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The Frontiers of Physics, Part IV: The BIG Picture

By
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One thing that I have noted during my career as a science fiction writer is that we practitioners of the art tend to be a conservative bunch. Not politically conservative, although some of us do tend to be right-of-center in your views. No, science fiction writers tend to be conservative about their science.

Most SF writers are still recycling what they learned about Einstein's Theory of Relativity by reading Robert Heinlein books originally published in the 1950s. Today, nearly a century after Einstein's best work, we are still mining the treasure trove of knowledge that he left us. We continue to explain to our readers why it is impossible to fly faster than the speed of light, or more likely, how it is that we have managed to evade his universal speed limit. Nor is faster-than-light travel the only time we pay homage to the Austrian patent clerk. We still write stories that have at their heart the twin paradox made possible by time dilation effect (see *Time for the Stars*, Robert Heinlein, Scribners, 1956). We delve into the wonders of the universe by orbiting neutron stars and diving into black holes, both concepts that were decades old before science fiction writers got around to using them in the 1970s and 1980s. The neutron star was postulated by Bade and Zwicky in 1933 and the black hole was described mathematically by Karl Schwarzschild in 1916.

Some time ago, I had the idea of helping matters by dashing off a quick article that explained some of the more up-to-date findings of physics — say those that have taken place in the last ten to twenty years. The subject proved to be larger than I had envisioned, and one article grew into two, then three, and now four. What I had originally thought I could do in 5000 words has grown to more than 30,000. If you wonder how much effort it is to write these articles, 30,000 words is half a paperback novel, and many who are awaiting the completion of *Antares Victory* would probably rather I had spent the effort on the book. Still, it was a project worth doing and one that made me update my own scientific knowledge, which like that of many of my colleagues, had been lagging.

The truth is that quite a lot has occurred in physics since I went through school in the 1960s. At no time in history have the discoveries been flying so fast and furiously. Just last week, for instance, it was announced that scientists have mapped all three billion letters of the human genome. While not a landmark of science on the cosmic scale, the achievement has a certain parochial interest to it. Considering that we and turtles are nearly identical biochemical machines, how is it that they live to be 150 years old, but we only live to seventy? Now that we understand our genetic code, perhaps we will be able to do something about this particular injustice of Mother Nature.

We began this series by paying homage to Sir Isaac Newton, one of the greatest minds to ever live. He wasn't much of a human being, mind you, but there is no doubting his intelligence. Newton held sway in the land of physics for 250 years before being dethroned by Albert Einstein's theories of relativity, which we reviewed in detail.

Having established a baseline of traditional knowledge, we delved next into the realm of the atom. Exciting discoveries in subatomic physics have largely cleaned up the mess physicists made of the field in the 1960s through 1980s, when they fired their cosmic bullets at thin foil targets in particle accelerators and discovered a veritable subatomic zoo emerging from the resulting collisions. The world of proton, neutron, and electron, has given way to even more fundamental particles, of quarks and leptons, baryons and fermions, and of the four fundamental forces of nature. For those who were able to absorb Part II of the *Frontiers of Physics* in one sitting, I congratulate you and stand in awe of your stamina.

From nuclear physics, we transitioned to the truly weird world of quantum mechanics, Superstring Theory, and the nascent M-Theory. We postulated a universe of four obvious dimensions and six hidden ones, a universe where a single particle can be in a lot more than two places at the same time, and where ordinary matter isn't what it seems. We learned that the basic building block of the universe is the cosmic string, and that depending on how this string vibrates, it can be a proton, neutron, electron, photon, or graviton.

So, having peered into the truly tiny and found the solid underpinnings of our universe to be less solid than we had believed, let us wrap up our explorations by reviewing some of the bigger discoveries of the recent past — in some cases, the past few months. Let us then leave behind our peering into the interiors of atoms, protons, and quarks and pull back from our subject to perceive the larger picture.

Our subject for this month will be the discoveries that are transforming modern cosmology and revealing our true place in the universe.

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In the Beginning

In the beginning God created the heavens and the earth;
and the earth being without form and empty, and darkness on the face of the deep,
and the Spirit of God moving gently on the face of the waters, then God said, Let there be light! And there was light.

And God saw the light, that it was good, and God separated between the light and darkness.

