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The Frontiers of Physics, Part III
Theories of Everything

By
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Introduction

This is the third article in a series to enlighten science fiction writers and readers about recent advances in physics and our understanding of the nature of the universe. If you haven't read the previous two, *"The Frontiers of Physics, Part I — The Basics,"* and *"The Frontiers of Physics, Part II — The Constituents of Matter,"* then you might want to do so before continuing too deeply into this month's article. For, as I have noted before, the more we learn about the universe, the weirder things become.

It is not just that things become more complicated as we discover more about the nature of the universe. They actually become counter-intuitive. In the history of modern physics, more than one scientist has balked at believing what his eyes were telling him simply because his brain was screaming, "this can't possibly be true!" To illustrate this point and to get everyone in the proper mood for what comes next, let us perform a quick thought experiment having to do with lasers and photons:

Let us postulate that we have a semiconductor laser (a laser diode) with an external cavity that produces light at a wavelength of 655 nm (nanometers) at a power level of 10 mW. The laser is located in… oh, let us say… Geneva, Switzerland. We pass light from that laser through a dispersion prism to separate out the residual infrared fluorescent light and focus the remaining light on a potassium-niobium-oxide ($KNbO_3$) crystal. The crystal is oriented to ensure degenerate collinear type I phase matching for signal and idler photons at a wavelength of 1310 nm. Upon leaving the crystal, the pump light from the laser is filtered out and the 1310 nm down-converted photons are focused into one input port of a standard 3-dB fiber coupler for a Swiss Telecom fiber optic telephone cable.

The 3-dB coupler causes half the photons to enter one fiber optic cable and the other half to enter a second cable. Let us postulate (in our imaginations) that the first cable runs through the usual telecommunications network to the suburb of Bellevue some 4.5 km northwest of Geneva, and the second cable runs to the village of Bernex, 7.3 km southwest of Geneva. At the end of the two cables is a photon detector in the form of a Michelson interferometer. The detector has two legs (left and right), at the ends of which are photon detectors to detect when a photon has chosen a particular leg. Because of the geography of Geneva and its suburbs, the two photon-detecting interferometers are located 10.9 km (about 6 miles) distant from one another.

Now, to perform our thought experiment, we assume that we shoot separated streams of photons down the two cables, and that upon reaching Bellevue and Bernex, each individual photon has a random chance of choosing either the left leg of the detector or the right leg. Got all of that firmly ensconced in your mind?

Good. Then here is the question. If you shoot a single pair of photons down both cables, what is the probability that two photons created simultaneously will enter the same side of their individual detector when they reach Bellevue and Bernex? In other words, if the Bellevue photon enters the left side of the detector, what chance that the Bernex photon will do the same? On the other hand, if the Bellevue photon enters the right leg, how often will the Bernex photon also enter the right leg?

The mathematics of probability are mysterious to most people, but in this case, the problem appears trivial. The combinations, after all, are right-right, left-left, left-right, and right-left. Thus, any single pair of photons can be expected to pass through the same leg of their two detectors two times out of four, or 50% of the time.

That was easy, wasn't it? So let us up the ante a bit. Instead of splitting up a single pair of photons and sending them down the two fiber optic cables, what if you do the same trick a billion times in a row? You split a billion pairs of photons, you send them to Bellevue and Bernex, and you detect the leg of each photometer that each photon took when it reached the suburbs. What are the chances that in *every single* case, both photons in a separated pair will choose the same side of their respective detectors?

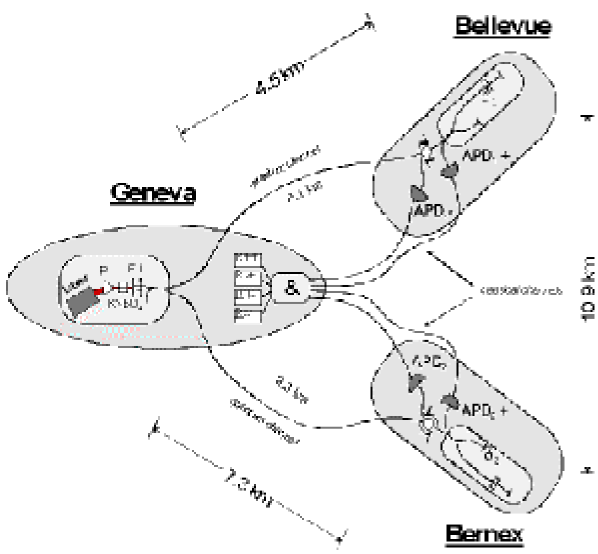

Figure 1: Experimental Apparatus for Quantum Entanglement Experiment

The calculation is a bit more complex, but still relatively easy to understand. If the chance that any give pair of photons will take the same path is 50%, then the chance that a billion pairs of photons in a row will do the same thing is 50% raised to the billionth power ($0.5^{1,000,000,000}$). I do not know what that number is because my reverse-Polish-notation calculator tells me that it is zero. We all know that it isn't zero, of course, but it is a number so close to zero that the chances of a billion split-up pairs of photons all choosing the same side of the Bellevue and Bernex detectors is vanishing small. That, at least, is the way we learned it in school.

Would you care to know what the probability really is?

Figure 2: The Geography of Geneva, Switzerland

As you may have guessed from the amount of detail I loaded into our imaginary experiment, there is nothing imaginary about it at all. It is an actual experiment performed by W. Tittel, J. Brendel, H. Zbinden, and N. Gisin for the Group of Applied Physics at the University of Geneva in 1997 and 1998. If you like, you can read up on it in *Physical Review Letters* (Volume 81, Number 17, 26 October 1998; or Volume 57, Number 5, May, 1998). In addition, to further orient you, Figure 1 shows a schematic diagram of the experimental apparatus and Figure 2 shows a map of Geneva and its suburbs.

When the Swiss scientists performed the experiment and measured the results, they found that the split-pairs of photons chose the same side of their respective detectors 95.5% of the time. Therefore, if you shoot a billion pairs of photons down the two fiber optic cables to the detectors located 10 km apart, and if you make fewer mistakes than did the Swiss scientists, the chance that all 1 billion pairs will choose the same side of the Bellevue and Bernex detectors approaches unity. In other words, they ALL do it!

If you have become mired in what appears to be useless detail, please take a moment to mentally pull back a moment. What we just said is that two different photons separated by 6 miles of space, somehow manage to ALWAYS GUESS RIGHT when it comes to making two independent random choices.

If that does not blow your mind, please go back and read the above description again.

The principle is called Quantum Entanglement and it has been proven to work for similar experiments since the 1960s. The Geneva Experiment, however, is the longest one that anyone has yet run (in terms of separation of the pair of particles), and thus, proves that something very weird is going on at the level of individual particles.

