CHAPTER 7

Our Miserable Future

The future ain't what it used to be.

—Yogi Berra

In one sense it is both remarkable and exciting to find ourselves in a universe dominated by nothing. The structures we can see, like stars and galaxies, were all created by quantum fluctuations from nothing. And the average total Newtonian gravitational energy of each object in our universe is equal to nothing. Enjoy the thought while you can, if you are so inclined, because, if all this is true, we live in perhaps the worst of all universes one can live in, at least as far as the future of life is concerned.

Remember that barely a century ago, Einstein was first developing his general theory of relativity. Conventional wisdom then held that our universe was static and eternal. In fact, Einstein not only ridiculed Lemaître for suggesting a Big Bang, but also invented the cosmological constant for the purpose of allowing a static universe.

Now, a century later we scientists can feel smug for having discovered the underlying expansion of the universe, the cosmic microwave background, dark matter, and dark energy.

But what will the future bring?

Poetry . . . of a sort.

Recall that the domination of the expansion of our universe by the energy of seemingly empty space was inferred from the fact that this expansion is speeding up. And, just as with inflation, as described in the last chapter, our observable universe is at the threshold of expanding faster than the speed of light. And with time, because of the accelerated expansion, things will only get worse.

This means that, the longer we wait, the less we will be able to see. Galaxies that we can now see will one day in the future be receding away from us at faster-than-light speed, which means that they will become invisible to us. The light they emit will not be able to make progress against the expansion of space, and it will never again reach us. These galaxies will have disappeared from our horizon.

The way this works is a little different than you might imagine. The galaxies do not suddenly disappear or twinkle out of existence in the night sky. Rather, as their recession speed approaches the speed of light, the light from these objects gets ever more redshifted. Eventually, all their visible light moves to infrared, microwave, radio wave, and so on, until the wavelength of light they emit ends up becoming larger than the size of the visible universe, at which point they become officially invisible.

We can calculate about how long this will take. Since the galaxies in our local cluster of galaxies are all bound together by their mutual gravitational attraction, they will not recede with the background expansion of the universe discovered by Hubble. Galaxies just outside our group are about 1/5000th the distance out to the point where the recession velocity of objects approaches the speed of light. It will take them about 150 billion years, about 10 times the current age of the universe, to get there, at which point all the light from the stars within the galaxies will have redshifted by a factor of about 5,000. By about 2 trillion years, their light will have redshifted by an amount that will make their wavelength equal to the size of the visible universe, and the rest of the universe will literally have disappeared.

Two trillion years may seem like a long time, and it is. In a cosmic sense, however, it is nowhere near an eternity. The longest-lived "main sequence" stars (which have the same evolutionary history as our Sun) have lifetimes far longer than our Sun and will still be shining in 2 trillion years (even as our own Sun dies out in about only 5 billion years). And so in the far future there may be civilizations on planets around those stars, powered by solar power, with water and organic materials. And there may be astronomers with telescopes on those planets. But when they look out at the cosmos, essentially everything we can now see, all 400 billion galaxies currently inhabiting our visible universe, will have disappeared!

I have tried to use this argument with Congress to urge the funding of cosmology now, while we still have time to observe all that we can! For a congressperson, however, two years is a long time. Two trillion is unthinkable.

In any case, those astronomers in the far future would be in for a big surprise, if they had any idea what they were missing, which they won't. Because not only will the rest of the universe have disappeared, as my colleague Robert Scherrer of Vanderbilt and I recognized a few years ago, but essentially all of the evidence that now tells us we live in an expanding universe that began in a Big Bang will also have disappeared, along with all evidence of the existence of the dark energy in empty space that will be responsible for this disappearance.

While less than a century ago conventional wisdom still held that the universe was static and eternal, with stars and planets coming and going, but on its largest scales the universe itself perduring, in the far future, long after any remnants of our planet and civilization have likely receded into the dustbin of history, the illusion that sustained our civilization until 1930 will be an illusion that will once again return, with a vengeance.

There are three main observational pillars that have led to the empirical validation of the Big Bang, so that, even if Einstein and Lemaître had never lived, the recognition that the universe began in a hot, dense state would have been forced upon us: the observed Hubble expansion; the observation of the cosmic microwave background; and the observed agreement between the abundance of light elements—hydrogen, helium, and lithium—we have measured in the universe with the amounts predicted to have been produced during the first few minutes in the history of the universe.