And God called the light, Day. And He called the darkness, Night. And there was evening, and there was morning the first day.

— Genesis, Chapter 1

In the beginning, God did create the heavens, and when he said “Let there be light!”, there was light — a whole lot of light! That light came in the form of the Big Bang, an explosion so titanic that it created the universe, an explosion of such hellish fury that we human beings cannot possibly comprehend its violence. Yet, our lack of imagination does not stop us from trying. It is our understanding of precisely what happened in those first few nanoseconds that will unlock for us the secret of the universe. Surprisingly, we may have found the key that fits into that particular lock and are even now beginning to feel the tumblers of knowledge fall into place.

The current theory is that the universe we inhabit exploded into being some 15 billion years ago. It did not begin as a single, infinitely dense lump of matter-energy located at a particular point in space that suddenly exploded, sending fragments rushing away at high speed through the cosmos. Rather, space itself, along with time, came into being at the moment of the Big Bang, and it is this bubble of space-time that is expanding out into the cosmos.

At the moment of creation, the universe was a tiny bubble of space-time some 10^{-33} centimeters in diameter (that is a billion-trillion-trillionth of a centimeter). This microscopic bubble came into existence more or less spontaneously, arising out of nothingness, possibly as the result of a random quantum fluctuation. The matter-energy bubble was so densely packed that a massive inflationary force caused it to explode outward. This is not the expansion we see today, but something infinitely more violent. In less than 10^{-35} seconds, the universe expanded from something much smaller than an electron to a ball about the size of a grapefruit, in what is known as the “inflationary phase” of the formation of the universe. While it was over very quickly, this period of inflation is supremely important, for it holds the key to understanding the universe. It was during the inflationary period that the universe coalesced into the dimensions (three spatial and one temporal) of which we are aware. It was also during this period that six additional dimensions that we know exist, but which we cannot find, went into hiding.

At grapefruit-size, the universe became large enough that the inflationary force disappeared, to be replaced by the steady expansion that we see today. As the universe expanded, it cooled. One millionth of a second (10^{-6} s) after the Big Bang, the most basic forces in nature become distinct: first gravity, then the strong force, which holds nuclei of atoms together, followed by the weak and electromagnetic forces. By the end of the first second, the temperature of the universe had dropped to the point where the fundamental particles and energy: quarks, electrons, photons, neutrinos and less familiar types froze out of the soup. Essentially the high energy “steam” of the big bang turned to the matter “ice” of the early universe. These fundamental particles, all of which were moving at a goodly percentage of the speed of light, smashed into one another to form protons and neutrons.

The nuclei of the lighter atoms formed at 3 seconds after the Big Bang as the temperature dropped to the point where protons and neutrons were able to stick to one another. It was during this period that the relative abundances of hydrogen and helium were fixed.

At about 10,000 years after the Big Bang, the “radiation era” began. Most energy in the universe was in the form of radiation — different wavelengths of light, X rays, radio waves and ultraviolet rays. Some 300,000 years after the Big Bang, the amount of energy present in its "frozen" form of matter, and in its "vaporized" form of radiation, were about equal in the universe.

As the expansion continued, the waves of light that formed the radiation were stretched to lower and lower energy levels, while the matter was largely unaffected. With the weakened radiation, free electrons in the universal soup were captured by the orphan nuclei, and true atoms formed. These simple atoms — hydrogen, helium, and lithium — became electrically neutral, and the cosmic soup turned transparent, freeing light rays of all wavelengths from interacting with matter. The energy that had been trapped in the cosmic soup suddenly burst free of the matter and radiated to the far corners of the universe. Thus, it is the era 300,000 years after the Big Bang into which we are looking when we measure the cosmic background radiation.

Not much happened in the universe for the next 300 million years. At the end of that period, the force of gravity (the first fundamental force to coalesce from out of the cosmic "soup") amplified slight irregularities in the density of the primordial gas, and regions of high density formed. As the hydrogen and helium gas mixture coalesced, their internal temperature increased due to compression. When the temperature and pressure at the heart of the gas clouds reached a sufficiently high level, hydrogen fusion began and stars began to light the black sky. Soon groups of stars coalesced into galaxies.

And the rest, as they say, is history.