Essentially, there are two possible explanations for this counter-intuitive result. Either 1) the two photons are somehow managing to communicate with one another at several thousand times the speed of light, or 2) the pair of photons is not really a pair of photons at all. It is, instead, a single photon that we have somehow managed to coax into simultaneously being in two places at once, with 6 miles of what we laughingly call “real space” in between. Either way, it appears that our knowledge of how the universe operates needs a little work.

Enough of Amazing Physics 101 for the time being. Let us return to our basic task, which is to explain the emerging “theories of everything.” Along the way, we will make the subject of Quantum Entanglement somewhat more clear.

<u>Quantum Mechanics</u>

In the first article in this series, we discussed the science of Newton and Einstein. Newton developed the Laws of Mechanics that we still teach in our classrooms today. High school students bend their brains learning that F=MA, and that gravity is a force defined by the equation $F=G\ (M_1M_2/r^2)$. Newton's universe was a huge mechanical clock. Just wind it up and watch it tick with metronome regularity for the rest of eternity. To Newton and his descendents in the scientific community, all things appeared knowable because all things were deterministic.

At the beginning of the twentieth century, Newton was supplanted by Einstein, who decreed that nothing can go faster than light, that mass is merely a "frozen" form of energy, and that gravity is not a force. Rather, gravity is a "curvature" of the space-time continuum. To Einstein, all of the laws of physics were consequences of the "geometry" of space-time.

Within a decade after Einstein, other physicists were pursuing courses of study that caused them to come up with a different theory of the way things are. They called their theory Quantum Mechanics. The quantum mechanicists did not view the laws of the universe in terms of the geometry of space-time the way Einstein did. They viewed them as having their origins in the tiny subatomic particles that go to make up atoms.

The experiment that eventually led to quantum mechanics was performed by Thomas Young in 1803. Young was the first to shine a beam of light through two closely spaced slits and note that they formed an interference pattern on a glass plate covered with photographic emulsion. This seminal experiment demonstrated that light is, indeed, a wave, and everyone would have been happy if science had let the matter rest at that point.

However, scientists being the way they are, they could not. Years after Young, another double-slit experiment was performed. Scientists allowed individual photons to pass through the slits one at a time. When they developed the photograph, they discovered that the interference pattern was still there, even though the photons could not possibly have interacted with others of their kind.

Then came the experiment that started scientists wondering about just how well they understood such things. It involved a double-slit experiment in which the photons were replaced by electrons. Though light is a wave, everyone at the time knew that electrons are particles. Therefore, it was something of a surprise when scientists observed that electrons also induce an interference pattern — even when they pass through the double slits one at a time! To make matters worse, when one slit was covered up, the interference pattern disappeared.

What these experiments proved was that 1) light is not a wave, but rather a particle, which scientists dubbed the "photon," 2) that electrons exhibit "wavelike" properties, even though they are also particles, and 3) even when these "particles" are sent through the slits one at a time, they still manage to go through both slits simultaneously. In other words, one object (the particle-like photon or electron) somehow ends up in two places at once. Sound familiar? It sounds just like the University of Switzerland experiment with quantum-entangled photons.

Faced with evidence that electromagnetic radiation has both particle and wave characteristics, Louis-Victor de Broglie of France suggested a solution to the problem in 1924. Broglie proposed that matter has wave, as well as particle, properties. He suggested that material particles can behave as waves and that their wavelength λ is related to their linear momentum, p, by the equation $\lambda = h/p$, where h is Planck's constant. It should be noted that all matter exhibits wavelike behavior, even you. However, since your linear momentum is huge compared to that of a photon or an electron, your wavelength is microscopic — too short to be noticed, in fact.

Broglie's proposal and other things led the German physicist, Werner Heisenberg, to postulate his Uncertainty Principle in 1927. The Uncertainty Principle states that the position and the velocity of an object cannot both be measured exactly, at the same time, even in theory. In fact, rather than being a theorem aimed at the imprecision of our instruments, Heisenberg's claim was that position and momentum are *inherently* unknowable, and indeed, that the very concepts of exact position and exact velocity together, in fact, have no real meaning in nature. In other words, it is possible for a subatomic particle to be two places at once; or to be more precise, that a single particle can be *everywhere* at once.

Heisenberg's Uncertainty Principle would be laughed off the stage as delusional except for one thing. Every experiment that we have conducted for 70 years has proven it correct, and in fact, our entire semiconductor and computer industries are built on the uncertainty principle. Without it, the tunneling diode and the transistor would not work!

The reason we are so confounded by Heisenberg is that the uncertainty principle flies in the face of human experience. It is easy to measure both the position and the velocity of an automobile. The uncertainties implied by Heisenberg for ordinary objects are too small to be observed. The complete rule stipulates that the product of the uncertainties in position and velocity is equal to or greater than the value of the quantity ($h/2\pi$), where h is Planck's constant. This value is 10^{-34} joule-second. Only for the exceedingly small masses of atoms and subatomic particles does the product of the uncertainties become significant.

Any attempt to measure precisely the velocity of a subatomic particle, such as an electron, will knock it about in an unpredictable way, so that a simultaneous measurement of its position has no validity. This result has nothing to do with inadequacies in the measuring instruments, the technique, or the observer; it arises out of the intimate connection in nature between particles and waves in the realm of subatomic dimensions.

Because every particle has a wave associated with it, each particle actually exhibits wavelike behavior. This means that the particle is most likely to be found in those places where the undulations of the wave are greatest, or most intense, but that doesn't mean that it *will* be found there. Position becomes a matter of probability.

The more intense the undulations of the associated wave become, however, the more ill defined becomes the wavelength. Since it is the wavelength that determines the momentum of the particle, a wave that has been localized to a precise point has a wavelength that is indeterminate. The particle therefore has a definite position, but we cannot figure out the velocity. A particle wave having a well-defined wavelength, on the other hand, is spread out; the associated particle, while having a rather precise velocity, may be almost anywhere. A quite accurate measurement of one observable involves a relatively large uncertainty in the measurement of the other.

The principle applies to other things than position and momentum. In fact, it relates to any two related (conjugate) pairs of observables, such as energy and time. The product of the uncertainty in an energy measurement and the uncertainty in the time interval the measurement takes also equals $h/2\pi$ or more. It is the energy-time pair of observables that the University of Switzerland experiment measures. There are other pairs, but we do not want to get too deeply into the heavy thinking just yet. That comes later.

