# The Unknown Universe

By

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## Preface

Once upon a time there were no laws of gravity, and people invented everything from intricate mechanical wheels to Gods to explain their universe. Once upon a time there were no laws of electricity, and magnetism was a Delphic force as mysterious as the center of the sun. Once upon a time there were no nuclear forces, and quaint models of plum pudding with raisons gave our best image of the atom. To the inquiring nature of humans, these mysteries served more as beacons to truth than shrouds of ignorance.  Careful observations follow theories that follow observation, and this wheel of enlightenment rolled out our modern world, as old conundrums fell to the blade of science. But now, with waning voids in our knowledge to buoy our curiosity, the lighthouse fades from view leaving behind a terrible refrain telling us science is dead. All the fundamental physics is known and, like a homeowner after the party, all that is left is to mop up a few crumbs, the few remaining enigmas.

I, however, do not accept this for a moment. In fact, I take just the opposite view: We know so little about our universe we barely have enough knowledge to ask the right questions, we barely have the steal to scratch the surface.

Plato convinced me easily enough: To cave dwellers seeing only shadows, it is next to impossible to deduce the true nature of the world. When you consider the vast universe, from the incomprehensible size to the inconceivably tiny world inside a nucleus, we see only shadows of shadows. How dare anyone say we know everything?

Modern science began less than five centuries ago. Since the sun will burn out in five billion years, we have 50 million more centuries to go. We have been working at science for one ten millionth of our allotted time, and somebody thinks we know it all? What chutzpah. It is like students quitting after the first four seconds of kindergarten.

However, there are pressing problems we cannot solve. Any one of these may trigger the earthquake that rocks our view of the world. The purpose of this book is to bring these issues from the scientific community to the world at large, and to impress on you how much we do not know.

## Other Titles

Dickens has always been one of my favorite writers, but when I saw the other 27 titles of David Copperfield, I began to realize how hard he worked. Since there is no handwritten manuscript for my opus, I thought I would include a few other titles for historical purposes.

1. Unknown Universe: Shadows of Shadows
2. Unknown Universe
3. What We do not Know
4. Today's Dark Age
5. Nature's Enigmas
6. The Puzzling World

7. Ten Problems that Shake the World

8. Nature's Best Kept Secrets

9. Something is Rotten in Denmark

10. The Beginning of Science

11. The Mysterious Universe

12. Incognitus Cosmographicum

13. We next come to the question of the universe, to which we do not have a satisfactory answer.

**Acknowledgement**

I would like to thank Nancy, Katherine, Jennifer, and Matthew, without whose infinite patience this book could not have been written.

# THE UNKNOWN UNIVERSE

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1. Cosmic Acceleration

I was raised knowing the universe is expanding, and cannot imagine the shock it must have been to the old-timers who had to change their view of the world from a static one to an ever-growing one. Now another shocker is smoldering, the universe is expanding faster than a California fire fueled by Santa Anna winds, and nobody knows why. Hmm.

2. Dark Matter

Imagine an intelligent race born and raised on an island with sand and palm trees, and ask them to describe the rest of the earth. Since we have seen only a small percentage of all of the kinds of matter in the universe, that is exactly what we are trying to do.

3. The Cosmic Ray Paradox.

Theory tells us that the energy of cosmic rays has an upper limit. Today we are measuring the energy of cosmic rays that far exceed this limit. Once again, the impossible is possible. Something is rotten in the State of Denmark.

4. Renormalization

What is infinity minus infinity? Mathematicians will frown on such a question, but in physics it is very often something small, but not zero. It mars the beauty of physics, but no one has obviated this procedure.

5. The Higgs Particle

The Nobel Laureate Leon Ledermen wrote a book, “The God Particle.” Since he was referring to the Higgs particle, I hope this tells you how important it is, even though it has never been observed and never measured.

6. Quantum Gravity

This is the hardest problem there is. What else can I say, except that no other problem has attracted so many great physicists and has remained unsolved.

7. Ashes to ashes: Things we know

In order to help us understand what we do not understand, this chapter is devoted to past riddles we have solved, or partially solved, including stars, binary stars, red giants, neutron stars, quasars, pulsars, blackholes, whiteholes, wormholes, and duds.