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Some Obvious Questions Concerning the Big Bang

You may note how slickly we glossed over the origin of the Big Bang in the previous section. "The Big Bang … came into existence more or less spontaneously, arising out of nothingness, possibly as the result of a random quantum fluctuation." Sounds very scientific, doesn't it? However, just exactly what does it mean? It means that the whole giant construct which we laughingly refer to as "the universe" suddenly appeared one day out of nothingness. Except, of course, that there were no "days" at the time, because there was no time at the time. Confusing, no?

Still, explaining something in hi-tech jargon and scientific mumbo-jumbo does not answer the obvious question, namely how so much "something" could suddenly appear out of "nothing." On the other hand, as in our interest in the human genome, perhaps we are being a little too parochial in asking the question that way. For instance, what makes us think that something appeared from out of nothing in the first place? Our eyes, and all of the stars we can see in the night sky? Paltry evidence at best.

Consider the possibility that nothing coalesced out of nothing during the Big Bang. That, at least, would have some logic to it.

Just How Much Energy is there in the Universe, Anyway?

Because we are made out of matter, we have a fondness for dividing the universe up into its matter component and its energy component. In fact, this dichotomy does not exist. Matter and energy are two forms of the same thing. Therefore, it makes sense to speak of the energy content of the universe and convert the matter to its energy equivalent. Indeed, that is what we do in subatomic physics when we speak of particle masses in terms of MeVs (million-electron-volts). That isn't their true mass, which would normally be measured in grams. However, the weight is so low that we find it easier to speak of the energy equivalent of the particle's mass. Fewer negative exponents to keep track of that way.

So, after converting all of the mass in the universe to its energy equivalent, how much energy is there in the universe? Judging by what we can see, quite a lot!

But aren't we forgetting something?

In addition to the matter and energy of the universe, there are the four fundamental forces that hold things together. Of these, gravity is the weakest, but also the most pervasive. If you consider gravity as being a negative form of energy, then you come to a startling conclusion, namely that the net energy content of the universe may, in fact, be zero.

But can we consider gravity to be negative energy?

To see the principle at work, we need only look a mere 150 million kilometers (93 million miles) distant to the sun. In a star, gravity is attempting to pull all of the mass of the dense cloud together, while the energy released by the thermonuclear reaction at the star's center attempts to push it apart. This balancing act continues until the star runs out of fuel, at which point it collapses in upon itself. At the moment of collapse, all of those megatons of mass give up their potential energy of position, often with spectacular results (see our various articles on supernovas).

Despite the massive explosions that often result from such collapses, the star loses energy during the process. Once gravity has its way with a star, its energy decreases. This means that gravity can be thought of as the negative equivalent of energy. If you add up all of the energy in the universe (in terms of radiation plus the energy equivalent of all of the matter), and then you subtract out the gravity, you discover that the two quantities are close to being in balance. In fact, they are *suspiciously* close to the balance point.

This balance between matter-energy and gravity was one of the major mysteries of science until last May, when a team of scientists announced the results of the BOOMERANG infrared telescope experiment. It turns out (according to them) that mass-energy and gravity are very closely balanced in the universe, and in fact, are equal to within the accuracy of our ability to measure. Nor is this tidy state of affairs an accident. Rather, it is inherent in the nature of the universe and is inextricably linked to the 10^{-35} seconds of inflation that followed the Big Bang.

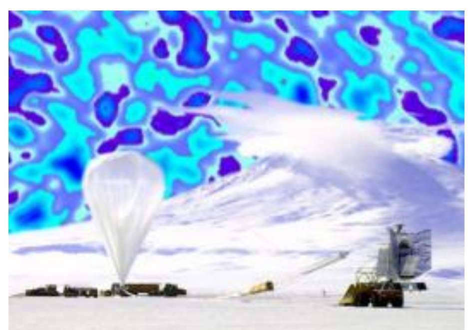

Figure 1: The BOOMERANG Infrared Telescope With Cosmic Background Radiation Results Superimposed Above

If matter-energy is exactly balanced by the negative energy of gravity (and the other forces), then the net energy of the universe is precisely zero, which makes its sudden appearance from out of nothingness a little easier to swallow. For a non-technical explanation of this process, see Genesis, Chapter 1, above. For a more technical treatment of the subject, keep reading.