The Crisis in Physics

So, in the 1930s, it became clear that physics was in crisis. After centuries spent delving deeply into the secrets of the universe, scientists had developed not one theory of physics, but two. Both had the advantage that every experiment we could think of to test them worked. They obviously describe the physical universe to perfection, at least to the degree that we understood it. Yet, having two theories of physics proved to be an embarrassment of riches. For, despite the fact that both theories conformed to every physical test, nothing could disguise the fact that the two theories were mutually exclusive. Being practical men, scientists used both theories, but confined them at opposite ends of the size spectrum.

For macroscopic problems, those measured in light-years, scientists used Einstein’s two theories of relativity, which despite their names, are actually quite different. The Special Theory of Relativity relates to time and velocity, and the relationship of matter to energy (matter is “frozen” energy in much the same way that ice is “frozen” steam). The General Theory of Relativity has to do with gravity and the overall shape of the space-time continuum. Both theories rely heavily on proofs that are geometric in nature.

For microscopic problems, scientists adopted the science of quantum mechanics, where nothing is ever certain, where particles can be anywhere in the universe until observed, and where two photons separated in space by six miles can somehow retain an intimate connection to one another. By the way, quantum mechanics does not limit this quantum entanglement to a distance of 10 kilometers. According to the theory, it does not matter whether the distance is 10 km, 10 light-years, or 10 times the radius of the visible universe. If the entangled photons are sent a million light-years distant and their entanglement is retained, then they will both continue to go down the left leg of the interferometer (or the right) every single time!

Obviously, since the two theories of physics relate to a single physical entity (the universe), there has to be some way to relate the two such that they are internally consistent. The search for some unifying principle to tie the macroscopic and microscopic worlds together began with Einstein, and continues up to this very day. It was not until the 1970s and 1980s that scientists began to make progress on the problem.

The source of their progress was found in the microscopic world of atoms, the realm where quantum mechanics is king. To understand the basis for the unification of physics, however, we need to review a bit of what we learned in the last article in this series. Let us then return (briefly) to the Standard Model.

The Standard Model of Matter

Physics was a mess in the 1960s and 1970s. Physicists were finding new subatomic particles weekly, and the subatomic zoo was becoming unwieldy in the extreme. With the discovery that the various particles could be arranged in a logical manner, however, physicists suddenly discovered that the proton and neutron are not the elementary particles they thought them to be. Instead, matter was found to contain even more elemental particles called quarks and leptons, and following quantum mechanics' bias, forces were attributed not to action at a distance, or the geometry of space-time, but rather, to things called "force carrying particles."

Over time, physicists began to develop the Standard Model of Elementary Particles. The standard model has been very successful in explaining every bit of data we have about such things. To summarize, the Standard Model states that "All matter consists of quarks and leptons, which interact by exchanging various types of quanta, which themselves carry three of the four basic forces of the universe: electromagnetic force, strong nuclear force, weak nuclear force." While easy to state in a single sentence, the Standard Model becomes more complex when one delves into it. Specifically, the model contains:

1. Thirty-six quarks, coming in six "flavors", three "colors", and their antimatter counterparts.
2. Eight varieties of gluons, the "force-carrying" particles of the strong nuclear force. Gluons are the particles that keep the quarks "glued together."
3. Four varieties of particles to describe the weak interaction (or weak nuclear force) and the electromagnetic force.
4. Six types of leptons to describe the weak interactions (including the electron, muon, tau lepton, and their respective neutrino counterparts).
5. A wide variety of "Higgs" particles necessary to make all of the masses and constants describing the particles come out correctly.
6. At least 19 arbitrary constants that describe of the masses of the particles and the strengths of the various interactions. These constants are determined experimentally.

Figure 3 shows the basic elementary particles associated with the Standard Model. The particles appear to come in three "generations," depending on the energy level at which the particles are formed. Generation I is the low energy form of the particles, and the one with which we are most familiar. For instance, both protons and neutrons are formed from up quarks (u-quarks) and down quarks (d-quarks) and are held together as the three quarks exchange gluons continuously at the speed of light.

Despite its success in explaining just about everything we know about subatomic particles, the Standard Model suffers from two basic defects. The first defect is that it is ugly! The second defect is that scientists cannot figure out how to account for gravity within the model. Let us take these problems one at a time.

Figure 3: The Elementary Particles

Quarks	Up (charge = +2/3)	Charm	Top (Truth)
	Down (-1/3)	Strange	Bottom (Beauty)
Leptons	Electron (-1)	Muon	Tau
	Electron neutrino (0)	Muon neutrino	Tau neutrino
	I (lightest)	II	III (heaviest)
	Three Generations of Matter		

Force Carriers	Photon
	Gluons
	W+, W-
	Z
	Higgson (?)

What do we mean when we say that the standard model is "ugly?" A true scientific theory must be internally self-consistent, with each part flowing inevitably from the mathematics of the other parts. The standard model is none of this. Its many arbitrary constants have to be determined arbitrarily. They are, in effect, fudge factors. The standard model was created when physicists took three independent theories of the basic forces of the universe and merely pasted them together. Of course, any theory that cannot explain gravity is not much of a theory.

Therefore, as a tool for research, the standard model is useful beyond belief. However, as a final theory of everything, it leaves a lot to be desired. That is why physicists have continued to search for a better tool.

Grand Unification Theories (GUTs)

After his great success with his two theories of relativity, Einstein spent the rest of his life trying to tie everything up with a beautiful, blue bow. He set out to unify all four of the forces of nature: electromagnetism, the strong nuclear force, the weak nuclear force, and gravity. He did not succeed, primarily because not enough had been discovered about the nature of the universe by the time of his death. However, his failure did not dissuade other physicists from following him down the path to unification, and they had some success in 1974 when they managed to combine the electromagnetic force with the weak nuclear force. The resulting theory was dubbed "Electroweak," which makes it sound like a cheap superhero. However, the electroweak theory received a boost in 1983 when the W+, W-, and Z, particles it predicted were all discovered at CERN, the European particle accelerator in Geneva.

The success of the electroweak theory gave impetus to an effort to unify the other forces of nature. This class of theories was called Grand Unified Theories (GUTs). Physicist Sheldon Glashow was the first to attempt a successful GUT. He looked at the three forces and noted that the electric force gets weaker with the inverse square of distance, like gravity. However, the strong nuclear force (or interaction) actually increases with distance. That is the reason that the positively charged nucleus holds together, and why quarks hold together inside a proton.

Each force is explained in terms of a field, and the exchange of the force-carrying particles called “bosons.” Photons are bosons of electromagnetism, weak bosons are the carriers of the weak force, and gluons are the carriers of the strong force. The problem was one sufficiently difficult to give even a genius a headache, but eventually, Glashow and his successors hit on the idea of using “symmetry” to crack open the puzzle.

