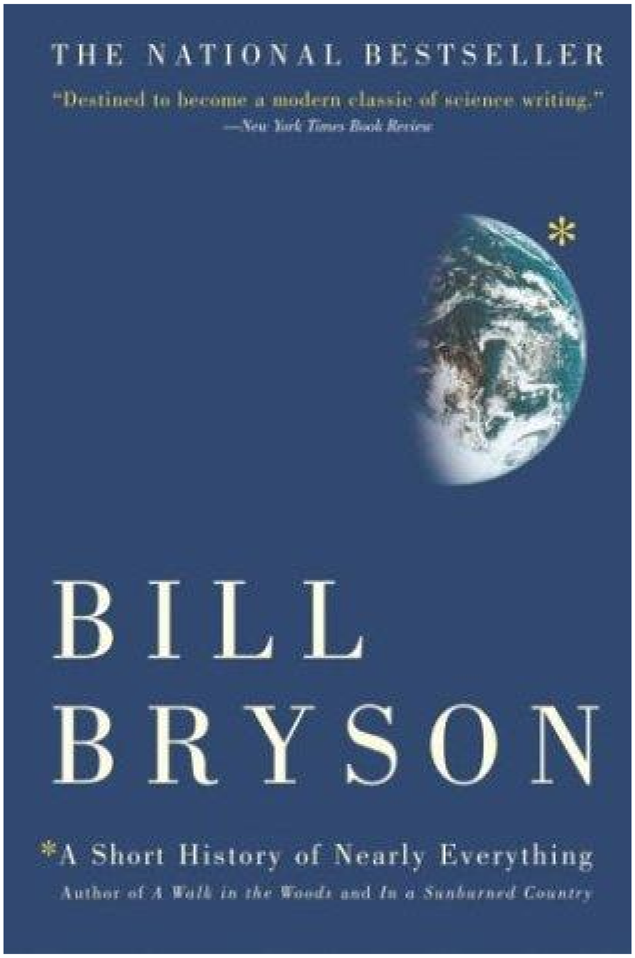

A Short History of Nearly

Everything

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by Bryson, Bill

The physicist Leo Szilard once announced to his friend Hans Bethe that he was thinking of keeping a diary: “I don’t intend to publish. I am merely going to record the facts for the information of God.”

“Don’t you think God knows the facts?” Bethe asked.

“Yes,” said Szilard.

“He knows the facts, but He does not know this version of the facts.”

-Hans Christian von Baeyer,

Taming the Atom

INTRODUCTION

Welcome. And congratulations. I am delighted that you could make it.

Getting here wasn’t easy, I know. In fact, I suspect it was a little tougher than you realize.

To begin with, for you to be here now trillions of drifting atoms had somehow to assemble in an intricate and intriguingly obliging manner to create you. It’s an arrangement so specialized and particular that it has never been tried before and will only exist this once. For the next many years (we hope) these tiny particles will uncomplainingly engage in all the billions of deft, cooperative efforts necessary to keep you intact and let you experience the supremely agreeable but generally underappreciated state known as existence.

Why atoms take this trouble is a bit of a puzzle. Being you is not a gratifying experience at the atomic level. For all their devoted attention, your atoms don’t actually care about you-indeed, don’t even know that you are there. They don’t even know thatthey are there. They are mindless particles, after all, and not even themselves alive. (It is a slightly arresting notion that if you were to pick yourself apart with tweezers, one atom at a time, you would produce a mound of fine atomic dust, none of which had ever been alive but all of which had once been you.) Yet somehow for the period of your existence they will answer to a single overarching impulse: to keep you you.

The bad news is that atoms are fickle and their time of devotion is fleeting-fleeting indeed. Even a long human life adds up to only about 650,000 hours. And when that modest milestone flashes past, or at some other point thereabouts, for reasons unknown your atoms will shut you down, silently disassemble, and go off to be other things. And that’s it for you.

Still, you may rejoice that it happens at all. Generally speaking in the universe it doesn’t, so far as we can tell. This is decidedly odd because the atoms that so liberally and congenially flock together to form living things on Earth are exactly the same atoms that decline to do it elsewhere.

Whatever else it may be, at the level of chemistry life is curiously mundane: carbon, hydrogen, oxygen, and nitrogen, a little calcium, a dash of sulfur, a light dusting of other very ordinary elements-nothing you wouldn’t find in any ordinary drugstore-and that’s all you need. The only thing special about the atoms that make you is that they make you. That is of course the miracle of life.

Whether or not atoms make life in other corners of the universe, they make plenty else; indeed, they make everything else. Without them there would be no water or air or rocks, no stars and planets, no distant gassy clouds or swirling nebulae or any of the other things that make the universe so usefully material. Atoms are so numerous and necessary that we easily overlook that they needn’t actually exist at all. There is no law that requires the universe to fill itself with small particles of matter or to produce light and gravity and the other physical properties on which our existence hinges.

There needn’t actually be a universe at all. For the longest time there wasn’t. There were no atoms and no universe for them to float about in.

There was nothing-nothing at all anywhere.

So thank goodness for atoms. But the fact that you have atoms and that they assemble in such a willing manner is only part of what got you here. To be here now, alive in the twenty-first century and smart enough to know it, you also had to be the beneficiary of an extraordinary string of biological good fortune. Survival on Earth is a surprisingly tricky business. Of the billions and billions of species of living thing that have existed since the dawn of time, most-99.99 percent-are no longer around. Life on Earth, you see, is not only brief but dismayingly tenuous. It is a curious feature of our existence that we come from a planet that is very good at promoting life but even better at extinguishing it.

The average species on Earth lasts for only about four million years, so if you wish to be around for billions of years, you must be as fickle as the atoms that made you. You must be prepared to change everything about yourself-shape, size, color, species affiliation, everything-and to do so repeatedly. That's much easier said than done, because the process of change is random. To get from "protoplasmal primordial atomic globule"

(as the Gilbert and Sullivan song put it) to sentient upright modern human has required you to mutate new traits over and over in a precisely timely manner for an exceedingly long while. So at various periods over the last 3.8 billion years you have abhorred oxygen and then doted on it, grown fins and limbs and jaunty sails, laid eggs, flicked the air with a forked tongue, been sleek, been furry, lived underground, lived in trees, been as big as a deer and as small as a mouse, and a million things more. The tiniest deviation from any of these evolutionary shifts, and you might now be licking algae from cave walls or lolling walrus-like on some stony shore or disgorging air through a blowhole in the top of your head before diving sixty feet for a mouthful of delicious sandworms.

Not only have you been lucky enough to be attached since time immemorial to a favored evolutionary line, but you have also been extremely-make that miraculously-fortunate in your personal ancestry. Consider the fact that for

3.8 billion years, a period of time older than the Earth's mountains and rivers and oceans, every one of your forebears on both sides has been attractive enough to find a mate, healthy enough to reproduce, and sufficiently blessed by fate and circumstances to live long enough to do so.

Not one of your pertinent ancestors was squashed, devoured, drowned, starved, stranded, stuck fast, untimely wounded, or otherwise deflected from its life's quest of delivering a tiny charge of genetic material to the right partner at the right moment in order to perpetuate the only possible sequence of hereditary combinations that could result-eventually, astoundingly, and all too briefly-in you.

This is a book about how it happened-in particular how we went from there being nothing at all to there being something, and then how a little of that something turned into us, and also some of what happened in between and since. That's a great deal to cover, of course, which is why the book is calledA Short History of Nearly Everything , even though it isn't really. It couldn't be. But with luck by the time we finish it will feel as if it is.

My own starting point, for what it's worth, was an illustrated science book that I had as a classroom text when I was in fourth or fifth grade. The book was a standard-issue 1950s schoolbookbattered, unloved, grimly hefty-but near the front it had an illustration that just captivated me: a cutaway diagram showing the Earth's interior as it would look if you cut into the planet with a large knife and carefully withdrew a wedge representing about a quarter of its bulk.

It's hard to believe that there was ever a time when I had not seen such an illustration before, but evidently I had not for I clearly remember being transfixed. I suspect, in honesty, my initial interest was based on a private image of streams of unsuspecting eastbound motorists in the American plains states plunging over the edge of a sudden 4,000-mile-high cliff running between Central America and the North Pole, but gradually my attention did turn in a more scholarly manner to the scientific import of the drawing and the realization that the Earth consisted of discrete layers, ending in the center with a glowing sphere of iron and nickel, which was as hot as the surface of the Sun, according to the caption, and I remember thinking with real wonder: "How do they know that?"