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A Universe of Critical Mass

Figure 2: The BOOMERANG Payload

The BOOMERANG experiment used a high altitude balloon to lift an infrared telescope to the edge of space, where it could measure minute differences in the temperature of the cosmic background radiation. The purpose was to resolve a long-running argument among cosmologists, namely whether the universe is open, closed, or flat. These terms deal with the question of how much mass (actually mass-energy) there is in the universe and whether it is sufficient to halt the universal expansion first detected by Edwin Hubble. It was Hubble's discovery that everything is rushing away from everything else that was the catalyst that eventually led to the Big Bang theory.

That the universe is expanding is undeniable, and since the universe possesses gravity, that expansion is slowing down over time. Depending on the density of matter in the universe, there are three possibilities for the far future. If that there is insufficient mass in the universe to halt the expansion, then it will just go flying apart forever. The galaxies will become ever more distant from one another. If there is insufficient gravity to halt the headlong rush to infinity, the universe is said to be "open."

The second possibility is that the universal expansion will eventually be halted by the pull of gravity, and that the galaxies will fall back in upon themselves. At the end of this scenario, all of the matter in the universe reunites in the Big Crunch, and possibly the cycle starts over. If there is sufficient matter density in the universe to halt the outward expansion and cause the Big Crunch, then the universe is said to be "closed."

Finally, there is the boundary between these two conditions. What if the density of the universe is just right to halt the outward expansion, but not strong enough to cause the universe to collapse back in upon itself? This condition is called the "critical density" condition. In effect, the universe will expand forever, but will approach zero velocity asymptotically. In other words, the expansion will slow continually, almost halting but not quite, for eternity. If the matter/gravity balance is such that the universe is balanced on this particular knife edge, the universe is said to be "flat."

For several decades, scientists have wrestled with this dilemma, which they have defined by a parameter represented by the Greek letter Omega, Ω. Omega is defined as the actual density of the universe divided by the critical density. So, if Ω is less than 1, the universe is open and will expand forever. If Ω is greater than one, the universe is closed and will fall back in upon itself with the Big Crunch. If Ω is precisely one, then the universe is critical density, and will come to a halt at $T=\infty$, but will not fall back in upon itself.

As we shall see in a bit, Inflation Theory, which we have already discussed, in inextricably related to the question of whether the universe is open, closed, or flat. Inflation Theory was developed to link important ideas in cosmology to those of subatomic physics. Specifically, there are certain questions about the universe that are difficult to answer unless the universe went through a violent inflationary period early in the Big Bang. These questions include:

1. Why is the universe so uniform on the largest length scales?
2. Why is the physical scale of the universe so much larger than the fundamental scale of gravity, the Planck length (1.6 x 10^{-33} cm), which is one billionth of one trillionth of the size of an atomic nucleus?
3. Why are there so many photons in the universe?
4. What physical process produced the initial fluctuations in the density of matter?

Inflation Theory, which postulates the exponential expansion that took place until 10^{-35} seconds after the Big Bang, was developed by Alan Guth, Andrei Linde, and Paul Steinhardt, and makes a number of predictions that are useful in answering the open/closed/flat controversy. Specifically, if we live in an Inflationary Universe, then the universe must exhibit certain characteristics, some of which we can actually measure. If there was a period of inflation during the big bang, then the following conditions are a natural consequence:

1. The density of the universe is close to the critical density, and thus the geometry of the universe is flat.
2. The fluctuations in the primordial density in the early universe had the same amplitude on all physical scales.
3. There should be, on average, equal numbers of hot and cold spots in the fluctuations of the cosmic microwave background temperature.

It is these last two predictions that the BOOMERANG experiment studied. The cryogenically cooled, infrared telescope spent 10 days at an altitude of 40,000 meters (120,000 feet) above Antarctica, peering into the sky overhead. As it peered, it mapped minute differences in the temperature of the Cosmic Background Radiation. These results are shown in the upper part of Figure 1. It turns out that, on average, there are indeed equal numbers of hot and cold spots in the fluctuations of the cosmic microwave background radiation, and that the fluctuations in the radiation prove that the primordial density in the early universe had the same amplitude on all physical scales. Scientists therefore conclude that if Predictions 2 and 3 hold up, then Prediction 1 must also be true. In other words, the universe is flat. There is just precisely enough matter in it to halt the outward expansion, given infinite time.