The Usefulness of Symmetry

Consider a square. It is symmetric (that is, the same) whether it is reflected in a horizontal axis, a vertical axis, or along a diagonal axis through its corners. It is also symmetric when rotated. Whether you rotate a square through 90, 180, 270, or 360 degrees, it always looks the same. Equilateral triangles also have reflective and rotational symmetry, though not to the same degree as a square. A circle has the most symmetry of any figure. In fact, it is symmetrical whether you flip it over, turn it upside down, or rotate it through an infinity of angles.

The concept of symmetry can also be applied to the laws of physics. The power of physics symmetry was first proven in the Special Theory of Relativity, which states that the laws of physics are the same in all inertial reference frames; that is, they are symmetrical or invariant under changes in uniform motion. This is why the speed of light is a constant and time is a variable. If it were not this way, then the laws of physics would be different depending on velocity, and there would be no symmetry.

General relativity, also, involves a symmetry principle, namely that the laws of physics are the same in a gravitational field as they are in an accelerating reference frame. This means that if you are in an elevator and cannot see out, there is no way for you to distinguish between acceleration and gravity. Since light bends in an elevator undergoing acceleration, then light must bend in a gravitation field. Ergo, *gravity cannot be a force!*

Soon after Einstein, scientists explained the conservation laws of physics in terms of symmetry. In an elastic collision, particles come out with the same total energy as they went in. In fact, we can look at the energy equations either forward or backward in time, and they are always the same. The law of conservation of energy, therefore, is just a symmetry with respect to time. Likewise, the law of conservation of momentum is a symmetry under translation through space; and the law of conservation of angular momentum, a symmetry under rotation in space.

In the Standard Model, symmetry was extended to the conservation of charge and spin. The electron and positron, for example, are symmetric with respect to charge, and so the laws of physics are invariant when the one is replaced by the other. In fact, Richard Feynman, Nobel Prize winning physicist, suggested that the positron is an electron moving backwards in time, and I used that very principle in *Procyon’s Promise*, one of my science fiction novels. Likewise, all particles and their antiparticles can be considered to be symmetric in several different ways.

The principle of symmetry is a powerful one for analyzing physics problems. While the electromagnetic and weak forces were unified through a symmetry relationship at high energy, the strong force has its own symmetry relationships. The strong force comes about when red, green, and blue color quarks exchange colors by passing gluons at the speed of light. In fact, the three quarks inside a proton or neutron look like a tiny dynamo spinning at an unbelievable speed. If the quarks move away from one another by as far as the diameter of a proton, it takes the gluons longer to travel between quarks, which in turn slows the speed of "rotation" of the colors. It is this reduction in the speed of rotation that gives rise to the increased attractive force that yanks the quarks back down into the subatomic particle.

Grand Unified Theories unified the three basic forces and the particles subject to these forces. Their symmetry equations rotated the quarks into the leptons and vice versa. GUTs had many successes. They explained the arrangement of leptons and quarks in each family of the Standard Model and they demonstrated why charge is quantized (comes in discrete values), and why mass is not. They also predicted that the strong, weak, and electromagnetic forces would be equal in strength at the energy level of 10^{15} GeV.

Suddenly, it looked as though things were coming together nicely. By unifying the three forces, quantum mechanics began to invade cosmology, the territory of Einstein. Specifically, energy levels of 10^{15} GeV may have existed 10^{-11} seconds after the Big Bang, and therefore, all of the forces were unified in the beginning of the universe.

So, the GUTs theorists, feeling their oats, made another prediction. They predicted that quarks would eventually decay as they rotated into leptons. This prediction meant that the proton, which earlier generations of scientists had thought to be immortal, would eventually break down because, after all, it was made of quarks. In fact, the GUTs advocates predicted that the half-life of the proton was approximately 10^{29} years. Although this is much longer than the age of the universe, it turns out that a large tank of water contains enough protons to produce one decay every year or two. Huge, underground experiments were soon set up to detect the decaying proton. By the middle of the 1980s, however, no confirmed case of a proton decaying had been detected, and the GUTs began to run out of steam.

Obviously, a new theory was required, and luckily, about the time the Grand Unified Theories breathed their last, a new theory came over the horizon. That was String Theory.

The Universe as Stradivarius

String theory was born before the advent of the GUTs boomlet. In 1968, Gabrielle Veneziano and Mahiko Suzuki both independently looked up the rarely used Euler-beta mathematical function to solve a problem they were having with a high-energy experiment at CERN. The 19th century math function turned out to describe the results of high-energy particle collisions precisely. For a couple of years, no one could explain why this odd mathematical formula worked. They only knew that it did. Then, in 1970, Yoichiro Nambu noted that the phenomenon the function was actually describing was a vibrating piece of string. Which brought about the obvious question, "Why on Earth does subatomic physics obey the formula for the vibratory modes of a string?"

Why indeed?

The problem with all previous unification theories was that they were mathematically useless when scientists tried to use them to predict things. That is because, when a scientist tried to solve a theory's imbedded equations, it did not take long before he or she ran into a term containing infinity in it. You obtain "infinity" in mathematics when trying to divide by zero. As we all learned in school, you cannot do that. Nor is this merely a mathematical nicety. In the late 1960s, I had a job running a Frieden mechanical calculator, and whenever I inadvertently divided by zero, we had to pull the plug and call the repairman.

The reason, it turned out, for all of these infinities that popped up in the middle of equations was that scientist treated particles as dimensionless points. If, however, they treated them as strings, then the infinities did not arise. They treated them as *tiny* strings, mind you; so small that they look like point-particles, even when observed in giant accelerator collisions. However, they have enough length to avoid the division by zero problem.

So, what exactly do they mean when scientists say that particles are composed of strings? Essentially, the theory is that the elementary particles — the proton, neutron, electron, photon, gluon, and every other particle in the subatomic zoo — are not so much "objects" as different modes of vibration of the string. In other words, when the string vibrates in one mode (think of an individual note on a musical instrument), then we see a photon. When it vibrates in another mode, we see an electron. If something causes the string's mode of vibration to change from the first to the second, then we see a photon turn into an electron — which we do, quite often. It is called the photoelectric effect.

When thinking about string theory, it helps to visualize a violin string, say one stretched taut across the bridge of an expensive Stradivarius. The string vibrates at a specific frequency, which is determined by its length and its tension. That is what those black peg-things at the end of the violin do. They vary the tension in the string to cause it to vibrate at different frequencies. In other words, they "tune" the string.

The reason the string only vibrates at certain frequencies is because both ends of the string are anchored to the violin, and whatever vibratory motion exists in the string, its nodes (the places where the vibratory motion is zero) must be at the ends of the string. Thus, if you divide the length of the string by the wavelength of the vibration, and you do not come out with a whole number, the string cannot vibrate at that frequency.