I didn't doubt the correctness of the information for an instant-I still tend to trust the pronouncements of scientists in the way I trust those of surgeons, plumbers, and other possessors of arcane and privileged information-but I couldn't for the life of me conceive how any human mind could work out what spaces thousands of miles below us, that no eye had ever seen and no X ray could penetrate, could look like and be made of. To me that was just a miracle. That has been my position with science ever since.

Excited, I took the book home that night and opened it before dinner-an action that I expect prompted my mother to feel my forehead and ask if I was all right-and, starting with the first page, I read.

And here's the thing. It wasn't exciting at all. It wasn't actually altogether comprehensible. Above all, it didn't answer any of the questions that the illustration stirred up in a normal inquiring mind: How did we end up with a Sun in the middle of our planet? And if it is burning away down there, why isn't the ground under our feet hot to the touch? And why isn't the rest of the interior melting-or is it? And when the core at last burns itself out, will some of the Earth slump into the void, leaving a giant sinkhole on the surface? And how do youknow this?How did you figure it out?

But the author was strangely silent on such details-indeed, silent on everything but anticlines, synclines, axial faults, and the like. It was as if he wanted to keep the good stuff secret by making all of it soberly unfathomable. As the years passed, I began to suspect that this was not altogether a private impulse. There seemed to be a mystifying universal conspiracy among textbook authors to make certain the material they dealt with never strayed too near the realm of the mildly interesting and was always at least a longdistance phone call from the frankly interesting.

I now know that there is a happy abundance of science writers who pen the most lucid and thrilling prose-Timothy Ferris, Richard Fortey, and Tim Flannery are three that jump out from a single station of the alphabet (and that's not even to mention the late but godlike Richard Feynman)-but sadly none of them wrote any textbook I ever used. All mine were written by men (it was always men) who held the interesting notion that everything became clear when expressed as a formula and the amusingly deluded belief that the children of America would appreciate having chapters end with a section of

questions they could mull over in their own time. So I grew up convinced that science was supremely dull, but suspecting that it needn't be, and not really thinking about it at all if I could help it. This, too, became my position for a long time.

Then much later-about four or five years ago-I was on a long flight across the Pacific, staring idly out the window at moonlit ocean, when it occurred to me with a certain uncomfortable forcefulness that I didn't know the first thing about the only planet I was ever going to live on. I had no idea, for example, why the oceans were salty but the Great Lakes weren't. Didn't have the faintest idea. I didn't know if the oceans were growing more salty with time or less, and whether ocean salinity levels was something I should be concerned about or not. (I am very pleased to tell you that until the late 1970s scientists didn't know the answers to these questions either. They just didn't talk about it very audibly.)

And ocean salinity of course represented only the merest sliver of my ignorance. I didn't know what a proton was, or a protein, didn't know a quark from a quasar, didn't understand how geologists could look at a layer of rock on a canyon wall and tell you how old it was, didn't know anything really. I became gripped by a quiet, unwonted urge to know a little about these matters and to understand how people figured them out. That to me remained the greatest of all amazements-how scientists work things out.

How does anybodyknow how much the Earth weighs or how old its rocks are or what really is way down there in the center? How can they know how and when the universe started and what it was like when it did? How do they know what goes on inside an atom? And how, come to that-or perhaps above all-can scientists so often seem to know nearly everything but then still can't predict an earthquake or even tell us whether we should take an umbrella with us to the races next Wednesday?

So I decided that I would devote a portion of my life-three years, as it now turns out-to reading books and journals and finding saintly, patient experts prepared to answer a lot of outstandingly dumb questions. The idea was to see if it isn't possible to understand and appreciate-marvel at, enjoy even-the wonder and accomplishments of science at a level that isn't too technical or demanding, but isn't entirely superficial either.

That was my idea and my hope, and that is what the book that follows is intended to be. Anyway, we have a great deal of ground to cover and much less than 650,000 hours in which to do it, so let's begin.

01 - How to Build a Universe

A Short History of Nearly

Everything

PART I LOST IN THE COSMOS

They re all in the same plane.

They re all going around in the

same direction. . . . It s perfect,

you know. It s gorgeous. It s

almost uncanny.

-Astronomer Geoffrey Marcy

describing the solar system

CHAPTER 1: HOW TO BUILD A UNIVERSE

NO MATTER HOW hard you try you will never be able to grasp just how tiny, how spatially unassuming, is a proton. It is just way too small.

A proton is an infinitesimal part of an atom, which is itself of course an insubstantial thing. Protons are so small that a little dib of ink like the dot on thisi can hold something in the region of 500,000,000,000 of them, rather more than the number of seconds contained in half a million years.

So protons are exceedingly microscopic, to say the very least.

Now imagine if you can (and of course you can t) shrinking one of those protons down to a billionth of its normal size into a space so small that it would make a proton look enormous. Now pack into that tiny, tiny space about an ounce of matter. Excellent. You are ready to start a universe.

I m assuming of course that you wish to build an inflationary universe. If you d prefer instead to build a more old-fashioned, standard Big Bang universe, you ll need additional materials. In fact, you will need to gather up everything there is every last mote and particle of matter between here and the edge of creation and squeeze it into a spot so infinitesimally compact that it has no dimensions at all. It is known as a singularity.

In either case, get ready for a really big bang. Naturally, you will wish to retire to a safe place to observe the spectacle. Unfortunately, there is nowhere to retire to because outside the singularity there is nowhere . When the universe begins to expand, it won t be spreading out to fill a larger emptiness. The only space that exists is the space it creates as it goes.

It is natural but wrong to visualize the singularity as a kind of pregnant dot hanging in a dark, boundless void. But there is no space, no darkness. The singularity has no around around it. There is no space for it to occupy, no place for it to be. We can t even ask how long it has been there whether it has just lately popped into being, like a good idea, or whether it has been there forever, quietly awaiting the right moment. Time doesn t exist. There is no past for it to emerge from.

And so, from nothing, our universe begins.

In a single blinding pulse, a moment of glory much too swift and expansive for any form of words, the singularity assumes heavenly dimensions, space beyond conception. In the first lively second (a second that many cosmologists will devote careers to shaving into ever-finer wafers) is produced gravity and the other forces that govern physics. In less than a minute the universe is a million billion miles across and growing fast. There is a lot of heat now, ten billion degrees of it, enough to begin the nuclear reactions that create the lighter elements principally hydrogen and helium, with a dash (about one atom in a hundred million) of lithium. In three minutes, 98 percent of all the matter there is or will ever be has been produced. We have a universe. It is a place of the most wondrous and gratifying possibility, and beautiful, too. And it was all done in about the time it takes to make a sandwich.

When this moment happened is a matter of some debate. Cosmologists have long argued over whether the moment of creation was 10 billion years ago or twice that or something in between. The consensus seems to be heading for a figure of about 13.7 billion years, but these things are notoriously difficult to measure, as we shall see further on. All that can really be said is that at some indeterminate point in the very distant past, for reasons unknown, there came the moment known to science ast = 0. We were on our way.

There is of course a great deal we don t know, and much of what we think we know we haven t known, or thought we ve known, for long. Even the notion of the Big Bang is quite a recent one. The idea had been kicking around since the 1920s, when Georges Lemaître, a Belgian priest-scholar, first tentatively proposed it, but it didn t really become an active notion in cosmology until the mid-1960s when two young radio astronomers made an extraordinary and inadvertent discovery.

Their names were Arno Penzias and Robert Wilson. In 1965, they were trying to make use of a large communications antenna owned by Bell Laboratories at Holmdel, New Jersey, but they were troubled by a persistent background noise a steady, steamy hiss that made any experimental work

impossible. The noise was unrelenting and unfocused. It came from every point in the sky, day and night, through every season. For a year the young astronomers did everything they could think of to track down and eliminate the noise. They tested every electrical system. They rebuilt instruments, checked circuits, wiggled wires, dusted plugs. They climbed into the dish and placed duct tape over every seam and rivet. They climbed back into the dish with brooms and scrubbing brushes and carefully swept it clean of what they referred to in a later paper as white dielectric material, or what is known more commonly as bird shit. Nothing they tried worked.

Unknown to them, just thirty miles away at Princeton University, a team of scientists led by Robert Dicke was working on how to find the very thing they were trying so diligently to get rid of. The Princeton researchers were pursuing an idea that had been suggested in the 1940s by the Russian-born astrophysicist George Gamow that if you looked deep enough into space you should find some cosmic background radiation left over from the Big Bang. Gamow calculated that by the time it crossed the vastness of the cosmos, the radiation would reach Earth in the form of microwaves. In a more recent paper he had even suggested an instrument that might do the job: the Bell antenna at Holmdel. Unfortunately, neither Penzias and Wilson, nor any of the Princeton team, had read Gamow s paper.