This result is surprising, to say the least. How is it that we seem to have hit the cosmic jackpot and have the precise, critical density of matter we need to balance the universe and make its net energy zero? Luck, it turns out, had nothing to do with it. The balance between matter-energy and gravity is inherent in the structure of the universe. In fact, upon further reflection, it could not have come out any other way.

One of the things that makes science so fascinating is its ability to extrapolate on present knowledge and to make predictions as to what we will learn in the future. If we live in a universe that is truly flat, then we must change our view of what the universe is and how it works. Not surprising, this new data tells us that we have been too timid in our theories, and that the way we have viewed the universe up until now has been too parochial. The time has come, it seems, to once again expand our horizons.

Before we do that, however, let us take a short detour and resolve another nagging problem of cosmology. I refer, of course, to the greatest detective story of all time, the search for the missing mass of the universe.

Figure 3: Galaxies rotate as though the stars were painted on a solid disk of glass, which, of course, they are not.

Dark Matter, Dark Energy, and the Missing Mass Problem

Like much of our science, the problem of the missing mass of the universe goes back more than 50 years. The first record of someone noting that part of the mass of the universe was missing was in 1932 when astronomer Jan Oort, after whom the Oort Cloud of comets is named, analyzed the motions of nearby stars in the Milky Way galaxy and decided that something was wrong. The stars appeared to be moving in orbit about the center of the galaxy, but at speeds well above local escape velocity. The following year, Fritz Zwicky examined the movements of clusters of galaxies and wondered how it was that galaxies existed at all. In order not to fly apart as they rotated, galaxies would have to be ten times more massive than they obviously were.

In 1973, Jeremiah P. Ostricker and James Peebles, while working on the orbital motions of stars in the flat disk of the galaxy, showed persuasive evidence that the missing matter problem was indeed real, and that the only way to explain stellar motion within the galaxy was to assume that the mass of the galaxy was ten times greater than it appears.

One of the great insights of the age of Galileo, Copernicus, and later, Sir Isaac Newton, was that the planets orbit the sun under the influence of the sun's gravitational field. If one assume that the sun's gravity acts from a central point (the center of the sun) and that it reaches radially outward with a force that falls off with the square of the distance (the inverse-square law), it is easy to show that a planetary orbit will be some form of an ellipse. When we look at the actual orbits of the planets, we discover that they are, indeed, ellipses. Furthermore, the closer an object is to the sun, the faster it orbits.

This is born out by telescopic observation. Mercury, the closest planet to the sun, orbits the system primary in a mere 88 days. Earth, at 150 million kilometers distance, takes a full year. And Pluto, some 40 times more distant than Earth, takes 248 years to go once around the sun.

Since gravity is universal, we would expect the same thing to happen in galaxies. Those stars nearest the core should move once around the galaxy much faster than those at the galactic rim. The only problem is that they don't. Essentially, all stars in a spiral galaxy like the Milky Way tend to rotate at the same rate, with the outer stars rotating a little faster than their inner brethren. If this weren't so, then the beautiful spiral arms of the galaxy would quickly "wind up," destroying their pattern.

That galaxies behave differently than star systems indicates that something is wrong with our model of either how gravity works or how galaxies are constructed. What is wrong is the idea that the gravity of the galaxy is concentrated into a single, central point. In fact, to explain the stellar motion in the galactic arms, we have to assume that the mass of the galaxy is not concentrated. Rather, it is spread throughout space, with a great deal of that mass outboard of the stars. In other words, the Copernican motion of the planets in the Solar System come from the fact that the sun's gravity is a *central* inverse-square force, and the motions of the stars in the arms of spiral galaxies is due to the fact that galactic gravity is a *distributed* inverse-square force. Nor is that the case in the Milky Way alone. It is the case for all galaxies, everywhere in the universe.