Let's begin with the Hubble expansion. How do we know the universe is expanding? We measure the recession velocity of distant objects as a function of their distance. However, once all visible objects outside of our local cluster (in which we are gravitationally bound) have disappeared from our horizon, there will no longer be any tracers of the expansion—no stars, galaxies, quasars, or even large gas clouds—that observers could track. The expansion will be so efficient that it will have removed all objects from our sight that are actually receding from us.

Moreover, on a timescale of less than a trillion years or so, all the galaxies in our local group will have coalesced into some large meta-galaxy. Observers in the far future will see more or less precisely what observers in 1915 thought they saw: a single galaxy housing their star and their planet, surrounded by an otherwise vast, empty, static space.

Recall also that all evidence that empty space has energy comes from observing the rate of speed-up of our expanding universe. But, once again, without tracers of the expansion, the acceleration of our expanding universe will be unobservable. Indeed, in a strange coincidence, we are living in the only era in the history of the universe when the presence of the dark energy permeating empty space is likely to be detectable. It is true that this era is several hundred billion years long, but in an eternally expanding universe it represents the mere blink of a cosmic eye.

If we assume that the energy of empty space is roughly constant, as would be the case for a cosmological constant, then in much earlier times the energy density of matter and radiation would have far exceeded that in empty space. This is simply because, as the universe expands, the density of matter and radiation decreases along with the expansion because the distance between particles grows, so there are fewer objects in each volume. At earlier times, say earlier than about 5 billion to 10 billion years ago, the density of matter and radiation would have been far greater than it is today. The universe at this time and earlier was therefore dominated by matter and radiation, with their consequent gravitational attraction. In this case, the expansion of the universe would have been slowing down at these early times, and the gravitational impact of the energy of empty space would have been unobservable.

By the same token, far in the future, when the universe is several hundred billion years old, the density of matter and radiation will have decreased even further, and one can calculate that dark energy will have a mean energy density far in excess of a thousand billion times greater than the density of all remaining matter and radiation in the universe. It will, by then, completely govern the gravitational dynamics of the universe on large scales. However, at that late age, the accelerating expansion will have become essentially unobservable. In this sense, the energy of empty space ensures, by its very nature, that there is a finite time during which it is observable, and, remarkably, we live during this cosmological instant.

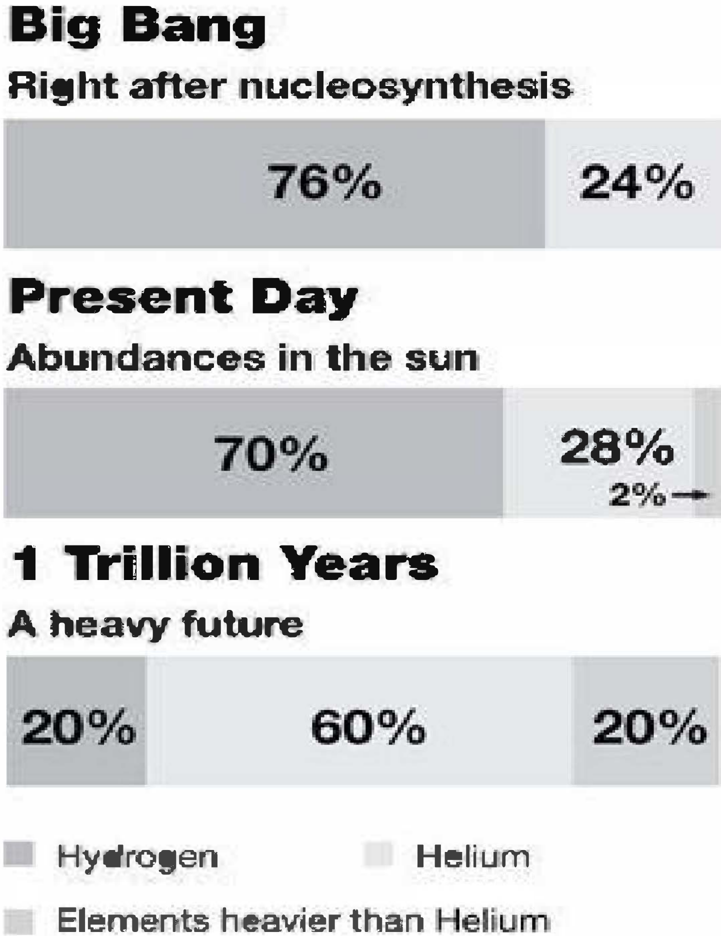
What about the other major pillar of the Big Bang, the cosmic microwave background radiation, which provides a direct baby picture of the universe? First, as the universe expands ever faster in the future, the temperature of the CMBR will fall. When the presently observable universe is about 100 times larger than it is now, the temperature of the CMBR will have fallen by a factor of 100, and its intensity, or the energy density stored within it, will have fallen by a factor of 100 million, making it about 100 million times harder to detect than it currently is.