The noise that Penzias and Wilson were hearing was, of course, the noise that Gamow had postulated. They had found the edge of the universe, or at least the visible part of it, 90 billion trillion miles away. They were seeing the first photons the most ancient light in the universe though time and distance had converted them to microwaves, just as Gamow had predicted. In his bookThe Inflationary Universe , Alan Guth provides an analogy that helps to put this finding in perspective. If you think of peering into the depths of the universe as like looking down from the hundredth floor of the Empire State Building (with the hundredth floor representing now and street level representing the moment of the Big Bang), at the time of Wilson and Penzias s discovery the most distant galaxies anyone had ever detected were on about the sixtieth floor, and the most distant things quasars were on about the twentieth. Penzias and Wilson s finding pushed our acquaintance with the visible universe to within half an inch of the sidewalk.

Still unaware of what caused the noise, Wilson and Penzias phoned Dicke at Princeton and described their problem to him in the hope that he might suggest a solution. Dicke realized at once what the two young men had found. Well, boys, we ve just been scooped, he told his colleagues as he hung up the phone.

Soon afterward theAstrophysical Journal published two articles: one by Penzias and Wilson describing their experience with the hiss, the other by Dicke s team explaining its nature. Although Penzias and Wilson had not been looking for cosmic background radiation, didn t know what it was when they had found it, and hadn t described or interpreted its character in any paper, they received the 1978 Nobel Prize in physics. The Princeton researchers got only sympathy. According to Dennis Overbye inLonely

Hearts of the Cosmos , neither Penzias nor Wilson altogether understood the significance of what they had found until they read about it in theNew York Times .

Incidentally, disturbance from cosmic background radiation is something we have all experienced. Tune your television to any channel it doesn t receive, and about 1 percent of the dancing static you see is accounted for by this ancient remnant of the Big Bang. The next time you complain that there is nothing on, remember that you can always watch the birth of the universe.

Although everyone calls it the Big Bang, many books caution us not to think of it as an explosion in the conventional sense. It was, rather, a vast, sudden expansion on a whopping scale. So what caused it?

One notion is that perhaps the singularity was the relic of an earlier, collapsed universe that we re just one of an eternal cycle of expanding and collapsing universes, like the bladder on an oxygen machine. Others attribute the Big Bang to what they call a false vacuum or a scalar field or vacuum energy

some quality or thing, at any rate, that

introduced a measure of instability into the nothingness that was. It seems impossible that you could get something from nothing, but the fact that once there was nothing and now there is a universe is evident proof that you can. It may be that our universe is merely part of many larger universes,

some in different dimensions, and that Big Bangs are going on all the time all over the place. Or it may be that space and time had some other forms altogether before the Big Bang forms too alien for us to imagine and that the Big Bang represents some sort of transition phase, where the universe went from a form we can t understand to one we almost can. These are very close to religious questions, Dr. Andrei Linde, a cosmologist at Stanford, told theNew York Times in 2001.

The Big Bang theory isn t about the bang itself but about what happened after the bang. Not long after, mind you. By doing a lot of math and watching carefully what goes on in particle accelerators, scientists believe they can look back to 10-43seconds after the moment of creation, when the universe was still so small that you would have needed a microscope to find it. We mustn t swoon over every extraordinary number that comes before us, but it is perhaps worth latching on to one from time to time just to be reminded of their ungraspable and amazing breadth. Thus 10-43is 0.0000000000000000000000000000000000000000001, or one 10 million trillion trillion trillionths of a second.[*]

Most of what we know, or believe we know, about the early moments of the universe is thanks to an idea called inflation theory first propounded in 1979 by a junior particle physicist, then at Stanford, now at MIT, named Alan Guth. He was thirty-two years old and, by his own admission, had never done anything much before. He would probably never have had his great theory except that he happened to attend a lecture on the Big Bang given by none other than Robert Dicke. The lecture inspired Guth to take an interest in cosmology, and in particular in the birth of the universe.

The eventual result was the inflation theory, which holds that a fraction of a moment after the dawn of creation, the universe underwent a sudden dramatic expansion. It inflated in effect ran away with itself, doubling in size every 10-34seconds. The whole episode may have lasted no more than 10-30seconds that s one million million million million millionths of a second but it changed the universe from something you could hold in your hand to something at least 10,000,000,000,000,000,000,000,000 times bigger. Inflation theory explains the ripples and eddies that make our

universe possible. Without it, there would be no clumps of matter and thus no stars, just drifting gas and everlasting darkness.

According to Guth s theory, at one ten-millionth of a trillionth of a trillionth of a trillionth of a second, gravity emerged. After another ludicrously brief interval it was joined by electromagnetism and the strong and weak nuclear forces the stuff of physics. These were joined an instant later by swarms of elementary particles the stuff of stuff. From nothing at all, suddenly there were swarms of photons, protons, electrons, neutrons, and much else between 1079and 1089of each, according to the standard Big Bang theory.

Such quantities are of course ungraspable. It is enough to know that in a single cracking instant we were endowed with a universe that was vast at least a hundred billion light-years across, according to the theory, but possibly any size up to infinite and perfectly arrayed for the creation of stars, galaxies, and other complex systems.

What is extraordinary from our point of view is how well it turned out for us. If the universe had formed just a tiny bit differently if gravity were fractionally stronger or weaker, if the expansion had proceeded just a little more slowly or swiftly then there might never have been stable elements to make you and me and the ground we stand on. Had gravity been a trifle stronger, the universe itself might have collapsed like a badly erected tent, without precisely the right values to give it the right dimensions and density and component parts. Had it been weaker, however, nothing would have coalesced. The universe would have remained forever a dull, scattered void.

This is one reason that some experts believe there may have been many other big bangs, perhaps trillions and trillions of them, spread through the mighty span of eternity, and that the reason we exist in this particular one is that this is one wecould exist in. As Edward P. Tryon of Columbia University once put it: In answer to the question of why it happened, I offer the modest proposal that our Universe is simply one of those things which happen from time to time. To which adds Guth: Although the creation of a universe might be very unlikely, Tryon emphasized that no one had counted the failed attempts.

Martin Rees, Britain s astronomer royal, believes that there are many universes, possibly an infinite number, each with different attributes, in different combinations, and that we simply live in one that combines things in the way that allows us to exist. He makes an analogy with a very large clothing store: If there is a large stock of clothing, you re not surprised to find a suit that fits. If there are many universes, each governed by a differing set of numbers, there will be one where there is a particular set of numbers suitable to life. We are in that one.

Rees maintains that six numbers in particular govern our universe, and that if any of these values were changed even very slightly things could not be as they are. For example, for the universe to exist as it does requires that hydrogen be converted to helium in a precise but comparatively stately manner specifically, in a way that converts seven one-thousandths of its mass to energy. Lower that value very slightly from 0.007 percent to 0.006

percent, say and no transformation could take place: the universe would consist of hydrogen and nothing else. Raise the value very slightly to 0.008

percent and bonding would be so wildly prolific that the hydrogen would long since have been exhausted. In either case, with the slightest tweaking of the numbers the universe as we know and need it would not be here.

I should say that everything is just rightso far . In the long term, gravity may turn out to be a little too strong, and one day it may halt the expansion of the universe and bring it collapsing in upon itself, till it crushes itself down into another singularity, possibly to start the whole process over again. On the other hand it may be too weak and the universe will keep racing away forever until everything is so far apart that there is no chance of material interactions, so that the universe becomes a place that is inert and dead, but very roomy. The third option is that gravity is just right

critical density is the cosmologists term for it and that it will hold the universe together at just the right dimensions to allow things to go on indefinitely. Cosmologists in their lighter moments sometimes call this the Goldilocks effect that everything is just right. (For the record, these three possible universes are known respectively as closed, open, and flat.) Now the question that has occurred to all of us at some point is: what would happen if you traveled out to the edge of the universe and, as it were, put

your head through the curtains? Where would your headbe if it were no longer in the universe? What would you find beyond? The answer, disappointingly, is that you can never get to the edge of the universe.

That s not because it would take too long to get there though of course it would but because even if you traveled outward and outward in a straight line, indefinitely and pugnaciously, you would never arrive at an outer boundary. Instead, you would come back to where you began (at which point, presumably, you would rather lose heart in the exercise and give up).