Thus, there is some form of matter that appears spread evenly through galactic space, and possibly through the space between galaxies, that we cannot see. That matter appears not to be in the form of interstellar gas or dust. We can see gas and dust when they are illuminated by nearby stars (see the Great Nebula of Orion or the Horsehead Nebula), or by the absorption lines they superimpose on the spectra of light that passes through them. It doesn't appear to be in the form of black holes, either. It is beginning to look like every spiral galaxy has a massive black hole at its heart, but if they are the source of the missing mass, galaxies would obey the planetary system model of motion. No, the missing mass must be something else. The candidates are cool matter, such as burned out stars, planets, moons, comets; hot matter, such as neutrinos or other massive, but so far undetected, subatomic particles; and dark energy.

Whoa, Hoss! Where did this dark energy come from?

Dark energy is a newcomer to the cosmological playing field. In fact, it is only about two years old and is the result of an experiment reported in *Science* in 1998. Astronomers, it seems, discovered that Type 1A supernovas are extremely predictable. They follow a very precise pattern during their lives, producing the same brightness vs. time curve. Thus, if one sees a distant Type 1A supernova (say in a galaxy millions of light-years distant), by noting the effective brightness and then adjusting for the real brightness (because all of them are the same), it is possible to measure with good accuracy the distance between us and the supernova.

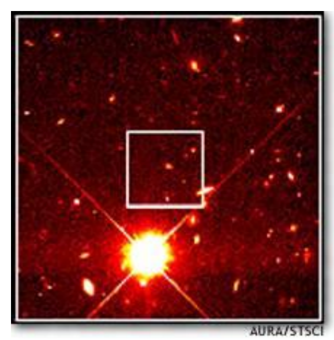

Figure 4: Type 1A Supernova Seen Behind Bright Foreground Star

Astronomers did a ten-year study of Type 1A supernovas as viewed in distant galaxies, and after determining the distance to the galaxy in question, measured its red-shift. Ever since Edwin Hubble, it has been an article of faith among astronomers that the higher the red-shift, the more distant the object. The only problem was that this wasn't what the experiment found. For most of the galaxies studied, the nearer the galaxies, the greater the red-shift. In other words, objects that were closer were receding faster than objects that were farther away.

This result completely screwed up standard astronomical dogma, and led to a surprising conclusion. Since peering into the distance in space is the same as peering backwards in time (because each light-year of distance is also a year into the past due to the fact that light travels at 300,000 kps and the light-year is defined in terms of how far light travels in a year), the results of the supernova theory was that the expansion rate of the universe is not slowing down as all of our cosmological models say it should. (Remember the definitions of open, closed, and flat.)

The rate of expansion is accelerating!

The only way this can happen is if there is some form of energy in space that has a repulsive effect that is much the same as gravity's attractive effect, except opposite. This new energy is, so far, unidentified. However, its source is relatively easy to postulate. It is likely the same "energy" that caused the infant universe to expand explosively in the first instants of the Big Bang. This unseen energy, or dark energy, is probably the cause of the short Inflationary Era at the universe's creation, which as we shall see shortly, may have been the most important 10^{-35} seconds in history.

Surprisingly, even this dark energy was foreseen by Albert Einstein, in terms of his "cosmological constant." The cosmological constant was initially proposed by Einstein to explain Hubble's results in the days before the Big Bang theory. It is, in effect, an expansionary force that acts throughout space. Later he claimed that coming up with the constant was his "biggest blunder." If the Type 1A supernova data holds up, perhaps he was premature in castigating himself.

BOOMERANG's measurements indicate that ordinary matter (baryonic matter) accounts for about 5 percent of the universe's content, as measured by its gravitational effect. Dark Matter accounts for about 30 percent, and Dark Energy accounts for 65% of the total. Needless to say, this result is substantially at odds with the way we were taught astronomy in school.

The Observable Universe vs. the Whole Universe

Which brings us back to the question of how the universe can be such a preposterous place that it has precisely enough matter in it for omega to equal one. Of all the billions of possibilities, how is it that we wound up with the only possibility for which there is but a single choice? To answer that question, we need to return to the Inflationary Hypothesis.

Remember that in those first few instants of the Big Bang, something caused the microscopic pea of a fireball to explode exponentially to the macroscopic size of a grapefruit. What if we are mistaken about that grapefruit? What if it expanded far beyond anything we have imagined? Wouldn't the size of the universe at the end of the Inflationary Era determine its current size? What if it is billions of times larger than we thought?