8. Strings

As far as we can tell, an electron is just a point. It is there and it is observed, but it has no size (which is the definition of a point). Try to imagine this (spend a few minutes--no cheating). Everything known about particle physics is based on point particles. Now try to imagine that a particle is really a string. This little modification can change our world more than the invention of the telescope.

9. Origin of the Universe

I think that one of the greatest accomplishments of physics is that, as difficult as it is, we can even think about this issue. In fact, it is so difficult, some people have stopped asking about it. But I would like to ask about it anyway.

10. Mysterinos.

This chapter is an odd-and-ends compilation. It describes things like gravitational waves, the mysterious force acting on Pioneer 10, the left-handed nature of the universe, and other pesky problems we are still wrestling with.

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## Chapter 1. *Darkness there, and nothing more*.

Poe's famous midnight thinker stared into the darkness seeing nothing, nothing except for what his imagination allowed. Now we stare out into the darkness, using every machination of modern technology, but are still limited by our imagination. The telescope expands our view of the universe to an inconceivable size, and allows us to see into the cold blackness that stretches back to the beginning of time. Today, as we peer into the dawn of the universe, we are bringing back questions from the past like mysterious fossils etched in bedrock. Our most cherished notions about the nature of matter are challenged, and Einstein's famous theory of general relativity, the cornerstone of our understanding of gravity, is placed under the microscope of scrutiny.

These recent observations are not the first to rock our view of the cosmos, but unlike the previous explosive revelations, these remain unsolved. The ultimate solution may cause us to abandon our most esteemed model of the universe, or may prove the existence of a new kind of matter never seen before.

To appreciate the full impact, let's step back and soak up a little history. It is fun to ask the question, "Where on earth was helium discovered?" It is fun because the answer is nowhere, nowhere on earth, that is. Helium was discovered on the sun, even though we never landed there and never will. This is because elements are like hapless criminals, leaving their fingerprints on everything they touch. To understand the details we must take a detour through the fascinating world of spectroscopy.

Start with hydrogen, the simplest atom. If you fill a glass tube with hydrogen and force an electric current through it, the gas will radiate, producing a dull glow. This is precisely what happens in the garish neon signs, which give the familiar sanguine radiance hawking everything from Jello to Mr. Peanut.

*QUESTION Suppose we take this light, from hydrogen, and pass it through a prism.[1] What happens?* I will give you some answers, three of which are wrong, just to get the wheels rolling.

1. Nothing.
2. It is refracted (bent), but still looks bluish.
3. It explodes into the color of a rainbow (the same thing that would happen to sunlight).
4. Four distinct colors emerge, each one refracted by a different amount.

This experiment is repeated countless times every year in every college physics labs, but as the nineteenth century entered its retirement years, this conundrum had physicists questioning their most cherished notions. It was as shocking as waking up one morning to a green sky. When explanations were ultimately found, it was so hard on some physicists that they refused to accept the new ideas. In fact, this era gave birth to the famous quote, “Physics progresses gravestone by gravestone.”[2]

If you gave this question to the physicists back then, before they did the experiment, they would circle number three as their prediction. I hear them pontificating, as they stroke their beard,

“Sunlight breaks into the rainbow, and so does light from a hot iron poker, or light from a brilliant light bulb filament, and so would light from any other substance. Get with the program.”

Maybe the last sentence is a stretch, but the correct answer knocked their whiskers off. To put it in perspective, recall the lesson of Copernicus and Ptolemy. Old Claudius had us believing everything revolved around the earth. No one ever shook things up us as much as Nicolas, telling us we are spinning wildly on an axis. The Church tried the usual--burning people at the stake (Giordano Bruno was burned at the stake in Italy in 1600)--but even its fiery dogma of ignorance was broken down by truth and reality.

Copernicus created quite an upheaval, but it was nothing compared to the hydrogen issue. Luckily the church was unable to burn anybody this time, so the revolution went a little more quickly, stymied slightly by old physicists clinging to their lost reality (I sometimes worry I am clinging to a lost reality).