But, after all, we have been able to detect the cosmic microwave background amidst all the other electronic noise on Earth, and we can imagine that observers in the far future will be 100 million times smarter than those we are blessed with today, so that all hope is not lost. Alas, it turns out that even the brightest observer one could imagine, with the most sensitive instrument one could build, will still be essentially out of luck in the distant future. This is because in our galaxy (or the meta-galaxy that will form when our galaxy merges with its neighbors, beginning with Andromeda in about 5 billion years) there is hot gas between stars, and this gas is ionized, so that it contains free electrons, and thus behaves like a plasma. As I described earlier, such a plasma is opaque to many types of radiation.

There is something called a “plasma frequency,” below which radiation cannot permeate a plasma without absorption. Based on the currently observed density of free electrons in our galaxy, we can estimate the plasma frequency in our galaxy, and if we do this, we find that the bulk of the CMB radiation from the Big Bang will be stretched, by the time the universe gets to be about 50 times its present age, to long enough wavelengths, and hence low enough frequencies, that it will be below our future (meta-) galaxy's plasma frequency at that time. After that, the radiation will essentially not be able to make it into our (meta-)galaxy to be observed, no matter how tenacious the observer. The CMBR, too, will have disappeared.

So no observed expansion, no leftover afterglow of the Big Bang. But what about the abundance of the light elements—hydrogen, helium, and lithium—which also provides a direct signature of the Big Bang?

Indeed, as I described in chapter 1, whenever I meet someone who doesn't believe in the Big Bang, I like to show them the following figure that I keep as a card in my wallet. I then say: "See! There was a Big Bang!"



This figure looks very complicated, I know, but it actually shows the relative predicted abundance of helium, deuterium, helium-3, and lithium, compared to hydrogen, based on our current understanding of the Big Bang. The upper curve, going up and to the right, displays the predicted abundance of helium, the second most abundant element in the universe, by weight, compared with hydrogen (the most abundant element). The next two curves, going down and to the right represent the predicted abundances of deuterium and helium-3, respectively, not by weight but by number of atoms compared to hydrogen. Finally, the lower curve represents the predicted abundance of the next lightest element, lithium, again by number.

The predicted abundances are plotted as functions of the assumed total density of normal matter (made of atoms) in the universe today. If varying this quantity produced no combination of all the predicted elemental abundances that fit with our observations, it would be strong evidence against their production in a hot Big Bang. Note that the predicted abundances of these elements vary by almost 10 orders of magnitude.

The unshaded boxes associated with each curve represent the allowed range of the actual estimated primordial abundance of these elements based on observations of old stars and hot gas in and outside of our galaxy

The vertical shaded band then represents that region where all the predictions and observations *do* agree. It is hard to imagine more concrete support than this agreement between predictions and observations, again for elements whose predicted abundances vary by 10 orders of magnitude, for an early, hot Big Bang where all the light elements were first produced.

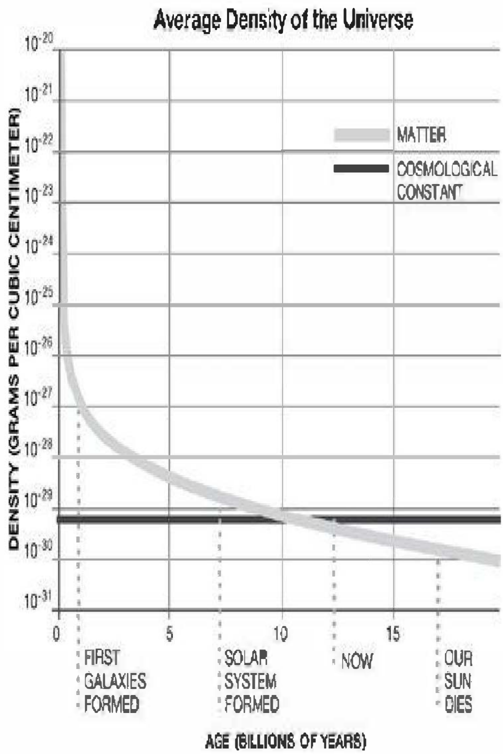
It is worth repeating the implications of this remarkable agreement more forcefully: Only in the first seconds of a hot Big Bang, with an initial abundance of protons and neutrons that would result in something very close to the observed density of matter in visible galaxies today, and a density of radiation that would leave a remnant that would correspond precisely to the observed intensity of the cosmic microwave background radiation today, would nuclear reactions occur that could produce precisely the abundance of light elements, hydrogen and deuterium, helium and lithium, that we infer to have comprised the basic building blocks of the stars that now fill the night sky.