Interestingly, assuming that the universe is huge compared to the part of it we can see resolves our quandary as to whether or not it is flat — that is, whether the mass density is critical and $\Omega = 1.0$. In fact, in such an oversize universe, the amount of mass-energy in the universe would have to be close to the critical value, almost by definition. In such a giant universe, one of the biggest mysteries of science suddenly becomes trivial.

Unfortunately, we are ill equipped to speak of a huge super-universe, both because we lack the vocabulary and experience with the concept. What we need are to define some new terms. One of these terms is "universe," which is defined as everything there is, or the totality of space-time, if you want to get technical about it. The universe is the "thing" that resulted from the Big Bang. So how large a "thing" can the universe be?

Applying Einstein's universal speed limit, if the universe exploded 15 billion years ago, then it cannot be more than 30 billion light-years in diameter, assuming that the explosion moved outward equally in all directions at the speed of light. The problem is that we can't apply Einstein's "nothing can go faster than light" restriction to the expansion of the universe.

As noted at the beginning of this article, modern Big Bang theory does not hold that the universe exploded at one central point and has been expanding away from that point for the last 15 billion years. Rather, space-time itself exploded, coming into existence at the moment of creation. While the Theory of Relativity states that nothing can travel through space at speeds greater than light, it places no such limitation on the expansion of space-time.

As we look farther out into space, we see the galaxies and stars receding faster and faster (subject to the cosmological constant factor). Actually, they are moving through space at about the same speed that we are. It is the "stretch" of the intervening space that makes them appear to recede. The rate of expansion between two points in space is determined by the distance between an observer and that which he is observing, and is given by the Hubble Constant, currently set at 70 ± 7 km/sec/mega-parsec.

Consider that if you look out far enough, the speed of recession will reach the speed of light, and then beyond that point, will exceed it. At this point, the stars are receding so quickly that the light they emit cannot overcome the rate of recession.

At the point where the rate of recession equals the speed of light, we become blind. That is the edge of the observable universe (by definition). In other words, we live in a bubble of visible stars approximately 28 billion light-years in diameter (assuming a Hubble Constant of 70). The only question is whether the real universe, the totality of space-time, also measures 28 billion light-years across?

The fact that the universe appears flat and omega equals one argues that the universe is substantially larger than the 28 billion light-years that we can see, which is why we have to start specifying what we mean when we say the word "universe." Do we mean the whole thing or just the part we can see?

To make sure that this point is clear, let us perform a thought experiment. Think of a human astronomer looking out into space 14 billion light-years and measuring the recession rate of a single star at 0.99c. With such a high red shift, that star is practically at the edge of our observable universe. Were it one percent more distant, it would be invisible.

What if there is an astronomer on a planet orbiting that star? If he looks back at us, we will appear to be receding from his telescope at 0.99c. We are at the edge of his observable universe. Yet, if he turns his telescope around, he can see 14 billion light-years in the other direction, which is 14 billion farther than we can see. Perhaps he sees a star in the opposite direction that is receding at 0.99c (which is 1.98c with respect to us). Perhaps there is another astronomer looking at our friend, and he, too, turns his telescope to look in the opposite direction, extending the chain of observations another 14 billion light-years (to a star receding from us at 2.97c).

The obvious question is how far this chain of observations can proceed until we run out of actual, physical universe. We used to believe that the difference was less than 10%. That is, the observable universe encompassed 90% of the real universe. Now, we aren't so sure. The results from the BOOMERANG telescope indicate that the physical universe may be many times the size of the observable universe, possibly a billion times larger! It all depends on how large the space-time bubble was at the end of the Inflationary Era. Was it the size of a grapefruit, the size of our observable universe, or somewhere in between? Obviously, the answer to that question will determine the physical size of the real universe some 15 billion years after the event.