In the actual experiment, the light is passed through a thin slit in order to collimate the beam. For this reason the light that is observed appears as thin lines, exactly four thin lines. If you would like to see the real thing, stop off at the physics department of any

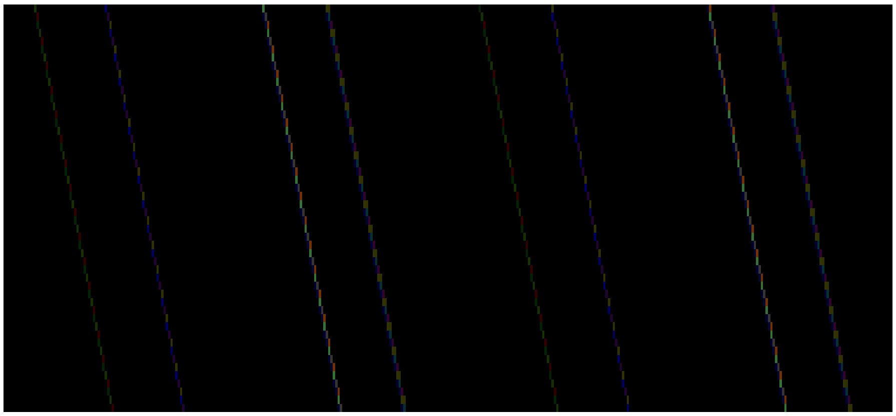

Figure 1.1. The four visible emission lines of hydrogen. The to the right is crimson, and the others are turquoise is blue and violet. Each line is a different wavelength of light.

university, they will be glad to show you. Just ask to see the spectrum of hydrogen from a gas discharge tube. Or, check out http://cfa- www.harvard.edu/seuforum/galSpeed/.

Figure 1.1 shows a picture I lifted from the internet.

So why did these thin little lines reduce the Copernican Revolution to just another day at the beaches? These lines, along with a few other experiments, gave birth to quantum mechanics, a view of nature that boggles the mind. While allowing us to understand our world, at the same time it severely limits our knowledge of the universe.

The essential point for now is that, according to quantum mechanics, energy is quantized. The hydrogen atom can absorb and emit light, but only by undergoing transitions through a discrete number of energy levels. It is like sitting in an airplane. You can move up or back, but you must take a seat, so your net displacement is quantized. In fact, I once interviewed a hydrogen atom who was kind enough to explain all this.[3] This quantization means that light can only be emitted at certain, discrete wavelengths, which you saw in Figure 1.1 These wavelengths are different for each atom. For example the spectrum of helium consists of more than four lines and looks nothing like Figure 1.1.

We are making good progress. Now you can understand how helium was discovered on the sun, the spectrum was observed, but that is still not my main point. My main point is this, elements can be discovered by observing the spectra of their light, and the spectra are unique.

While physicists have continually brought us to ever smaller scales, down to protons and neutrons, and now even smaller--to the quarks that are the building blocks of these teeny particles, astronomers have been making our universe larger and larger. The first modern explosion came with the discovery of an island universe, which I saw one night in

Massachusetts. I was riding back from a lecture given by John Wheeler, one of Einstein's most famous students. I was studying generalizations of Einstein's theory and was very grateful to the encouragement Wheeler gave me. He spoke at Mt. Holyoke College and we were driving back to RPI, where I was a graduate student. We stopped somewhere on a peak in the Berkshires (there are no rest rooms nearby), and Frank Ferrandino, an astrophysics student, was looking up as we were looking down. He was pointing out the constellations, and showed us how to find Andromeda, which we saw with our naked eyes. You have to know just where to look, and it is faint, but you can tell it is not quite a point like the other stars.

Even with a telescope it is nebulous, a fact good enough to justify one of the early names, nebula. Then came the Great Debate. Two astronomers duked it out: In one corner was Harlow Shapley, saying our Milky Way was the whole enchilada, while Heber Curtis was saying it was time to think outside the box. I am taking a little poetic license, the actual debate, in 1920, took place at the Smithsonian Museum of Natural History, but the idea of another galaxy was tough to swallow back then. Copernicus was hard enough, now this? Years gave Curtis the victory (see Technical Note at chapter's end about Cepheid variables), and nowadays we know there are many billions of galaxies, and galaxies like our beloved Milky Way are more common than candy bars on Halloween. Another name for these blurry spots, as others came to found, was island universe, my favorite, but this moniker was also doomed.