The same is true for the subatomic universal "strings" of string theory.

Subatomic strings can either be open at both ends like a violin string, or else closed in a small loop, depending on which form of theory you are partial to (more on that later). Like an open string, for a closed string to vibrate, an exactly even number of wavelengths must fit around its circumference. And like a violin string (or a loop), the cosmic strings have length and are under tension. Specifically, their length is approximately 10^{-35} meters and the string tension force is 10^{43} Newtons. For those of us who were never weaned from the English measurement system, the tension in the string is 5×10^{39} tons! That string vibrates at a hell of a high frequency! No wonder it looks to us like a particle.

Here, unfortunately, is where things start to get a little complicated.

While four-dimensional objects ourselves, we humans tend to think better in three dimensions. Therefore, we sometimes have trouble visualizing what the "shape" of an object is when it is moving through not only the three space dimensions, but also the time dimension. That is what we need to do now. As the strings move, they trace out a path through space-time. Seen on an x-t graph, when two particles combine, two closed-loop strings combine to form one larger string (See Figure 4). This diagram is known as the "pants diagram." Strings obey Einstein's equations of relativity as they move through space-time, thus uniting quantum mechanics and general relativity in a viable way.

String theory was first applied to bosons, the carriers of force. What got physicists excited was the fact that when they calculated what a "particle" consisting of a closed loop string vibrating in its simplest mode would look like, they discovered that they had described a massless particle with a spin of +2. That is the description of the theoretical particle postulated as the carrier of the "gravity" force, the graviton. Eureka! For the first time since Einstein, someone had finally managed to come up with a theory that included gravity.

A Surplus of Dimensions

One would think that string theory would have been an instant success. In fact, it went back to sleep almost as quickly as it had awakened. That was because string theory seemed to require too many dimensions in the universe to work. In fact, it required 26 dimensions, which was 22 more than we appear to have. Besides, at the time that string theory emerged into the light of day, the Standard Model, and then the Grand Unified Theories, seemed to be providing the answers we needed in our quest for unification.

By 1984, however, things began to look up for string theory. That was the year that Michael Green and John Schwarz showed that string theory could be simplified from 26 down to 10. It was still too many, but they were progressing in the right direction. The principle they used to pull this trick was called supersymmetry. The SUSY theory, as it is called, rotates fermions (matter thingies) into bosons (force carriers) and vice versa. Each half-spin fermion has an integral spin superpartner boson, and each integral spin boson has a half-spin superpartner fermion. The superpartners of fermions are called sparticles (squarks and sleptons), and the superpartners of bosons are called bosinos (gluinos, photinos, Winos, and gravitinos). These superpartners are super-heavy, however, and thus may only have existed during the first 10^{-43} seconds of the universe. It is a certainty that none of them are around today, and that it will be quite some time before our particle accelerators are sufficiently powerful to make superpartners from scratch. Still, supersymmetry solved a nagging problem involving string theory, while still pointing the way to a universe that was considerably weirder than the one we thought we were living in.

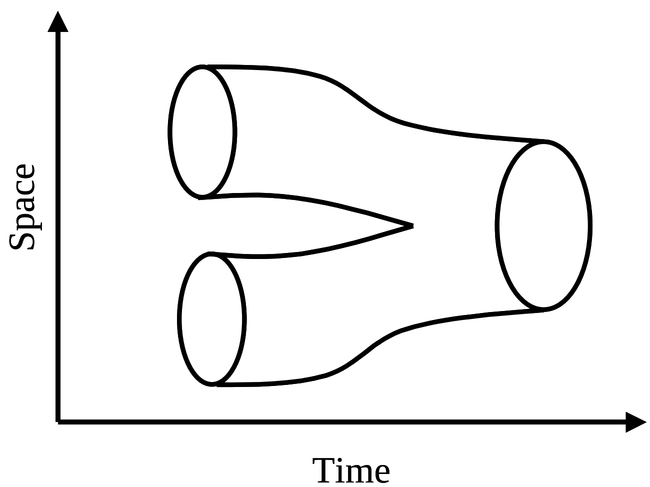

Figure 4: Two Closed-loop Strings Combine Into One

You see, it turned out that we really do need all of those extra dimensions to make the puzzle fit together properly. And, as the old storytellers say, therein lies another tale!

The Poverty of Living with Four Dimensions

According to Einstein, the universe consists of three spatial dimensions (length, breadth, height) and one time dimension (time). Now, if an elemental particle is nothing other than a string vibrating in a particular mode, then the number of possible modes is determined by the number of dimensions in which the strings can vibrate. It quickly became obvious to string theorists that something was seriously awry if our universe is formed by the four dimensions we recognize. You see, in a 4-D universe, there are insufficient combinations of vibratory modes with which to account for all the varieties of particles we have already discovered.

To understand why four dimensions are too few, we will have to take a short detour into a subject most people would rather avoid, namely higher dimensional mathematics and field theory. Do not worry, we will keep it brief.

One of the things that first year engineering students hate the most is their sudden introduction to weird forms of mathematics. Two of these are Vector Algebra and Analytical Solid Geometry. Later, usually in Strength of Materials class, engineers have to learn a math that is an even bigger headache, one involving a thing called "tensors." So, let us get it over with and describe these three kinds of "measurements."

- Scalars — Everyone understands scalars. They are bits of data that require only a single number to describe them. The most common scalar is the temperature reading you get every day when you turn on the weather report. "It will be 150 degrees in Phoenix today, in the shade!" Another scalar is speed. The officer clocks you doing 85 mph in a 40 zone, and it will cost you about $300 in fines.

- Vectors — Vectors are also common in life, except the average person is blissfully ignorant of their existence. Vectors are bits of data that require two numbers to describe them. The most common is velocity. In order to properly describe a car's velocity, you need both the *magnitude* and the *direction* of its motion.

  Velocity must be measured as "60 mph due north." When you give the speed (60 mph), you are only giving half the velocity. That is why "speed" is a scalar quantity and "velocity" is a vector quantity. If this seems a bit esoteric to you, consider the following situations: Situation 1: "Car A, with a velocity of 61 mph due north, collides with Car B, whose velocity is 60 mph due north." Situation 2: "Car A, with a velocity of 61 mph due north, collides with Car B, whose velocity is 60 mph due *south*."

  Do you see the need for both the magnitude and direction of both cars' velocities? Even though both cars' speeds are the same in both situations, Situation 1 results in a crumpled fender and some scratched paint, while Situation 2 results in death for all parties concerned.