The reason for this is that the universe bends, in a way we can t adequately imagine, in conformance with Einstein s theory of relativity (which we will get to in due course). For the moment it is enough to know that we are not adrift in some large, ever-expanding bubble. Rather, space curves, in a way that allows it to be boundless but finite. Space cannot even properly be said to be expanding because, as the physicist and Nobel laureate Steven Weinberg notes, solar systems and galaxies are not expanding, and space itself is not expanding. Rather, the galaxies are rushing apart. It is all something of a challenge to intuition. Or as the biologist J. B. S. Haldane once famously observed: The universe is not only queerer than we suppose; it is queerer than we can suppose.

The analogy that is usually given for explaining the curvature of space is to try to imagine someone from a universe of flat surfaces, who had never seen a sphere, being brought to Earth. No matter how far he roamed across the planet s surface, he would never find an edge. He might eventually return to the spot where he had started, and would of course be utterly confounded to explain how that had happened. Well, we are in the same position in space as our puzzled flatlander, only we are flummoxed by a higher dimension.

Just as there is no place where you can find the edge of the universe, so there is no place where you can stand at the center and say: This is where it all began. This is the centermost point of it all. We areall at the center of it all. Actually, we don t know that for sure; we can t prove it mathematically. Scientists just assume that we can t really be the center of the universe think what that would imply but that the phenomenon must be the same for all observers in all places. Still, we don t actually know.

For us, the universe goes only as far as light has traveled in the billions of years since the universe was formed. This visible universe the universe we know and can talk about is a million million million million (that s 1,000,000,000,000,000,000,000,000) miles across. But according to most theories the universe at large the meta-universe, as it is sometimes called is vastly roomier still. According to Rees, the number of light-years to the edge of this larger, unseen universe would be written not with ten zeroes, not even with a hundred, but with millions. In short, there s more space than you can imagine already without going to the trouble of trying to envision some additional beyond.

For a long time the Big Bang theory had one gaping hole that troubled a lot of people namely that it couldn t begin to explain how we got here.

Although 98 percent of all the matter that exists was created with the Big Bang, that matter consisted exclusively of light gases: the helium, hydrogen, and lithium that we mentioned earlier. Not one particle of the heavy stuff so vital to our own being carbon, nitrogen, oxygen, and all the rest emerged from the gaseous brew of creation. But and here s the troubling point to forge these heavy elements, you need the kind of heat and energy of a Big Bang. Yet there has been only one Big Bang and it didn t produce them.So where did they come from?

Interestingly, the man who found the answer to that question was a cosmologist who heartily despised the Big Bang as a theory and coined the term Big Bang sarcastically, as a way of mocking it. We ll get to him shortly, but before we turn to the question of how we got here, it might be worth taking a few minutes to consider just where exactly here is.

A Short History of Nearly

Everything

CHAPTER 2: WELCOME TO THE SOLAR

SYSTEM

ASTRONOMERS THESE DAYS can do the most amazing things. If someone struck a match on the Moon, they could spot the flare. From the tiniest throbs and wobbles of distant stars they can infer the size and character and even potential habitability of planets much too remote to be seen planets so distant that it would take us half a million years in a spaceship to get there. With their radio telescopes they can capture wisps of radiation so preposterously faint that thetotal amount of energy collected from outside the solar system by all of them together since collecting began (in 1951) is less than the energy of a single snowflake striking the ground, in the words of Carl Sagan.

In short, there isn t a great deal that goes on in the universe that astronomers can t find when they have a mind to. Which is why it is all the more remarkable to reflect that until 1978 no one had ever noticed that Pluto has a moon. In the summer of that year, a young astronomer named James Christy at the U.S. Naval Observatory in Flagstaff, Arizona, was making a routine examination of photographic images of Pluto when he saw that there was something there something blurry and uncertain but definitely other than Pluto. Consulting a colleague named Robert Harrington, he concluded that what he was looking at was a moon. And it wasn t just any moon. Relative to the planet, it was the biggest moon in the solar system.

This was actually something of a blow to Pluto s status as a planet, which had never been terribly robust anyway. Since previously the space occupied by the moon and the space occupied by Pluto were thought to be one and the same, it meant that Pluto was much smaller than anyone had supposed smaller even than Mercury. Indeed, seven moons in the solar system, including our own, are larger.

Now a natural question is why it took so long for anyone to find a moon in our own solar system. The answer is that it is partly a matter of where

astronomers point their instruments and partly a matter of what their instruments are designed to detect, and partly it s just Pluto. Mostly it s where they point their instruments. In the words of the astronomer Clark Chapman: Most people think that astronomers get out at night in observatories and scan the skies. That s not true. Almost all the telescopes we have in the world are designed to peer at very tiny little pieces of the sky way off in the distance to see a quasar or hunt for black holes or look at a distant galaxy. The only real network of telescopes that scans the skies has been designed and built by the military.

We have been spoiled by artists renderings into imagining a clarity of resolution that doesn t exist in actual astronomy. Pluto in Christy s photograph is faint and fuzzy a piece of cosmic lint and its moon is not the romantically backlit, crisply delineated companion orb you would get in aNational Geographic painting, but rather just a tiny and extremely indistinct hint of additional fuzziness. Such was the fuzziness, in fact, that it took seven years for anyone to spot the moon again and thus independently confirm its existence.

One nice touch about Christy s discovery was that it happened in Flagstaff, for it was there in 1930 that Pluto had been found in the first place. That seminal event in astronomy was largely to the credit of the astronomer Percival Lowell. Lowell, who came from one of the oldest and wealthiest Boston families (the one in the famous ditty about Boston being the home of the bean and the cod, where Lowells spoke only to Cabots, while Cabots spoke only to God), endowed the famous observatory that bears his name, but is most indelibly remembered for his belief that Mars was covered with canals built by industrious Martians for purposes of conveying water from polar regions to the dry but productive lands nearer the equator.

Lowell s other abiding conviction was that there existed, somewhere out beyond Neptune, an undiscovered ninth planet, dubbed Planet X. Lowell based this belief on irregularities he detected in the orbits of Uranus and Neptune, and devoted the last years of his life to trying to find the gassy giant he was certain was out there. Unfortunately, he died suddenly in 1916, at least partly exhausted by his quest, and the search fell into abeyance while Lowell s heirs squabbled over his estate. However, in 1929, partly as

a way of deflecting attention away from the Mars canal saga (which by now had become a serious embarrassment), the Lowell Observatory directors decided to resume the search and to that end hired a young man from Kansas named Clyde Tombaugh.

Tombaugh had no formal training as an astronomer, but he was diligent and he was astute, and after a year s patient searching he somehow spotted Pluto, a faint point of light in a glittery firmament. It was a miraculous find, and what made it all the more striking was that the observations on which Lowell had predicted the existence of a planet beyond Neptune proved to be comprehensively erroneous. Tombaugh could see at once that the new planet was nothing like the massive gasball Lowell had postulated, but any reservations he or anyone else had about the character of the new planet were soon swept aside in the delirium that attended almost any big news story in that easily excited age. This was the first American-discovered planet, and no one was going to be distracted by the thought that it was really just a distant icy dot. It was named Pluto at least partly because the first two letters made a monogram from Lowell s initials. Lowell was posthumously hailed everywhere as a genius of the first order, and Tombaugh was largely forgotten, except among planetary astronomers, who tend to revere him.

A few astronomers continue to think there may be a Planet X out there a real whopper, perhaps as much as ten times the size of Jupiter, but so far out as to be invisible to us. (It would receive so little sunlight that it would have almost none to reflect.) The idea is that it wouldn t be a conventional planet like Jupiter or Saturn it s much too far away for that; we re talking perhaps 4.5 trillion miles but more like a sun that never quite made it. Most star systems in the cosmos are binary (double-starred), which makes our solitary sun a slight oddity.

As for Pluto itself, nobody is quite sure how big it is, or what it is made of, what kind of atmosphere it has, or even what it really is. A lot of astronomers believe it isn t a planet at all, but merely the largest object so far found in a zone of galactic debris known as the Kuiper belt. The Kuiper belt was actually theorized by an astronomer named F. C. Leonard in 1930, but the name honors Gerard Kuiper, a Dutch native working in America,

who expanded the idea. The Kuiper belt is the source of what are known as short-period comets those that come past pretty regularly of which the most famous is Halley s comet. The more reclusive long-period comets (among them the recent visitors Hale-Bopp and Hyakutake) come from the much more distant Oort cloud, about which more presently.

It is certainly true that Pluto doesn t act much like the other planets. Not only is it runty and obscure, but it is so variable in its motions that no one can tell you exactly where Pluto will be a century hence. Whereas the other planets orbit on more or less the same plane, Pluto s orbital path is tipped (as it were) out of alignment at an angle of seventeen degrees, like the brim of a hat tilted rakishly on someone s head. Its orbit is so irregular that for substantial periods on each of its lonely circuits around the Sun it is closer to us than Neptune is. For most of the 1980s and 1990s, Neptune was in fact the solar system s most far-flung planet. Only on February 11, 1999, did Pluto return to the outside lane, there to remain for the next 228 years.