This little outing in the Berkshires was quite a moment for me, seeing another galaxy for the first time, but it was broken by an angry motorist, honking his horn to assuage his annoyance. As he passed, the pitch lowered--an effect heard all the time-- but being physicists (or back then, physicist wannabes) we plunged into a discussion of the Doppler effect. This includes the mathematical formulas that describe the lowering of pitch, or increase in wavelength, as the source moves away from us.

By the way, and back to galaxies, this brings up another question:

***Question*** *How do you find out what these mysterious clouds of light are made of?*

1. Send out a probe, collect some stuff, and bring it back to earth to analyze.
2. Ask an astrologer.
3. Send out a manned probe, after we settle on Mars.
4. Examine the spectra.

Number one would take hundreds of millions of years, if we could do it. I will not even address number two, and number three is another dig. Anyway, I know you got the right answer, and astronomers wasted no time doing just that, examining the spectra. They did it for every galaxy they found, and just as one blazing enigma yielded to explanation, more provocative ones ignited in their place.

Figure 1.3 Vesto Melvin Slipher

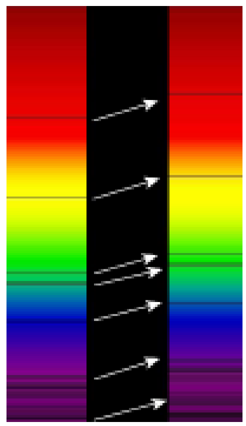

Figure 1.4  The (absorption) line are shifted to the red due to the recessional velocity.

Vesto Melvin Slipher is a name you do not hear every day. I grabbed his mug from the internet since it is also a face you do not see every day. He was born in Indiana, studied at the University of Indiana, and became famous during the second decade of the twentieth century. Well, not that famous, but in my book he should be. He was studying the spectra of light from distant galaxies and found something curious. The spectra looked like known elements, but the lines were a little off. Look at the hydrogen spectrum again. The red line corresponds to a wavelength of precisely 656 nanometers (a billion nanometers is a meter). Slipher saw a wavelength just slightly bigger than 656nm. The other lines were shifted in the same manner, each to a longer wavelenth. Figure 1.4 shows another example of a spectrum that is shifted. Note that the lines are dark, which means we are looking at an absorption spectrum (see Technical Note at end of chapter). The lines on the right are moved up towards the red, so we call this red-shifted. Sometimes we find them blue shifted, but this is the editorial we since I am a theoretical physicist and spend very little time behind the wheel.

Something as extraordinary as this calls for a question, so here it is.

*Question: What causes the spectrum to be redshifted?*

1. Dirt on the telescope lens.
2. A mischievous God, like Zeus throwing lightning bolts.
3. The ozone.
4. The galaxies are really moving away from us.
5. Light gets tired, traveling zillions of miles and all.

When I taught astronomy, I usually gave easy tests, but every once in a while a few students were determined to undermine my facile approach. Refusing to come to class they found trouble in the simplest questions, but often relied on ozone as the panacea to all issues. I do not know why this is, but that is why I included it, and yes, it is the wrong answer. Number two could be argued, but let's try science instead. This question shows how devious I can be--I already gave you the answer! Remember the angry motorist in the Berkshires? The pitch is lowered, or the wavelength of sound is increased, since he is moving away from us. It is called the Doppler effect and holds for light as well as sound. Once again, number 4 is the correct answer.

Since nothing exists in isolation except isolation itself, I must bring in another thread of the fabric of revolution--Mercury. I am not speaking about the speedy messenger long before FedEx, I am referring to the speedy planet, zooming around the sun once every 88 days. Too small to have an atmosphere, its ravaged surface exposes the callous ferocity of our solar system, but I wander. I want to mention its orbit, which is elliptical. The point of its orbit closest to the sun is called the perihelion. One of the greatest triumphs of the human genius was Newton. Old Isaac unraveled nature's secrets, and discovered the universal law of gravitation and the equation of motion. Applying his laws to the solar system, he proved that Mercury, as all planets, speeds around the sun in an elliptical orbit (nowadays, physics majors derive this in their sophomore or junior year). The theory also predicts that the perihelion is fixed in space and time.

All this amazing theory, corroborated by observations as plentiful as dandelions in my backyard, made many people very happy. But happiness, like a rainbow, never lasts, and soon Mercury proved to be a pesky problem. If I were writing this book in 1910, I would definitely include pesky Mercury as a chapter. The perihelion of Mercury moves. It precesses around the sun 1,043 seconds of arc every century.