As Einstein might have put it, only a very malicious (and, therefore, in his mind unimaginable) God would have conspired to have created a universe that so unambiguously points to a Big Bang origin without its having occurred.

Indeed, when the rough agreement between the inferred helium abundance in the universe with the predicted helium abundance arising from a Big Bang was first demonstrated in the 1960s, this was one of the key bits of data that helped the Big Bang picture win out over the then very popular steady-state model of the universe championed by Fred Hoyle and his colleagues.

In the far future, however, things will be quite different. Stars burn hydrogen, producing helium, for example. At the present time only about 15 percent or so of all the observed helium in the universe could have been produced by stars in the time since the Big Bang—once again, a compelling bit of evidence that a Big Bang was required to produce what we see. But in the far future this will not be the case, because many more generations of stars will have lived and died.

When the universe is a trillion years old, for example, far more helium will have been produced in stars than will have been produced in the Big Bang itself. This situation is displayed in the following chart:



When 60 percent of the visible matter in the universe is comprised of helium, there will be no necessity for production of primordial helium in a hot Big Bang in order to produce agreement with observations.

Observers and theorists in some civilization in the far future will, however, be able to use this data to infer that the universe must have had a finite age. Because stars burn hydrogen to helium, there will be an upper limit on how long stars could have existed in order not to further deplete the ratio between hydrogen and helium. Thus, future scientists will estimate that the universe in which they live is less than about a trillion years old. But any direct signature that the beginning involved a Big Bang, rather than some other kind of spontaneous creation of our future single (meta-)galaxy, will be lacking.

Remember that Lemaître derived his claim of a Big Bang purely on the basis of thinking about Einstein's general relativity. We can assume that any advanced civilization in the far future will discover the laws of physics, electromagnetism, quantum mechanics, and general relativity. Will some Lemaître of the far future therefore be able to derive a similar claim?

Lemaître's conclusion that our universe had to begin in a Big Bang was unavoidable, but it was based on an assumption that will not be true for the observable universe of the far future. A universe with matter stretching out uniformly in all directions, one that is isotropic and homogenous, cannot be static, for the reasons Lemaître and eventually Einstein recognized. However, there is a perfectly good solution of Einstein's equations for a single massive system surrounded by an otherwise empty static space. After all, if such a solution did not exist, then general relativity would not be able to describe isolated objects like neutron stars or, ultimately, black holes.

Large mass distributions like our galaxy are unstable, so eventually our (meta-)galaxy will itself collapse to form a massive black hole. This is described by a static solution of Einstein's equation called the Schwarzschild solution. But the time frame for our galaxy to collapse to form a massive black hole is much longer than the time frame for the rest of the universe to disappear. Thus, it will seem natural for scientists of the future to imagine that our galaxy could have existed for a trillion years in empty space without significant collapse and without requiring an expanding universe surrounding it.

Of course, speculations about the future are notoriously difficult. I am writing this, in fact, while at the World Economic Forum in Davos, Switzerland, which is full of economists who invariably predict the behavior of future markets and revise their predictions when they turn out to be horribly wrong. More generally, I find any predictions of the far future, and even the not-so-far future, of science and technology to be even sketchier than those of “the dismal science.” Indeed, whenever I’m asked about the near future of science or what the next big breakthrough will be, I always respond that if I knew, I would be working on it right now!

Thus, I like to think of the picture I have presented in this chapter as something like the picture of the future presented by the third ghost in Dickens’s *A Christmas Carol*. This is the future as it *might be*. After all, since we have no idea what the dark energy permeating empty space is, we also therefore cannot be certain that it will behave like Einstein’s cosmological constant and remain constant. If it doesn’t, the future of the universe could be far different. The expansion may not continue to accelerate, but instead may once again slow down over time so that distant galaxies will not disappear. Alternatively, perhaps there will be some new observable quantities we cannot yet detect that may provide astronomers in the future with evidence that there was once a Big Bang.

Nevertheless, based on everything we know about the universe today, the future I have sketched out is the most plausible one, and it is fascinating to consider whether logic, reason, and empirical data might still somehow induce future scientists to infer the correct underlying nature of our universe, or whether it will forever remain obscured behind the horizon. Some brilliant future scientist exploring the fundamental nature of forces and particles might derive a theoretical picture that will suggest that inflation must have happened, or that there must be an energy in empty space, which would further explain why there are no galaxies within the visible horizon. But I am not so sanguine about this.