- Tensors — in certain more esoteric situations, even two pieces of data are insufficient to fully define a value. When more than two numbers are required, then science moves to the tensor, which is a rectangular array of numbers (usually square) that define all of the things you need to know about a quantity. The most common tensor is that used to calculate the stress in a material, and it looks like so:

S_{11}	S_{21}	S_{31}
S_{21}	S_{22}	S_{32}
S_{31}	S_{23}	S_{33}

The nine numbers of the stress tensor define how much "stress" a material is subjected to, and is measured in terms of force per area (psi, or pounds per square inch). Three of the numbers refer to the amount of compression or tension a small cube of metal is subjected to at the point of interest in the structure. The other six numbers are the values for the shear forces, which tend to "tear" the metal locally.

If all of this explanation seems especially far from your life, consider this. Imagine you are flying on an airplane, and one of those nine numbers representing the stress at the root of the aircraft's wing exceeds the strength of aluminum. Do you know what happens then? Simple. The wing falls off! So you see, although the stress tensor is far from simple, it is important to know what *all* of those numbers for every cubic inch of structure in a wing and under every condition of loading. This is one of the reasons why engineering pays better than most jobs.

g_{11}	g_{12}	g_{13}	g_{14}
g_{21}	g_{22}	g_{23}	g_{24}
g_{31}	g_{32}	g_{33}	g_{34}
g_{41}	g_{42}	g_{43}	g_{44}

Figure 5: The Riemann Metric Tensor

When Einstein started working on his General Theory of Relativity, he found himself stuck because he lacked the proper mathematics to describe what he needed to describe. He asked for help from a friend, Marcel Grossman, who then dived into the library to look through mathematics texts to help his friend. What he found was a paper by George Riemann, published in 1858, which was just what Einstein was looking for. Riemann was a shy mathematician who had been noodling about trying to find a mathematical way to describe a surface — any surface! What he came up with was a 4 x 4 matrix with which he could describe any surface conceivable, real or imagined. Moreover, while the matrix has 16 numbers in it, since six are duplicates, Riemann concluded that any surface could be described by a tensor of 10 numbers for each point on the surface. His discovery became known as the Riemann metric tensor, and it is very important in the world of geometry. Because Einstein thought gravity could be defined by the geometry of space-time, the Riemann tensor became the basis for the General Theory of Relativity.

For those who think we have lost our way, take heart. We now have enough background to understand the problem with what might be called "real world" string theory. Because the universe has four dimensions (three space and one time), a Riemann metric tensor can be constructed to define every point in the universe. Either you can build an infinite number of boxes containing 16 actual numbers, or you can substitute a mathematical expression for each of the little g_{xy}'s that defines that value for every point in space (or you can take the middle road and insert mathematical expressions into some number of boxes smaller than infinity). Look, nobody said it would be easy!

Or, if you want to describe a vibrating string in four dimensions, you can merely fill in the proper equations of a vibrating string into each spot in the table. Unfortunately, as you may have already guessed, if you do this, you will find that you only have 10 different modes of vibrations, which is way too few to describe the several hundred subatomic particles that we have already discovered, not to mention the equal number of supersymmetric particles that we believe are out there, but which do not, as of this moment, exist.

So it turns out that the thought that subatomic particles are merely the different vibratory modes of the cosmic string stretched out under unbelievable tension will not work so long as we limit ourselves to four dimensions.

Could it be that the mathematics of string theory, which requires ten dimensions to be internally consistent, might actually be describing OUR UNIVERSE? I do not know how to tell you this, but scientists are beginning to believe that is exactly what it means. Welcome to the ten-dimensional universe!

Ten Dimensions: Love Them or Leave Them

Which brings a rather obvious question into play? If the universe has ten dimensions, *where the hell are the other six?* The answer scientists give is that they have been "compactified" — now there is an ugly word!

Huh?

To understand "compactification," consider the lowly garden hose. A garden hose is a three dimensional object. It has length (a lot of it), width, and breadth. The width and breadth are very small compared to the length, but close up; you can see that the hose is three-dimensional. As you pull back from it, something strange happens. The farther away you are, the more one-dimensional the hose looks. Depth goes immediately, making the round hose appear to be a rectangle lying on the ground. This is because human depth perception is not very good. Our eyes just are not set far enough apart on our heads. Then, as you pull back farther, the width becomes smaller and smaller, until eventually, you cannot see it at all.

In effect, two of the dimensions of this three dimensional object have become compactified. They are still there, and participate in the vibration of the hose when water flows through it, but you just cannot see them from a distance. It just looks like a one-dimensional line jumping around like mad, spraying cold water all over your spouse.

In the same way, scientists believe that the extra six dimensions in the universe curled up into tiny loops, which just happen to be the same size as the 10^{-35} meter length of the strings. Coincidence, or some grand design at work?

Even though they are too small to see, the compactified dimensions are extremely important because they allow us to build a 10 x 10 tensor that adequately describes the vibrations to yield every particle we have yet discovered or postulated in the subatomic zoo. Indeed, this 10 x 10 tensor does more than that. To our utter amazement, just about every principle we have discovered in science to date is buried inside that tensor, if only you know where to look. Figure 6 is a poor attempt to explain the concept:

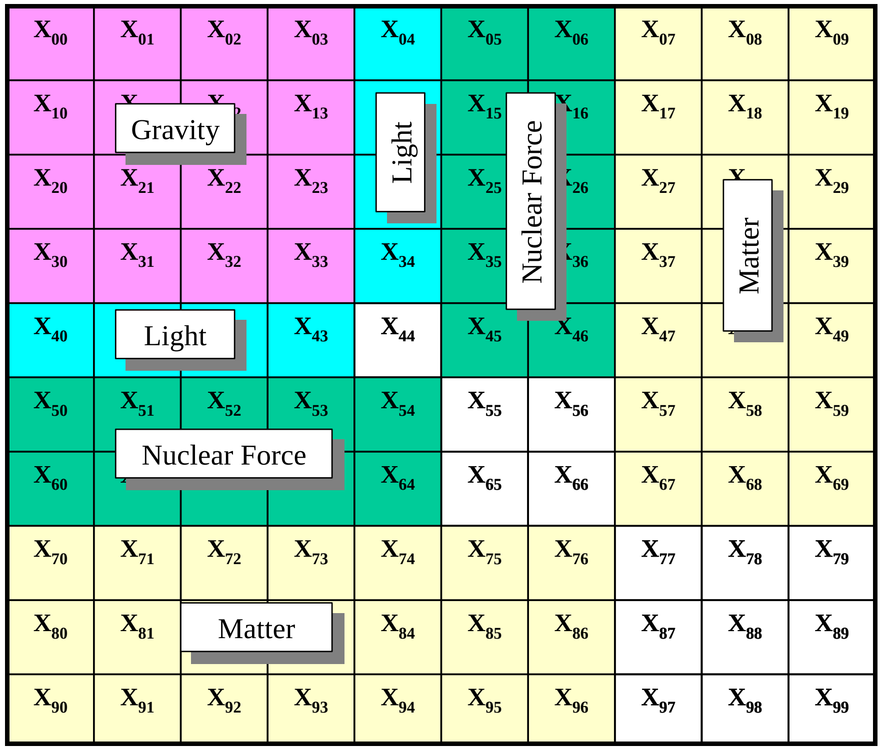

Figure 6: 10 x 10 Superstring Matrix

This is why string theory is so attractive to physicists. It is just too damned elegant to be wrong! It ties everything up into a neat little ball, it explains why all of those particles that can be everywhere at once are actually aspects of the geometry of space-time, just like Einstein thought, and it derives mathematically just about everything we have learned about physics in the last few centuries.