It was not too hard to realize that the other planets whirling around the sun produce a modest tug on Mercury. In fact, calculations show that this effect will produce a precession of the perihelion of 1,000 seconds of an arc per century--1,000 seconds, but no more.

You see the quandary of the old-timers--how on earth to account for those 43 seconds, but this was not the first time astronomers were left in the dark. Years earlier Uranus was known to be an outlaw, breaking the gravitational law of Newton. Times like these are quite fertile for theoreticians like me. We unleash our imagination, creating new theories and models from thin air, hoping we shed some light on nature's secrets. It was the same back then, and Newton's law of gravitation was quickly put on trial. George Airy, British astronomer and mathematician with more medals than a four star general, theorized that Newton's inverse square law did not hold at large distances. After all, just because a theory works on one scale does not mean it applies to all. In fact, when applied to the tiny atomic world, Newton's laws crash and burn like the Tunguska comet (see Technical Notes at this chapter's end). But there was another explanation of the errant behavior of Uranus: Perhaps there is something else out there yanking the great mass off course. Taking this idea and running with it, Urbain Jean Joseph Le Verrier (born in 1811 in Saint-Lô, France) and John Cough Adams (born in 1819 in Lidcott, England) actually used Newton's laws to determine where such a planet could be.

Armed with hard calculations, William and sister Caroline Herschel swung their telescope where the theoreticians predicted, and before another perplexing mystery could pop up, it was found. The discovery of Georgium Sidus was made. What, you never heard of it? That's because no one could stand Herschel's putative name (except maybe King George), so Neptune took over following the rule that no planet is allowed two words. The discovery is a fascinating story,[4] but I must get on with my own little story. Also, I am not sure how much Caroline had to do with it, but she gave up her professional music career to work  with brother Bill to grind lenses and work on the astronomy, so I include her as well.

Figure 1.5 Caroline Herschel, sister of William (courtesy, NASA).

Back to Mercury and its errant orbit. What could be a more natural explanation than the existence of another planet. It would be so close to the sun that it would be very hard to see, which explains why we had not. Our friend Urbain Jean Joseph had such good luck in predicting Neptune, it prompted him to work diligently on the Mercury issue, pondering the 43 seconds. Urbain was a terrific mathematician and he was able to calculate that a planet 13 million miles from the sun (the earth is 93 million) that streaks around once every 20 days would do the trick. That same year, 1859, a French country doctor Lescarbault, who had a modest telescope, saw the planet. By now it was clear that it needed a name. Le Verrier knew the fate of Georgium Sidus and stuck to the rules, one word. He came up with Vulcan and by 1860 awards were flying faster than the new planet, and soon other sightings were published.

You did not know this? Let me pose a question.

*QUESTION:* Why is *Vulcan, the planet closest to the sun, unknown today?*

1. It is too small to be considered a bona fide planet.
2. Le Verrerier needed cash, and created a hoax.
3. It is classified top secret by the Air Force, who know all about it as well as the little Vulcans that landed in Roswell.
4. They were seeing things.

The definitive answer did not come along until the next century,[5] so let us go to the first decades of the twentieth century when two more famous names arise: Einstein and Hubble. Everyone knows about Albert, and most people know about Edwin too, since the orbiting telescope is named in his honor. These guys were very active during this period, and Albert came up with the General Theory of Relativity in 1915. This theory is a theory of gravity that turns out to be better than Isaac's, and more accurate too. In fact, it predicts that the perihelion of planetary orbits should precess, and it even predicts the amount of precession. Would you like to guess what it predicts for Mercury? Yup, 43 seconds of an arc per century, right on the nose. And that was the end of Vulcan, and no one has seen it since.

Albert's theory, GR, can not only be applied to planets, it can be used to model the entire universe in which we live. This is so cool I cannot understand why everybody does not become a physicist, but experience shows me they do not, so I will go on. During the mid 1920s it was shown that GR can describe a universe that is expanding or contracting (but not static). At the same time, Hubble was thinking about Vesto's redshifts. Actually, Edwin was doing a lot more than thinking. Working at Mount Wilson Observatory, he made measurements, collected data, and came across the most startling discovery of the century (actually, there are a few most startling discoveries, but I take poetic license). Here is what he said,[6]

"The results establish a roughly linear relation between velocities and distances among nebulae for which velocities have been previously published, and the relation appears to dominate the distribution velocities."