So if Pluto really is a planet, it is certainly an odd one. It is very tiny: just one-quarter of 1 percent as massive as Earth. If you set it down on top of the United States, it would cover not quite half the lower forty-eight states.

This alone makes it extremely anomalous; it means that our planetary system consists of four rocky inner planets, four gassy outer giants, and a tiny, solitary iceball. Moreover, there is every reason to suppose that we may soon begin to find other even larger icy spheres in the same portion of space. Then wewill have problems. After Christy spotted Pluto s moon, astronomers began to regard that section of the cosmos more attentively and as of early December 2002 had found over six hundred additional Trans-Neptunian Objects, or Plutinos as they are alternatively called. One, dubbed Varuna, is nearly as big as Pluto s moon. Astronomers now think there may be billions of these objects. The difficulty is that many of them are awfully dark. Typically they have an albedo, or reflectiveness, of just 4 percent, about the same as a lump of charcoal and of course these lumps of charcoal are about four billion miles away.

And how far is that exactly? It s almost beyond imagining. Space, you see, is just enormous just enormous. Let s imagine, for purposes of edification and entertainment, that we are about to go on a journey by rocketship. We

won t go terribly far just to the edge of our own solar system but we need to get a fix on how big a place space is and what a small part of it we occupy.

Now the bad news, I m afraid, is that we won t be home for supper. Even at the speed of light, it would take seven hours to get to Pluto. But of course we can t travel at anything like that speed. We ll have to go at the speed of a spaceship, and these are rather more lumbering. The best speeds yet achieved by any human object are those of theVoyager 1 and2spacecraft, which are now flying away from us at about thirty-five thousand miles an hour.

The reason theVoyager craft were launched when they were (in August and September 1977) was that Jupiter, Saturn, Uranus, and Neptune were aligned in a way that happens only once every 175 years. This enabled the twoVoyagers to use a gravity assist technique in which the craft were successively flung from one gassy giant to the next in a kind of cosmic version of crack the whip. Even so, it took them nine years to reach Uranus and a dozen to cross the orbit of Pluto. The good news is that if we wait until January 2006 (which is when NASA sNew Horizons spacecraft is tentatively scheduled to depart for Pluto) we can take advantage of favorable Jovian positioning, plus some advances in technology, and get there in only a decade or so though getting home again will take rather longer, I m afraid. At all events, it s going to be a long trip.

Now the first thing you are likely to realize is that space is extremely well named and rather dismayingly uneventful. Our solar system may be the liveliest thing for trillions of miles, but all the visible stuff in it the Sun, the planets and their moons, the billion or so tumbling rocks of the asteroid belt, comets, and other miscellaneous drifting detritus fills less than a trillionth of the available space. You also quickly realize that none of the maps you have ever seen of the solar system were remotely drawn to scale.

Most schoolroom charts show the planets coming one after the other at neighborly intervals the outer giants actually cast shadows over each other in many illustrations but this is a necessary deceit to get them all on the same piece of paper. Neptune in reality isn t just a little bit beyond Jupiter,

it s way beyond Jupiter five times farther from Jupiter than Jupiter is from us, so far out that it receives only 3 percent as much sunlight as Jupiter.

Such are the distances, in fact, that it isn t possible, in any practical terms, to draw the solar system to scale. Even if you added lots of fold-out pages to your textbooks or used a really long sheet of poster paper, you wouldn t come close. On a diagram of the solar system to scale, with Earth reduced to about the diameter of a pea, Jupiter would be over a thousand feet away and Pluto would be a mile and a half distant (and about the size of a bacterium, so you wouldn t be able to see it anyway). On the same scale, Proxima Centauri, our nearest star, would be almost ten thousand miles away. Even if you shrank down everything so that Jupiter was as small as the period at the end of this sentence, and Pluto was no bigger than a molecule, Pluto would still be over thirty-five feet away.

So the solar system is really quite enormous. By the time we reach Pluto, we have come so far that the Sun our dear, warm, skin-tanning, life-giving Sun has shrunk to the size of a pinhead. It is little more than a bright star.

In such a lonely void you can begin to understand how even the most significant objects Pluto s moon, for example have escaped attention. In this respect, Pluto has hardly been alone. Until theVoyager expeditions, Neptune was thought to have two moons;Voyager found six more. When I was a boy, the solar system was thought to contain thirty moons. The total now is at least ninety, about a third of which have been found in just the last ten years.

The point to remember, of course, is that when considering the universe at large we don t actually know what is in our own solar system.

Now the other thing you will notice as we speed past Pluto is that we are speeding past Pluto. If you check your itinerary, you will see that this is a trip to the edge of our solar system, and I m afraid we re not there yet.

Pluto may be the last object marked on schoolroom charts, but the system doesn t end there. In fact, it isn t even close to ending there. We won t get to the solar system s edge until we have passed through the Oort cloud, a vast celestial realm of drifting comets, and we won t reach the Oort cloud for another I m so sorry about this ten thousand years. Far from marking

the outer edge of the solar system, as those schoolroom maps so cavalierly imply, Pluto is barely one-fifty-thousandth of the way.

Of course we have no prospect of such a journey. A trip of 240,000 miles to the Moon still represents a very big undertaking for us. A manned mission to Mars, called for by the first President Bush in a moment of passing giddiness, was quietly dropped when someone worked out that it would cost $450 billion and probably result in the deaths of all the crew (their DNA torn to tatters by high-energy solar particles from which they could not be shielded).

Based on what we know now and can reasonably imagine, there is absolutely no prospect that any human being will ever visit the edge of our own solar system ever. It is just too far. As it is, even with the Hubble telescope, we can t see even into the Oort cloud, so we don t actually know that it is there. Its existence is probable but entirely hypothetical.[ ]

About all that can be said with confidence about the Oort cloud is that it starts somewhere beyond Pluto and stretches some two light-years out into the cosmos. The basic unit of measure in the solar system is the Astronomical Unit, or AU, representing the distance from the Sun to the Earth. Pluto is about forty AUs from us, the heart of the Oort cloud about fifty thousand. In a word, it is remote.

But let s pretend again that we have made it to the Oort cloud. The first thing you might notice is how very peaceful it is out here. We re a long way from anywhere now so far from our own Sun that it s not even the brightest star in the sky. It is a remarkable thought that that distant tiny twinkle has enough gravity to hold all these comets in orbit. It s not a very strong bond, so the comets drift in a stately manner, moving at only about 220 miles an hour. From time to time some of these lonely comets are nudged out of their normal orbit by some slight gravitational perturbation a passing star perhaps. Sometimes they are ejected into the emptiness of space, never to be seen again, but sometimes they fall into a long orbit around the Sun. About three or four of these a year, known as long-period comets, pass through the inner solar system. Just occasionally these stray visitors smack into something solid, like Earth. That s why we ve come

out here now because the comet we have come to see has just begun a long fall toward the center of the solar system. It is headed for, of all places, Manson, Iowa. It is going to take a long time to get there three or four million years at least so we ll leave it for now, and return to it much later in the story.

So that s your solar system. And what else is out there, beyond the solar system? Well, nothing and a great deal, depending on how you look at it.

In the short term, it s nothing. The most perfect vacuum ever created by humans is not as empty as the emptiness of interstellar space. And there is a great deal of this nothingness until you get to the next bit of something. Our nearest neighbor in the cosmos, Proxima Centauri, which is part of the three-star cluster known as Alpha Centauri, is 4.3 light-years away, a sissy skip in galactic terms, but that is still a hundred million times farther than a trip to the Moon. To reach it by spaceship would take at least twenty-five thousand years, and even if you made the trip you still wouldn t be anywhere except at a lonely clutch of stars in the middle of a vast nowhere.

To reach the next landmark of consequence, Sirius, would involve another 4.6 light-years of travel. And so it would go if you tried to star-hop your way across the cosmos. Just reaching the center of our own galaxy would take far longer than we have existed as beings.

Space, let me repeat, is enormous. The average distance between stars out there is 20 million million miles. Even at speeds approaching those of light, these are fantastically challenging distances for any traveling individual. Of course, it ispossible that alien beings travel billions of miles to amuse themselves by planting crop circles in Wiltshire or frightening the daylights out of some poor guy in a pickup truck on a lonely road in Arizona (they must have teenagers, after all), but it does seem unlikely.