The problem with it has nothing to do with its elegance. The problem is that although we believe this theory to be well on its way to explaining the basic principle of the universe to us, we have not a clue as to *why* it is the basic theory of the universe. In this respect, we are like the scientists who first noticed that various elements had similar properties, and that they could be arranged in a tabular form that eventually became known as the Periodic Table of the Elements. Those who first put the PTOE together did not have an atomic theory of matter. They were not sure why gold, silver, and platinum were related to one another. They just knew that they were and belonged in the same family. As soon as they put the table together, it immediately become obvious that Element 8 was missing. Element 8 is oxygen and its discovery by Jason Priestly was the result of the search he launched once he realized that an element was missing.

So we look at our 10 x 10 matrix and see all of the beautiful symmetries and equations that are contained therein, and we ask ourselves that age-old question of science: "Just what the hell does all of this mean?"

As we ask, we work to improve our understanding of the theory. We try out different permutations and combinations, and we search for the Theory of Everything.

Theories of Everything

For those who are wondering if this month's article will end this month, take heart. We are on the home stretch. Just one more esoteric thing to learn and you will be as smart as I am, which is to say, your level of ignorance will have been slightly alleviated.

Scientists being the way they are, they cannot stop at having one string theory. There are currently a total of five contending for supremacy in the Superstring universe. Why so many? Because there are several ways theorists can build string theories. They all begin with the elementary ingredient, which is a wiggling tiny string. They can then choose whether their strings will be open or closed, and then they decide whether their theory will include only the force-carrying bosons, or whether they will want the building blocks of matter, the fermions, as well. A bosons-only string theory is easy. For string theories in which matter actually exists, you must invoke supersymmetry, which means an equal matching between bosons and fermions. A supersymmetric string theory is called a Superstring Theory. The five current Superstring theories are shown in the table, with some of their characteristics. Note that the strange codes such as SO(32) denote specific kinds of matrices into which the various parameters of the string theory fit.

Type	**Space-time Dimensions**	**Details**
Bosonic	26	Only bosons, no fermions means only forces, no matter, with both open and closed strings. Major flaw: a particle with imaginary mass, called the **tachyon**
I	10	Supersymmetry between forces and matter, with both open and closed strings, no tachyon, group symmetry is **SO(32)**
IIA	10	Supersymmetry between forces and matter, with closed strings only, no tachyon, massless fermions spin both ways (nonchiral)
IIB	10	Supersymmetry between forces and matter, with closed strings only, no tachyon, massless fermions only spin one way (chiral)
HO	10	Supersymmetry between forces and matter, with closed strings only, no tachyon, heterotic, meaning right moving and left moving strings differ, group symmetry is **SO(32)**
HE	10	Supersymmetry between forces and matter, with closed strings only, no tachyon, heterotic, meaning right moving and left moving strings differ, group symmetry is **E8 x E8**

When one takes compactification of dimensions into account, things get messier. That is because there a many ways in string theory to make six dimensions much smaller than the standard four we can observe in our universe. The good news is that the number of string theories has been shrinking in recent years. That is because string theorists have recently become aware of an exciting possibility. The five different theories may not be five different theories at all. They may be five different subsets of a single larger theory. Like the blind men examining the elephant, all of the above (and numerous competitors) may turn out to be aspects of a single, giant, overarching theory.

That is the theory that is the goal of modern physicists. It is a theory of everything, and they have dubbed it the M-Theory, for "the Mother of All Theories." Because of the fast pace at which knowledge is growing, theorists have named this period "the second string revolution." Who knows, you may wake some morning soon to see a headline in the newspaper that says, "Scientists Finally Understand Universe." If you do, then you should take it with a grain of salt. For we all know how accurate newspapers are when it comes to science. Furthermore, there is the problem that scientists frequently find that when they discover something new, they are left with more questions than answers.

Still, we are getting close and that should be exciting to every science fiction reader and writer alive. For as the University of Switzerland experiment into quantum entanglement proves, some of the things that we find inconvenient about the universe, such as Einstein's Universal Speed Limit, may not be so universal after all.

If we are going to find a loophole that will get the human race to the stars, then we may want to start looking in the Superstring Tensor. So far we seem to have found every other bit of scientific knowledge we have ever learned in there. Why not a faster-than-light drive?

#

The End

Appendix A: The Elementary Particles: Fermions and Bosons

Leptons and the weak force			**Quarks and the strong force**			**Bosons: the exchange particles of the force fields of nature**		
Name	**Charge**	**Mass**	**Name**	**Charge**	**Mass**	**Name**	**Spin**	**Carrier of force**
Electron	-1	1	**Up**	2/3	20	**Photon**	1	Electromagnetic force
Electron neutrino	0	0	**Down**	- 1/3	20	**Gluons (8 different ones)**	1	Strong nuclear force
Muon	0	200	**Charm**	2/3	3000	**W+, W, and Z bosons**	1	Weak nuclear force
Muon neutrino	0	0	**Strange**	- 1/3	300	**Graviton**	2	Gravitational force
Tau	-1	3600	**Top**	2/3	350000			
Tau neutrino	0	0	**Bottom**	- 1/3	11000			

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NOVELS

1. Life Probe - US$7.50

The Makers searched for the secret to faster-than-light travel for 100,000 years. Their chosen instruments were the Life Probes, which they launched in every direction to seek out advanced civilizations among the stars. One such machine searching for intelligent life encounters 21st century Earth. It isn't sure that it has found any...

2. Procyon's Promise - US$7.50

Three hundred years after humanity made its deal with the Life Probe to search out the secret of faster-than-light travel, the descendants of the original expedition return to Earth in a starship. They find a world that has forgotten the ancient contract. No matter. The colonists have overcome far greater obstacles in their single-minded drive to redeem a promise made before any of them were born...