I am no Hubble, but here is how I would say it,

"Cosmic secrets have been unearthed, shattering our view of the universe. Observations show the cosmos is exploding apart, as distant galaxies race away faster than a soccer mom in a van. Even more astounding, the further the galaxy, the faster it goes."

You get the idea. When I taught astronomy the students always liked this, so I'll give you the famous formula Hubble made up: $v = H \times d$, which states that the velocity of a galaxy is equal to a constant, $H$, times the distance $d$ (the distance of the galaxy from earth). In honor of Hubble we call $H$ Hubble's constant.

Now, finally, the title of this chapter begins to make sense. I am talking about the fact that our universe is expanding. Hubble's data were so convincing, and fit so well with mathematical solutions of Einstein's equation, it did not take long for this to be accepted as gospel. The universe is expanding because Einstein's equations say it must (Einstein's equation also say it may contract, but Hubble showed us it is expanding). By the way, this holds for distant galaxies. Galaxies that are nearby, like Andromeda, actually move toward us due to the gravitational attraction.

As years went by, more and more galaxies succumbed to Hubble's law. The field of cosmology might have gotten as dull as my hoe, but eventually outlaws emerged. Distant galaxies, lurking on the edge of our visible universe, are caught by astronomers loping away from us. Like criminals beyond the reach of justice, they are not going as fast as expected.

I am sure you would not want me to gloss over the controversy that arose some years ago, so I will not. Until Hubble, every one had a firm belief that the universe was a fixed, static thing, allowing motions within, such as planets buzzing around stars, or stars zooming around other stars. This is the household view, where you and the pooch can roam around, but the structure is firm.

Even Albert had trouble letting go. He had the temerity to apply his equations to the cosmos, providing a mathematical model of the universe itself. But the equations did not work! I remember vividly going through this exercise as a graduate student: Where one equation gives the density of matter in the universe, another says the density is zero, clearly wrong since we see matter all over. Bummer. In order to obtain a sensible solution, Einstein changed his equations by introducing a cosmological constant. Solutions were found and he was happy. Briefly.

Why briefly? This was before Hubble's explosive revelation, and Albert assumed the universe was static. What Einstein missed was this: His equations were telling him the universe was not static. Einstein did not hear their plaintive wail, but others did. By assuming the universe can expand (or contract), the equations of general relativity give a beautiful solution without the cosmological constant. These solutions, with Hubble's observations, put the kibosh on Einstein's static universe and his cosmological constant. What did Albert say about all this? He said the cosmological constant was the biggest blunder of his life. Perhaps he gave up on his pet term a little too easily, you can decide later.

But if the universe is expanding, then what was it like before? A million years ago it would have been smaller than it is now, and two million years ago even smaller, and so on, until, at one time, it was no bigger than the period at the end of this sentence. And before that even smaller.

This was too hard too take, for some. Astronomer Fred Hoyle, and others, promulgated the steady state theory. On the large--very large--scale, the universe seems to be homogeneous, the same here as there. Suppose we take this symmetry further, and assume the universe is the same now as it always was, on average. How can this be if the universe is expanding? The answer is that matter is being created continuously. Since the universe is so big, do not worry about going into your basement one morning and seeing a new pile of matter. In order to account for the universe as we now see it, you would have to wait centuries and centuries just to see a new electron, which you probably would not notice anyway.

And so it came to pass that there were two camps, the expanding universe groupies and the steady state cosmology fans. How do good scientists convince everybody they are right? Cast the other view in the pejorative. And so it came to pass that the steady state advocates made fun of the other side, smirking that the universe began from a big bang. And so it came to pass this tactic backfired and subsequent measurements prove we live in an expanding universe. And so it came to pass we had the big bang, and the name was good.

Cosmology was settled and that is that. Or, that was that. Like theoreticians like me who never stop theorizing, observers never stop observing. In 1998 a paper was published that rocked the world. It is the subject of this chapter and according to some, represents today's biggest problem. What in the world happened?