for space and time. While the mathematical relation between energy, space and time, $E=m(s/t)^2$, would have to hold in that universe as well, the new universe would be very different from ours because it will have different starting values. We're indeed fortunate, to put it mildly, that our universe happens to have had the initial values of space and time that ultimately led to conditions which permit our existence.

XI. The Bottom Line

About 400 years ago, Isaac Newton developed his theory of gravity and applied it to everything that was known at the time. It seemed to work in every case, small and large. But about 300 years later Albert Einstein realized that, under conditions that we don't experience in our everyday lives, Newton's theory had to be modified by using the equations of general relativity. His idea was that the force of gravity isn't really a force in the usual sense of the word but rather a warping of space or more precisely a warping of space-time. Since then, physicists have tried to figure out "how the universe works" by assuming that his equations of general relativity apply to the universe as a whole.

But when one takes a different approach to understanding the evolution of the universe by assuming that another of Einstein's equations, $E=mc^2$, applies to the entire universe and then following that assumption to its logical conclusions, it turns out that the required augmentation to general relativity does the trick. The assumption that the laws of physics are scale invariant and $E=mc^2$ always applies everywhere on every scale explains the observed evolution of the universe from its initial inflation to its current expansion and everything in between. All of the changes in the size and composition of the universe result from the dance between energy and warped space-time imposed by the constraint that E must always be equal to mc^2.

If you realize that energy, space and time are the only real things and think of the universe as nothing but warped space-time in a dance with fluctuations in the concentration of energy, Newton's theory of gravity modified by general relativity and by the assumption that $E=mc^2$ applies at all space-time scales accounts for everything that's observed with no need for extra rolled-up dimensions, virtual quantum particles, supersymmetric particles, the inflaton or the graviton.

So when one focuses on ultimate reality and then considers the constraints on the universe's evolution caused by the requirement that E must equal mc^2 in the universe and everything in it, a candidate for a theory of everything emerges.

Glossary

Antimatter – Matter made up of particles similar to those found in normal matter except that they all have the opposite electrical charge. When matter and antimatter collide they both vanish in a flash of energy.

Big Bang – A commonly held theory that the universe started at a specific moment in time and has been expanding ever since. It is consistent with all current astronomical observations.

Black Hole – A place in which so much mass has been compressed into so little space and gravity is so strong that nothing, not even light, can escape. Black holes are common in the universe with most, if not all, galaxies having one at their center.

Dark Energy – The repulsive energy required to account for the fact that the expansion of the universe is accelerating.

Dark Matter – Hypothetical matter that some physicists think causes the extra gravity required to account for the observed movement of stars in galaxies and galaxies in clusters of galaxies.

Decoherence – When a quantum particle is observed, the probability wave that's used to determine the many places it can be found collapses to designate a single spot. This phenomenon is called decoherence.

Energy – The characteristic of something that empowers it to change something else. Energy can be transformed and concentrated but it can't be destroyed or created. Thus the total amount of energy in the universe is fixed.

Entropy – The amount of disorder in a system. The second law of thermodynamics says that the entropy in a closed system will always increase over time.

General Theory of Relativity – Einstein's theory of gravity that says that the force of gravity is caused by warped space-time. It has never failed an experiment and makes very accurate predictions.

Graviton – The hypothetical quantum particle of gravity assuming that space-time is quantized, not continuous (see **Quantized** below).

Gravity – The force between concentrations of energy and/or entities with mass.

Higgs Particle – The ubiquitous quantum particle whose interactions with some other particles cause them to be massive.

Inflation – The commonly held theory that assumes that the universe expanded at an exponential rate at the beginning of its existence. Inflation explains many of the observed characteristics of the universe such as its homogeneity and the flat shape of space-time.

Inflaton – The hypothetical quantum particle that caused inflation.

Mass – A characteristic of some quantum particles that makes them resistant to a force that would cause them to accelerate. Two massive bodies are attracted to each other through the force of gravity. On the Earth, mass is the same as weight.

Quantized - Something such as energy, space-time, a particle or a field that is made up of quanta; smallest possible pieces that can't be further subdivided.

Quantum Mechanics – A theory of the characteristics and interactions of particles that's based on quantum field theory. It assumes that the value of energy is quantized rather than continuous. It has never failed an experiment and makes very accurate predictions.

Quantum Particles – The particles described by quantum mechanics. Examples mentioned in this paper include:

- **Electron –** The fundamental negatively charged particle in an atom.
- **Neutrino –** A fundamental neutral particle emitted in a nuclear reaction.
- **Proton –** The positively charged particle in the nucleus of an atom. It is not fundamental but made up of smaller fundamental particles called **quarks**.

Relativity – A principle that says that the characteristics of things are not absolute. Rather they are relative to the characteristics of other things that they are associated with.

Special Theory of Relativity – Einstein's theory of non-accelerating movement in space-time. It's based on the fact that the speed of light is the same for all observers no matter how they're moving. It has never failed an experiment and makes very accurate predictions.

Speed of Light – The speed of anything that has no mass, like photons which are the particles of electromagnetic radiation. It's the maximum possible speed in the universe.

Standard Model of Particle Physics – The commonly held theory of the characteristics of and interactions between quantum particles. It does not include the force of gravity. It makes extremely accurate predictions and has never failed an experimental test. All of the particles and forces predicted by the theory have been observed.

String Theory – The theory which says that, at a deeper level, all quantum particles are strings of energy vibrating in space-time. It doesn't make any unique predictions which can be used to validate or disprove the theory but it does predict the existence of the graviton thereby encompassing more phenomena than the Standard Model.

Supersymmetry – A quantum theory that predicts that every known particle has a partner that plays the opposite role in quantum mechanics; the partners of the particles of matter, fermions, are bosons which carry the forces of interactions and visa versa. No hypothetical supersymmetric particles have been observed.

Symmetry – A property of systems that allows them to be changed in specified ways without changing their appearance. Symmetry is a powerful concept in constructing mathematical descriptions of physical systems.

Warped Space-time – Since Einstein, physicists have realized that space and time are intimately related. They refer to “space-time”. Space-time is a real thing which is malleable and can change. Space can be warped or twisted and time can speed up or slow down. The shape of space-time can be:

Flat – with rectangular, straight coordinates as in Euclidian geometry. In flat space the circumference of a circle is precisely equal to pi times its diameter, or

Hyperbolic – shaped like a saddle, or

Spherical – shaped like a sphere.