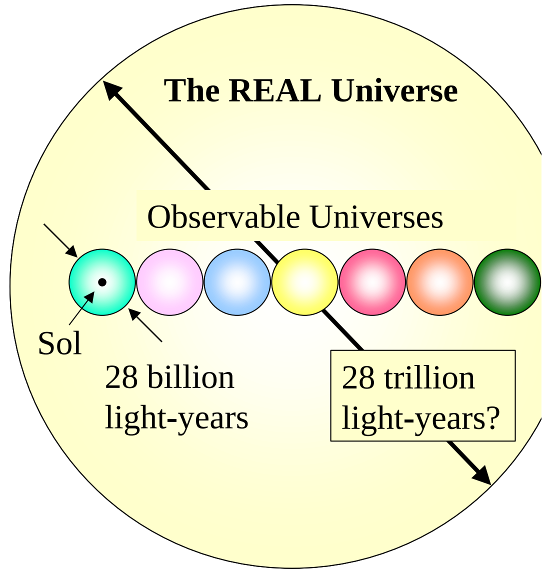

Figure 5: Is the REAL Universe Significantly Larger than the Observable Universe?

<u>An Observable Universe With Critical Mass</u>

So what does it mean if the universe is flat, the matter-energy density is critical, and Ω=1? It could mean that we were really, *really*, REALLY lucky, and everything just happened to work out right. Of course, scientists have learned to be suspicious of seeming strokes of luck akin to drawing an inside straight flush a trillion times in a row.

It turns out that if the real universe is larger than the observable universe, then it is not surprising that the observable universe appears flat. In fact, it could not be otherwise. To understand the concept, let us look at something smaller, namely your backyard.

Your backyard appears flat. In actuality, it probably is flat. However, if you used satellite positioning and a really good Earthmover to grade it, you could make sure that every part of the yard was the same distance from the Earth's center. If you did this, it would not be flat. It would be a small section of a sphere some 12,500 kilometers (7900 miles) in diameter.

However, it would still appear to be flat!

That is because the radius of the sphere is so large and the section covered by your back yard is so small, that the degree of curvature is imperceptible. In fact, you would have trouble measuring the curvature, let alone seeing it.

In a cosmos where the observable universe is very much smaller than the whole universe, it doesn't matter whether the universe is open, closed or flat. To anyone seeing only the observable universe, local space will appear to be flat, just as your back yard appears to be flat. That is because astronomers limited to viewing out to a range of 14 billion light-years in all directions won't be able to see enough of the whole to detect any curvature.

Which is why we believe that the cosmos appears flat to us. Whether it is or isn't, we can't see enough of it to come to any other inference.

<u>Conclusion</u>

So it has happened to us again. We work for years to discover the science behind one of the mysteries of the universe, only to find that not only has the mystery turned into a triviality, but that the universe has proved to be vastly larger than we had previously imagined. The mighty human race, Lords of Creation, Masters of All They Survey, has suddenly been relegated to the status of a microbe in the grander scheme of things. No, we were microbes when the universe was only 28 billion light-years across. Having expanded it to something on the order of 28 *trillion* light-years, we have shrunk in to the size of a single proton, or even an individual quark. It's enough to shake a person's confidence in himself.

Whether future discoveries will confirm this new view of creation, or will demonstrate the danger of letting one's speculations outrun their knowledge, only time will tell. What is patently obvious, however, is that the excitement on the frontiers of physics will continue unabated for some time to come. If anything, the speed of discovery is accelerating, with major insights seemingly announced every few weeks..

Why, just last month, the INTERNET was alive with reports that someone had managed to exceed light-speed in the laboratory by a factor of 300. Details are not yet available, but the experiment in question is probably further proof of the weird behavior of quantum-entangled particles (which we discussed in Part III of this series). It is just a guess, but I believe that Albert Einstein's reign over the land of physics is about to come to an end. We seem ripe for a revolution in physics, and the first decade of the twenty first century may see a general overhaul of just about everything we know.

With that wild thought, I leave you with your heads spinning and an ancient Chinese curse ringing in your ears: *"May you live in interesting times!"*

Funny, it doesn't sound like a curse at all. In fact, it sounds like that which makes life worth living, especially if one is a science fiction writer!

#

The End

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NOVELS

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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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14. The Art of Writing, Volume II - US$10.00

This collection covers the Art of Writing articles published during 1998. The book is 62,000 words in length and builds on the foundation of knowledge provided by Volume I of this popular series.

15. The Art of Science Fiction, Volume I - US$10.00

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This collection covers the *Art of Science Fiction* articles published during 1998. The book is 67,000 words in length and builds on the foundation of knowledge provided by Volume I of this popular series.

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.