Still, statistically the probability that there are other thinking beings out there is good. Nobody knows how many stars there are in the Milky Way estimates range from 100 billion or so to perhaps 400 billion and the Milky Way is just one of 140 billion or so other galaxies, many of them even larger than ours. In the 1960s, a professor at Cornell named Frank Drake, excited by such whopping numbers, worked out a famous equation

designed to calculate the chances of advanced life in the cosmos based on a series of diminishing probabilities.

Under Drake s equation you divide the number of stars in a selected portion of the universe by the number of stars that are likely to have planetary systems; divide that by the number of planetary systems that could theoretically support life; divide that by the number on which life, having arisen, advances to a state of intelligence; and so on. At each such division, the number shrinks colossally yet even with the most conservative inputs the number of advanced civilizations just in the Milky Way always works out to be somewhere in the millions.

What an interesting and exciting thought. We may be only one of millions of advanced civilizations. Unfortunately, space being spacious, the average distance between any two of these civilizations is reckoned to be at least two hundred light-years, which is a great deal more than merely saying it makes it sound. It means for a start that even if these beings know we are here and are somehow able to see us in their telescopes, they re watching light that left Earth two hundred years ago. So they re not seeing you and me. They re watching the French Revolution and Thomas Jefferson and people in silk stockings and powdered wigs people who don t know what an atom is, or a gene, and who make their electricity by rubbing a rod of amber with a piece of fur and think that s quite a trick. Any message we receive from them is likely to begin Dear Sire, and congratulate us on the handsomeness of our horses and our mastery of whale oil. Two hundred light-years is a distance so far beyond us as to be, well, just beyond us.

So even if we are not really alone, in all practical terms we are. Carl Sagan calculated the number of probable planets in the universe at large at 10

billion trillion a number vastly beyond imagining. But what is equally beyond imagining is the amount of space through which they are lightly scattered. If we were randomly inserted into the universe, Sagan wrote, the chances that you would be on or near a planet would be less than one in a billion trillion trillion. (That s 1033, or a one followed by thirty-three zeroes.) Worlds are precious.

Which is why perhaps it is good news that in February 1999 the International Astronomical Union ruled officially that Pluto is a planet. The universe is a big and lonely place. We can do with all the neighbors we can get.

A Short History of Nearly

Everything

CHAPTER 3: THE REVEREND EVANS S

UNIVERSE

WHEN THE SKIES are clear and the Moon is not too bright, the Reverend Robert Evans, a quiet and cheerful man, lugs a bulky telescope onto the back deck of his home in the Blue Mountains of Australia, about fifty miles west of Sydney, and does an extraordinary thing. He looks deep into the past and finds dying stars.

Looking into the past is of course the easy part. Glance at the night sky and what you see is history and lots of it the stars not as they are now but as they were when their light left them. For all we know, the North Star, our faithful companion, might actually have burned out last January or in 1854

or at any time since the early fourteenth century and news of it just hasn t reached us yet. The best we can say can ever say is that it was still burning on this date 680 years ago. Stars die all the time. What Bob Evans does better than anyone else who has ever tried is spot these moments of celestial farewell.

By day, Evans is a kindly and now semiretired minister in the Uniting Church in Australia, who does a bit of freelance work and researches the history of nineteenth-century religious movements. But by night he is, in his unassuming way, a titan of the skies. He hunts supernovae.

Supernovae occur when a giant star, one much bigger than our own Sun, collapses and then spectacularly explodes, releasing in an instant the energy of a hundred billion suns, burning for a time brighter than all the stars in its galaxy. It s like a trillion hydrogen bombs going off at once, says Evans.

If a supernova explosion happened within five hundred light-years of us, we would be goners, according to Evans

it would wreck the show, as he

cheerfully puts it. But the universe is vast, and supernovae are normally much too far away to harm us. In fact, most are so unimaginably distant that their light reaches us as no more than the faintest twinkle. For the month or so that they are visible, all that distinguishes them from the other stars in the sky is that they occupy a point of space that wasn t filled before. It is these anomalous, very occasional pricks in the crowded dome of the night sky that the Reverend Evans finds.

To understand what a feat this is, imagine a standard dining room table covered in a black tablecloth and someone throwing a handful of salt across it. The scattered grains can be thought of as a galaxy. Now imagine fifteen hundred more tables like the first one enough to fill a Wal-Mart parking lot, say, or to make a single line two miles long each with a random array of salt across it. Now add one grain of salt to any table and let Bob Evans walk among them. At a glance he will spot it. That grain of salt is the supernova.

Evans s is a talent so exceptional that Oliver Sacks, inAn Anthropologist on Mars , devotes a passage to him in a chapter on autistic savants quickly adding that there is no suggestion that he is autistic. Evans, who has not met Sacks, laughs at the suggestion that he might be either autistic or a savant, but he is powerless to explain quite where his talent comes from.

I just seem to have a knack for memorizing star fields, he told me, with a frankly apologetic look, when I visited him and his wife, Elaine, in their picture-book bungalow on a tranquil edge of the village of Hazelbrook, out where Sydney finally ends and the boundless Australian bush begins. I m not particularly good at other things, he added. I don t remember names well.

Or where he s put things, called Elaine from the kitchen.

He nodded frankly again and grinned, then asked me if I d like to see his telescope. I had imagined that Evans would have a proper observatory in his backyard a scaled-down version of a Mount Wilson or Palomar, with a sliding domed roof and a mechanized chair that would be a pleasure to maneuver. In fact, he led me not outside but to a crowded storeroom off the kitchen where he keeps his books and papers and where his telescope a white cylinder that is about the size and shape of a household hot-water tank rests in a homemade, swiveling plywood mount. When he wishes to observe, he carries them in two trips to a small deck off the kitchen.

Between the overhang of the roof and the feathery tops of eucalyptus trees growing up from the slope below, he has only a letter-box view of the sky, but he says it is more than good enough for his purposes. And there, when the skies are clear and the Moon not too bright, he finds his supernovae.

The termsupernova was coined in the 1930s by a memorably odd astrophysicist named Fritz Zwicky. Born in Bulgaria and raised in Switzerland, Zwicky came to the California Institute of Technology in the 1920s and there at once distinguished himself by his abrasive personality and erratic talents. He didn t seem to be outstandingly bright, and many of his colleagues considered him little more than an irritating buffoon. A fitness buff, he would often drop to the floor of the Caltech dining hall or other public areas and do one-armed pushups to demonstrate his virility to anyone who seemed inclined to doubt it. He was notoriously aggressive, his manner eventually becoming so intimidating that his closest collaborator, a gentle man named Walter Baade, refused to be left alone with him. Among other things, Zwicky accused Baade, who was German, of being a Nazi, which he was not. On at least one occasion Zwicky threatened to kill Baade, who worked up the hill at the Mount Wilson Observatory, if he saw him on the Caltech campus.

But Zwicky was also capable of insights of the most startling brilliance. In the early 1930s, he turned his attention to a question that had long troubled astronomers: the appearance in the sky of occasional unexplained points of light, new stars. Improbably he wondered if the neutron the subatomic particle that had just been discovered in England by James Chadwick, and was thus both novel and rather fashionable might be at the heart of things.

It occurred to him that if a star collapsed to the sort of densities found in the core of atoms, the result would be an unimaginably compacted core. Atoms would literally be crushed together, their electrons forced into the nucleus, forming neutrons. You would have a neutron star. Imagine a million really weighty cannonballs squeezed down to the size of a marble and well, you re still not even close. The core of a neutron star is so dense that a single spoonful of matter from it would weigh 200 billion pounds. A spoonful!
But there was more. Zwicky realized that after the collapse of such a star there would be a huge amount of energy left over enough to make the

biggest bang in the universe. He called these resultant explosions supernovae. They would be they are the biggest events in creation.

On January 15, 1934, the journalPhysical Review published a very concise abstract of a presentation that had been conducted by Zwicky and Baade the previous month at Stanford University. Despite its extreme brevity one paragraph of twenty-four lines the abstract contained an enormous amount of new science: it provided the first reference to supernovae and to neutron stars; convincingly explained their method of formation; correctly calculated the scale of their explosiveness; and, as a kind of concluding bonus, connected supernova explosions to the production of a mysterious new phenomenon called cosmic rays, which had recently been found swarming through the universe. These ideas were revolutionary to say the least. Neutron stars wouldn t be confirmed for thirty-four years. The cosmic rays notion, though considered plausible, hasn t been verified yet.

Altogether, the abstract was, in the words of Caltech astrophysicist Kip S.

Thorne, one of the most prescient documents in the history of physics and astronomy.