3. Antares Dawn - US$6.00

When the super giant star Antares exploded in 2512, the human colony on Alta found their pathway to the stars gone, isolating them from the rest of human space for more than a century. Then one day, a powerful warship materialized in the system without warning. Alarmed by the sudden appearance of such a behemoth, the commanders of the Altan Space Navy dispatched one of their most powerful ships to investigate. What ASNS Discovery finds when they finally catch the intruder is a battered hulk manned by a dead crew.

That is disturbing news for the Altans. For the dead battleship could easily have defeated the whole of the Altan navy. If it could find Alta, then so could whomever it was that beat it. Something must be done…

4. Antares Passage - US$7.50

After more than a century of isolation, the paths between stars are again open and the people of Alta in contact with their sister colony on Sandar. The opening of the foldlines has not been the unmixed blessing the Altans had supposed, however.

For the reestablishment of interstellar travel has brought with it news of the Ryall, an alien race whose goal is the extermination of humanity. If they are to avoid defeat at the hands of the aliens, Alta must seek out the military might of Earth. However, to reach Earth requires them to dive into the heart of a supernova.

5. Antares Victory – First Time in Print – US$7.50

After a century of warfare, humanity finally discovered the Achilles heel of the Ryall, their xenophobic reptilian foe. Spica – Alpha Virginis – is the key star system in enemy space. It is the hub through which all Ryall starships must pass, and if humanity can only capture and hold it, they will strangle the Ryall war machine and end their threat to humankind forever.

It all seemed so simple in the computer simulations: Advance by stealth, attack without warning, strike swiftly with overwhelming power. Unfortunately, conquering the Ryall proves the easy part. With the key to victory in hand, Richard and Bethany Drake discover that they must also conquer human nature if they are to bring down the alien foe …

6. Thunderstrike! - US$7.50

The new comet found near Jupiter was an incredible treasure trove of water ice and rock. Immediately, the water-starved Luna Republic and the Sierra Corporation, a leader in asteroid mining, were squabbling over rights to the new resource. However, all thoughts of profit and fame were abandoned when a scientific expedition discovered that the comet's trajectory placed it on a collision course with Earth!

As scientists struggled to find a way to alter the comet's course, world leaders tried desperately to restrain mass panic, and two lovers quarreled over the direction the comet was to take, all Earth waited to see if humanity had any future at all…

7. The Clouds of Saturn - US$7.50

When the sun flared out of control and boiled Earth's oceans, humanity took refuge in a place that few would have predicted. In the greatest migration in history, the entire human race took up residence among the towering clouds and deep clear-air canyons of Saturn's upper atmosphere. Having survived the traitor star, they returned to the all-too-human tradition of internecine strife. The new city-states of Saturn began to resemble those of ancient Greece, with one group of cities taking on the role of militaristic Sparta...

8. The Sails of Tau Ceti – US$7.50

Starhopper was humanity's first interstellar probe. It was designed to search for intelligent life beyond the solar system. Before it could be launched, however, intelligent life found Earth. The discovery of an alien light sail inbound at the edge of the solar system generated considerable excitement in scientific circles. With the interstellar probe nearing completion, it gave scientists the opportunity to launch an expedition to meet the aliens while they were still in space. The second surprise came when *Starhopper's* crew boarded the alien craft. They found beings that, despite their alien physiques, were surprisingly compatible with humans. That two species so similar could have evolved a mere twelve light years from one another seemed too coincidental to be true.

One human being soon discovered that coincidence had nothing to do with it...

9. Gibraltar Earth – First Time in Print — $7.50

It is the 24th Century and humanity is just gaining a toehold out among the stars. Stellar Survey Starship *Magellan* is exploring the New Eden system when they encounter two alien spacecraft. When the encounter is over, the score is one human scout ship and one alien aggressor destroyed. In exploring the wreck of the second alien ship, spacers discover a survivor with a fantastic story.

The alien comes from a million-star Galactic Empire ruled over by a mysterious race known as the Broa. These overlords are the masters of this region of the galaxy and they allow no competitors. This news presents Earth's rulers with a problem. As yet, the Broa are ignorant of humanity's existence. Does the human race retreat to its one small world, quaking in fear that the Broa will eventually discover Earth? Or do they take a more aggressive approach?

Whatever they do, they must do it quickly! Time is running out for the human race…

10. Gibraltar Sun – First Time in Print — $7.50

The expedition to the Crab Nebula has returned to Earth and the news is not good. Out among the stars, a million systems have fallen under Broan domination, the fate awaiting Earth should the Broa ever learn of its existence. The problem would seem to allow but three responses: submit meekly to slavery, fight and risk extermination, or hide and pray the Broa remain ignorant of humankind for at least a few more generations. Are the hairless apes of Sol III finally faced with a problem for which there is no acceptable solution?

While politicians argue, Mark Rykand and Lisa Arden risk everything to spy on the all-powerful enemy that is beginning to wonder at the appearance of mysterious bipeds in their midst…

11. Gibraltar Stars – First Time in Print — US$7.50

The great debate is over. The human race has rejected the idea of pulling back from the stars and hiding on Earth in the hope the Broa will overlook us for a few more generations. Instead, the World Parliament, by a vote of 60-40, has decided to throw the dice and go for a win. Parliament Hall resounds with brave words as members declare victory inevitable.

With the balance of forces a million to one against *Homo sapiens Terra*, those who must turn patriotic speeches into hard-won reality have their work cut out for them. They must expand humanity's foothold in Broan space while contending with a supply line that is 7000 light-years long.

If the sheer magnitude of the task isn't enough, Mark and Lisa Rykand discover they are in a race against two very different antagonists. The Broa are beginning to wonder at the strange two-legged interlopers in their domain; while back on Earth, those who lost the great debate are eager to try again.

Whoever wins the race will determine the future of the human species… or, indeed, whether it has one.

12. Gridlock and Other Stories - US$6.00

Where would you visit if you invented a time machine, but could not steer it? What if you went out for a six-pack of beer and never came back? If you think nuclear power is dangerous, you should try black holes as an energy source — or even scarier, solar energy! Visit the many worlds of Michael McCollum. I guarantee that you will be surprised!

Non-Fiction Books

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17. The Astrogator's Handbook – Expanded Edition and Deluxe Editions

The Astrogator's Handbook has been very popular on Sci Fi – Arizona. The handbook has star maps that show science fiction writers where the stars are located in space rather than where they are located in Earth's sky. Because of the popularity, we are expanding the handbook to show nine times as much space and more than ten times as many stars. The expanded handbook includes the positions of 3500 stars as viewed from Polaris on 63 maps. This handbook is a useful resource for every science fiction writer and will appeal to anyone with an interest in astronomy.