Physics is, after all, an empirical science, driven by experiment and observation. Had we not observationally inferred the existence of dark energy, I doubt any theorist would have been bold enough to suggest its existence today. And while it is also possible to imagine tentative signatures that might suggest something is wrong with the picture of a single galaxy in a static universe without a Big Bang—perhaps some observation of elemental abundances that appears anomalous—I suspect that Occam's razor will suggest that the simplest picture is the correct one, and that the anomalous observations might be explained by some local effects.

Ever since Bob Scherrer and I laid out the challenge that future scientists will use falsifiable data and models—the very paragon of good science—but in the process that they will come up with a false picture of the universe, many of our colleagues have tried to suggest ways to probe that the universe is actually expanding in the far future. I too can imagine possible experiments. But I cannot see that they would be well motivated.

For example, you would need to eject bright stars from our galaxy and send them off into space, wait a billion years or so for them to explode, and try to observe their recession velocities as a function of the distance they reach before they explode in order to probe to see if they are getting any extra kick from a possible expansion of space. A tall order, but even if you could imagine somehow pulling this off, I cannot see the National Science Foundation of the future actually funding the experiment without at least some other motivation for arguing on behalf of an expanding universe. And if somehow stars from our galaxy are naturally ejected and detectable as they move out toward the horizon, it is not clear to me that observing an anomalous acceleration of some of these objects would be interpreted in terms of such a bold and strange proposal as an expanding universe dominated by dark energy.

We can consider ourselves lucky that we live at the present time. Or as Bob and I put it in one of the articles we wrote: "We live at a very special time . . . the only time when we can observationally verify that we live at a very special time!"

We were being somewhat facetious, but it is sobering to suggest that one can use the best observational tools and theoretical tools at one's disposal and nevertheless come up with a completely false picture of the large-scale universe.

I should point out, nevertheless, that even though incomplete data *can* lead to a false picture, this is far different from the (false) picture obtained by those who choose to ignore empirical data to invent a picture of creation that would otherwise contradict the evidence of reality (young earthers, for example), or those who instead require the existence of something for which there is no observable evidence whatsoever (like divine intelligence) to reconcile their view of creation with their a priori prejudices, or worse still, those who cling to fairy tales about nature that presume the answers before questions can even be asked. At least the scientists of the future will be basing their estimates on the best evidence available to them, recognizing as we all do, or at least as scientists do, that new evidence may cause us to change our underlying picture of reality.

In this regard, it is worth adding that perhaps we are missing something even today that might have been observable had only we lived 10 billion years ago or perhaps could see if we lived 100 billion years into the future. Nevertheless, I should stress that the Big Bang picture is too firmly grounded in data from every area to be proved invalid in its general features. But some new, nuanced understanding of the fine details of the distant past or distant future, or of the origin of the Big Bang and its possible uniqueness in space, might easily emerge with new data. In fact, I hope it will. One lesson that we can draw from the possible future end of life and intelligence in the universe is that we need to have some cosmic humility in our claims, even if such a thing is difficult for cosmologists.

Either way, the scenario I have just described has a certain poetic symmetry, even if it is equally tragic. Long into the future, scientists will derive a picture of the universe that will hearken back to the very picture we had at the beginning of the last century, which itself ultimately served as the catalyst for investigations that led to the modern revolutions in cosmology. Cosmology will have come full circle. I for one find that remarkable, even if it underscores what some may view as the ultimate futility of our brief moment in the sun.

Regardless, the fundamental problem illustrated by the possible future end of cosmology is that we have only one universe to test—the one we live in. While test it we must if we want to have any hope of understanding how what we now observe arose, we nevertheless are limited in both what we can measure and in our interpretations of the data.

If many universes exist, and if we could somehow probe more than one, we might have a better chance of knowing which observations are truly significant and fundamental and which arise only as an accident of our circumstances.

As we shall see next, while the latter possibility is unlikely, the former is not, and scientists are pressing forward with new tests and new proposals to further our understanding of the unexpected and strange features of our universe.

Before proceeding, however, it is perhaps worth ending with another, more literary picture of the likely future I have presented here and one that is particularly relevant to the subject of this book. It comes from Christopher Hitchens's response to the scenario I have just described. As he put it, "For those who find it remarkable that we live in a universe of Something, just wait. Nothingness is heading on a collision course right toward us!"