Interestingly, Zwicky had almost no understanding of why any of this would happen. According to Thorne, he did not understand the laws of physics well enough to be able to substantiate his ideas. Zwicky s talent was for big ideas. Others Baade mostly were left to do the mathematical sweeping up.

Zwicky also was the first to recognize that there wasn t nearly enough visible mass in the universe to hold galaxies together and that there must be some other gravitational influence what we now call dark matter. One thing he failed to see was that if a neutron star shrank enough it would become so dense that even light couldn t escape its immense gravitational pull. You would have a black hole. Unfortunately, Zwicky was held in such disdain by most of his colleagues that his ideas attracted almost no notice.

When, five years later, the great Robert Oppenheimer turned his attention to neutron stars in a landmark paper, he made not a single reference to any of Zwicky s work even though Zwicky had been working for years on the same problem in an office just down the hall. Zwicky s deductions concerning dark matter wouldn t attract serious attention for nearly four decades. We can only assume that he did a lot of pushups in this period.

Surprisingly little of the universe is visible to us when we incline our heads to the sky. Only about 6,000 stars are visible to the naked eye from Earth, and only about 2,000 can be seen from any one spot. With binoculars the number of stars you can see from a single location rises to about 50,000, and with a small two-inch telescope it leaps to 300,000. With a sixteen-inch telescope, such as Evans uses, you begin to count not in stars but in galaxies. From his deck, Evans supposes he can see between 50,000 and 100,000 galaxies, each containing tens of billions of stars. These are of course respectable numbers, but even with so much to take in, supernovae are extremely rare. A star can burn for billions of years, but it dies just once and quickly, and only a few dying stars explode. Most expire quietly, like a campfire at dawn. In a typical galaxy, consisting of a hundred billion stars, a supernova will occur on average once every two or three hundred years.

Finding a supernova therefore was a little bit like standing on the observation platform of the Empire State Building with a telescope and searching windows around Manhattan in the hope of finding, let us say, someone lighting a twenty-first-birthday cake.

So when a hopeful and softspoken minister got in touch to ask if they had any usable field charts for hunting supernovae, the astronomical community thought he was out of his mind. At the time Evans had a ten-inch telescope a very respectable size for amateur stargazing but hardly the sort of thing with which to do serious cosmology and he was proposing to find one of the universe s rarer phenomena. In the whole of astronomical history before Evans started looking in 1980, fewer than sixty supernovae had been found. (At the time I visited him, in August of 2001, he had just recorded his thirty-fourth visual discovery; a thirty-fifth followed three months later and a thirty-sixth in early 2003.)

Evans, however, had certain advantages. Most observers, like most people generally, are in the northern hemisphere, so he had a lot of sky largely to himself, especially at first. He also had speed and his uncanny memory.

Large telescopes are cumbersome things, and much of their operational time is consumed with being maneuvered into position. Evans could swing his little sixteen-inch telescope around like a tail gunner in a dogfight, spending no more than a couple of seconds on any particular point in the sky. In consequence, he could observe perhaps four hundred galaxies in an

evening while a large professional telescope would be lucky to do fifty or sixty.

Looking for supernovae is mostly a matter of not finding them. From 1980

to 1996 he averaged two discoveries a year not a huge payoff for hundreds of nights of peering and peering. Once he found three in fifteen days, but another time he went three years without finding any at all.

There is actually a certain value in not finding anything, he said. It helps cosmologists to work out the rate at which galaxies are evolving. It s one of those rare areas where the absence of evidenceisevidence.

On a table beside the telescope were stacks of photos and papers relevant to his pursuits, and he showed me some of them now. If you have ever looked through popular astronomical publications, and at some time you must have, you will know that they are generally full of richly luminous color photos of distant nebulae and the like fairy-lit clouds of celestial light of the most delicate and moving splendor. Evans s working images are nothing like that. They are just blurry black-and-white photos with little points of haloed brightness. One he showed me depicted a swarm of stars with a trifling flare that I had to put close to my face to see. This, Evans told me, was a star in a constellation called Fornax from a galaxy known to astronomy as NGC1365. (NGC stands for New General Catalogue, where these things are recorded. Once it was a heavy book on someone s desk in Dublin; today, needless to say, it s a database.) For sixty million silent years, the light from the star s spectacular demise traveled unceasingly through space until one night in August of 2001 it arrived at Earth in the form of a puff of radiance, the tiniest brightening, in the night sky. It was of course Robert Evans on his eucalypt-scented hillside who spotted it.

There s something satisfying, I think, Evans said, about the idea of light traveling for millions of years through space andjust at the right moment as it reaches Earth someone looks at the right bit of sky and sees it.

It just seems right that an event of that magnitude should be witnessed.

Supernovae do much more than simply impart a sense of wonder. They come in several types (one of them discovered by Evans) and of these one

in particular, known as a Ia supernova, is important to astronomy because it always explodes in the same way, with the same critical mass. For this reason it can be used as a standard candle to measure the expansion rate of the universe.

In 1987 Saul Perlmutter at the Lawrence Berkeley lab in California, needing more Ia supernovae than visual sightings were providing, set out to find a more systematic method of searching for them. Perlmutter devised a nifty system using sophisticated computers and charge-coupled devices in essence, really good digital cameras. It automated supernova hunting.

Telescopes could now take thousands of pictures and let a computer detect the telltale bright spots that marked a supernova explosion. In five years, with the new technique, Perlmutter and his colleagues at Berkeley found forty-two supernovae. Now even amateurs are finding supernovae with charge-coupled devices. With CCDs you can aim a telescope at the sky and go watch television, Evans said with a touch of dismay. It took all the romance out of it.

I asked him if he was tempted to adopt the new technology. Oh, no, he said, I enjoy my way too much. Besides

he gave a nod at the photo of

his latest supernova and smiled

I can still beat them sometimes.

The question that naturally occurs is What would it be like if a star exploded nearby? Our nearest stellar neighbor, as we have seen, is Alpha Centauri, 4.3 light-years away. I had imagined that if there were an explosion there we would have 4.3 years to watch the light of this magnificent event spreading across the sky, as if tipped from a giant can.

What would it be like if we had four years and four months to watch an inescapable doom advancing toward us, knowing that when it finally arrived it would blow the skin right off our bones? Would people still go to work? Would farmers plant crops? Would anyone deliver them to the stores?

Weeks later, back in the town in New Hampshire where I live, I put these questions to John Thorstensen, an astronomer at Dartmouth College. Oh no, he said, laughing. The news of such an event travels out at the speed of light, but so does the destructiveness, so you d learn about it and die

from it in the same instant. But don t worry because it s not going to happen.

For the blast of a supernova explosion to kill you, he explained, you would have to be ridiculously close

probably within ten light-years or so. The

danger would be various types of radiation cosmic rays and so on. These would produce fabulous auroras, shimmering curtains of spooky light that would fill the whole sky. This would not be a good thing. Anything potent enough to put on such a show could well blow away the magnetosphere, the magnetic zone high above the Earth that normally protects us from ultraviolet rays and other cosmic assaults. Without the magnetosphere anyone unfortunate enough to step into sunlight would pretty quickly take on the appearance of, let us say, an overcooked pizza.

The reason we can be reasonably confident that such an event won t happen in our corner of the galaxy, Thorstensen said, is that it takes a particular kind of star to make a supernova in the first place. A candidate star must be ten to twenty times as massive as our own Sun and we don t have anything of the requisite size that s that close. The universe is a mercifully big place. The nearest likely candidate he added, is Betelgeuse, whose various sputterings have for years suggested that something interestingly unstable is going on there. But Betelgeuse is fifty thousand light-years away.

Only half a dozen times in recorded history have supernovae been close enough to be visible to the naked eye. One was a blast in 1054 that created the Crab Nebula. Another, in 1604, made a star bright enough to be seen during the day for over three weeks. The most recent was in 1987, when a supernova flared in a zone of the cosmos known as the Large Magellanic Cloud, but that was only barely visible and only in the southern hemisphere and it was a comfortably safe 169,000 light-years away.

Supernovae are significant to us in one other decidedly central way.

Without them we wouldn t be here. You will recall the cosmological conundrum with which we ended the first chapter that the Big Bang created lots of light gases but no heavy elements. Those came later, but for a very long time nobody could figure out howthey came later. The problem

was that you needed something really hot hotter even than the middle of the hottest stars to forge carbon and iron and the other elements without which we would be distressingly immaterial. Supernovae provided the explanation, and it was an English cosmologist almost as singular in manner as Fritz Zwicky who figured it out.

He was a Yorkshireman named Fred Hoyle. Hoyle, who died in 2001, was described in an obituary inNature as a cosmologist and controversialist and both of those he most certainly was. He was, according toNature s obituary, embroiled in controversy for most of his life and put his name to much rubbish. He claimed, for instance, and without evidence, that the Natural History Museum s treasured fossil of an Archaeopteryx was a forgery along the lines of the Piltdown hoax, causing much exasperation to the museum s paleontologists, who had to spend days fielding phone calls from journalists from all over the world. He also believed that Earth was not only seeded by life from space but also by many of its diseases, such as influenza and bubonic plague, and suggested at one point that humans evolved projecting noses with the nostrils underneath as a way of keeping cosmic pathogens from falling into them.

It was he who coined the term Big Bang, in a moment of facetiousness, for a radio broadcast in 1952. He pointed out that nothing in our understanding of physics could account for why everything, gathered to a point, would suddenly and dramatically begin to expand. Hoyle favored a steady-state theory in which the universe was constantly expanding and continually creating new matter as it went. Hoyle also realized that if stars imploded they would liberate huge amounts of heat 100 million degrees or more, enough to begin to generate the heavier elements in a process known as nucleosynthesis. In 1957, working with others, Hoyle showed how the heavier elements were formed in supernova explosions. For this work, W.

A. Fowler, one of his collaborators, received a Nobel Prize. Hoyle, shamefully, did not.

According to Hoyle s theory, an exploding star would generate enough heat to create all the new elements and spray them into the cosmos where they would form gaseous clouds the interstellar medium as it is known that could eventually coalesce into new solar systems. With the new

theories it became possible at last to construct plausible scenarios for how we got here. What we now think we know is this:

About 4.6 billion years ago, a great swirl of gas and dust some 15 billion miles across accumulated in space where we are now and began to aggregate. Virtually all of it 99.9 percent of the mass of the solar system went to make the Sun. Out of the floating material that was left over, two microscopic grains floated close enough together to be joined by electrostatic forces. This was the moment of conception for our planet. All over the inchoate solar system, the same was happening. Colliding dust grains formed larger and larger clumps. Eventually the clumps grew large enough to be called planetesimals. As these endlessly bumped and collided, they fractured or split or recombined in endless random permutations, but in every encounter there was a winner, and some of the winners grew big enough to dominate the orbit around which they traveled.

It all happened remarkably quickly. To grow from a tiny cluster of grains to a baby planet some hundreds of miles across is thought to have taken only a few tens of thousands of years. In just 200 million years, possibly less, the Earth was essentially formed, though still molten and subject to constant bombardment from all the debris that remained floating about.

At this point, about 4.5 billion years ago, an object the size of Mars crashed into Earth, blowing out enough material to form a companion sphere, the Moon. Within weeks, it is thought, the flung material had reassembled itself into a single clump, and within a year it had formed into the spherical rock that companions us yet. Most of the lunar material, it is thought, came from the Earth s crust, not its core, which is why the Moon has so little iron while we have a lot. The theory, incidentally, is almost always presented as a recent one, but in fact it was first proposed in the 1940s by Reginald Daly of Harvard. The only recent thing about it is people paying any attention to it.

When Earth was only about a third of its eventual size, it was probably already beginning to form an atmosphere, mostly of carbon dioxide, nitrogen, methane, and sulfur. Hardly the sort of stuff that we would associate with life, and yet from this noxious stew life formed. Carbon

dioxide is a powerful greenhouse gas. This was a good thing because the Sun was significantly dimmer back then. Had we not had the benefit of a greenhouse effect, the Earth might well have frozen over permanently, and life might never have gotten a toehold. But somehow life did.

For the next 500 million years the young Earth continued to be pelted relentlessly by comets, meteorites, and other galactic debris, which brought water to fill the oceans and the components necessary for the successful formation of life. It was a singularly hostile environment and yet somehow life got going. Some tiny bag of chemicals twitched and became animate.

We were on our way.

Four billion years later people began to wonder how it had all happened.

And it is there that our story next takes us.

A Short History of Nearly

Everything

PART IITHE SIZE OF THE EARTH

Nature and Nature s laws lay hid in

night;

God said, Let Newton be! And all

was light.

-Alexander Pope

A Short History of Nearly

Everything

CHAPTER 4: THE MEASURE OF THINGS

IF YOU HAD to select the least convivial scientific field trip of all time, you could certainly do worse than the French Royal Academy of Sciences Peruvian expedition of 1735. Led by a hydrologist named Pierre Bouguer and a soldier-mathematician named Charles Marie de La Condamine, it was a party of scientists and adventurers who traveled to Peru with the purpose of triangulating distances through the Andes.

At the time people had lately become infected with a powerful desire to understand the Earth to determine how old it was, and how massive, where it hung in space, and how it had come to be. The French party s goal was to help settle the question of the circumference of the planet by measuring the length of one degree of meridian (or 1/360 of the distance around the planet) along a line reaching from Yarouqui, near Quito, to just beyond Cuenca in what is now Ecuador, a distance of about two hundred miles.[3]

Almost at once things began to go wrong, sometimes spectacularly so. In Quito, the visitors somehow provoked the locals and were chased out of town by a mob armed with stones. Soon after, the expedition s doctor was murdered in a misunderstanding over a woman. The botanist became deranged. Others died of fevers and falls. The third most senior member of the party, a man named Pierre Godin, ran off with a thirteen-year-old girl and could not be induced to return.

At one point the group had to suspend work for eight months while La Condamine rode off to Lima to sort out a problem with their permits.

Eventually he and Bouguer stopped speaking and refused to work together.

Everywhere the dwindling party went it was met with the deepest suspicions from officials who found it difficult to believe that a group of French scientists would travel halfway around the world to measure the world. That made no sense at all. Two and a half centuries later it still seems a reasonable question. Why didn t the French make their measurements in France and save themselves all the bother and discomfort of their Andean adventure?

The answer lies partly with the fact that eighteenth-century scientists, the French in particular, seldom did things simply if an absurdly demanding alternative was available, and partly with a practical problem that had first arisen with the English astronomer Edmond Halley many years before long before Bouguer and La Condamine dreamed of going to South America, much less had a reason for doing so.

Halley was an exceptional figure. In the course of a long and productive career, he was a sea captain, a cartographer, a professor of geometry at the University of Oxford, deputy controller of the Royal Mint, astronomer royal, and inventor of the deep-sea diving bell. He wrote authoritatively on magnetism, tides, and the motions of the planets, and fondly on the effects of opium. He invented the weather map and actuarial table, proposed methods for working out the age of the Earth and its distance from the Sun, even devised a practical method for keeping fish fresh out of season. The one thing he didn t do, interestingly enough, was discover the comet that bears his name. He merely recognized that the comet he saw in 1682 was the same one that had been seen by others in 1456, 1531, and 1607. It didn t become Halley s comet until 1758, some sixteen years after his death.

For all his achievements, however, Halley s greatest contribution to human knowledge may simply have been to take part in a modest scientific wager with two other worthies of his day: Robert Hooke, who is perhaps best remembered now as the first person to describe a cell, and the great and stately Sir Christopher Wren, who was actually an astronomer first and architect second, though that is not often generally remembered now. In 1683, Halley, Hooke, and Wren were dining in London when the conversation turned to the motions of celestial objects. It was known that planets were inclined to orbit in a particular kind of oval known as an ellipse

a very specific and precise curve, to quote Richard Feynman but it wasn t understood why. Wren generously offered a prize worth forty shillings (equivalent to a couple of weeks pay) to whichever of the men could provide a solution.

Hooke, who was well known for taking credit for ideas that weren t necessarily his own, claimed that he had solved the problem already but

declined now to share it on the interesting and inventive grounds that it would rob others of the satisfaction of discovering the answer for themselves. He would instead conceal it for some time, that others might know how to value it. If he thought any more on the matter, he left no evidence of it. Halley, however, became consumed with finding the answer, to the point that the following year he traveled to Cambridge and boldly called upon the university s Lucasian Professor of Mathematics, Isaac Newton, in the hope that he could help.

Newton was a decidedly odd figure brilliant beyond measure, but solitary, joyless, prickly to the point of paranoia, famously distracted (upon swinging his feet out of bed in the morning he would reportedly sometimes sit for hours, immobilized by the sudden rush of thoughts to his head), and capable of the most riveting strangeness. He built his own laboratory, the first at Cambridge, but then engaged in the most bizarre experiments. Once he inserted a bodkin a long needle of the sort used for sewing leather into his eye socket and rubbed it around betwixt my eye and the bone as near to [the] backside of my eye as I could just to see what would happen.