ORIGIN STORY

A BIG HISTORY OF EVERYTHING

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Preface

We tell stories to make sense of things. It's in our blood.

—Lia Hills, "Return to the Heart"

The idea of a modern origin story is in the air. For me, it began with a course on the history of everything that I first taught at Macquarie University in Sydney in 1989. I saw that course as a way of getting at the history of humanity. At the time, I taught and researched Russian and Soviet history. But I worried that teaching a national or imperial history (Russia was both nation and empire) conveyed the subliminal message that humans are divided, at the most fundamental level, into competing tribes. Was that a helpful message to teach in a world with nuclear weapons? As a schoolboy during the Cuban missile crisis, I vividly remember thinking we were on the verge of an apocalypse. Everything was about to be destroyed. And I remember wondering if there were kids "over there" in the Soviet Union who were equally scared. After all, they, too, were humans. As a child, I had lived in Nigeria. That gave me a strong sense of a single, extraordinarily diverse human community, a feeling that was confirmed when, as a teenager, I went to Atlantic College, an international school in South Wales.

Several decades later, as a professional historian, I began to think about how to teach a unified history of humanity. Could I teach about the heritage shared by all humans and tell that story with some of the grandeur and awe of the great national histories? I became convinced that we needed a story in which our Paleolithic ancestors and Neolithic farmers could play as important a role as the rulers, conquerors, and emperors who have dominated so much historical scholarship.

Eventually, I understood that these were not original ideas. In

1986, the great world historian William McNeill argued that writing histories of "the triumphs and tribulations of humanity as a whole" was "the moral duty of the historical profession in our time."[1] Even earlier, but in the same spirit, H. G. Wells wrote a history of humanity as a response to the carnage of World War I.

> There can be no peace now, we realize, but a common peace in all the world; no prosperity but a general prosperity. But there can be no common peace and prosperity without common historical ideas.... With nothing but narrow, selfish, and conflicting nationalist traditions, races and peoples are bound to drift towards conflict and destruction.[2]

Wells understood something else, too: If you want to teach the history of humanity, you probably need to teach the history of everything. That's why his *Outline of History* turned into a history of the universe. To understand the history of humanity, you have to understand how such a strange species evolved, which means learning about the evolution of life on planet Earth, which means learning about the evolution of planet Earth, which means learning about the evolution of stars and planets, which means knowing about the evolution of the universe. Today, we can tell that story with a precision and scientific rigor that were unthinkable when Wells wrote.

Wells was looking for unifying knowledge—knowledge that links disciplines as well as peoples. All origin stories unify knowledge, even the origin stories of nationalist historiography. And the most capacious of them can lead you across many time scales and through many concentric circles of understanding and identity, from the self to the family and clan, to a nation, language group, or religious affiliation, to the huge circles of humanity and life, and eventually to the idea that you are part of an entire universe or cosmos.

But in recent centuries, increasing cross-cultural contacts have shown how embedded all origin stories and religions are in local customs and environments. That is why globalization and the spread of new ideas corroded faith in traditional knowledge. Even true believers began to see that there were multiple origin stories that said very different things. Some people responded with aggressive, even violent, defenses of their own religious, tribal, or national traditions. But many simply lost faith and conviction, and along with them, they lost their bearings, their sense of their place in the universe. That loss of faith helps explain the pervasive *anomie,* the feeling of aimlessness, meaninglessness, and sometimes even despair that shaped so much literature, art, philosophy, and scholarship in the twentieth century. For many, nationalism offered some sense of belonging, but in today's globally connected world, it is apparent that nationalism divides humanity even as it connects citizens within a particular country.

I have written this book in the optimistic belief that we moderns are not doomed to a chronic state of fragmentation and meaninglessness. Within the creative hurricane of modernity, there is emerging a new, global origin story that is as full of meaning, awe, and mystery as any traditional origin story but is based on modern scientific scholarship across many disciplines.[3] That story is far from complete, and it may need to incorporate the insights of older origin stories about how to live well and how to live sustainably. But it is worth knowing, because it draws on a global heritage of carefully tested information and knowledge and it is the first origin story to embrace human societies and cultures from around the world. It is a collective global project, a story that should work as well in Buenos Aires as in Beijing, as well in Lagos as in London. Today, many scholars are engaged in the exciting task of building and telling this modern origin story, looking for the guidance and sense of shared purpose that it may provide, like all origin stories, but for today's globalized world.

My own attempts to teach a history of the universe began in 1989. In 1991, as a way to describe what I was doing, I started using the term *big history*.[4] Only as the story slowly came into focus did I realize that I was trying to tease out the main lines of an emerging global origin story. Today, big history is being taught in universities in many different parts of the world, and through the Big History Project, it is also being taught in thousands of high schools.

We will need this new understanding of the past as we grapple with the profound global challenges and opportunities of the twenty-first century. This book is my attempt to tell an up-to-date version of this huge, elaborate, beautiful, and inspiring story.

Introduction

The forms that come and go—and of which your body is but one —are the flashes of my dancing limbs. Know Me in all, and of what shall you be afraid?

—Imagined words of the Hindu god Shiva, from Joseph Campbell, *The Hero with a Thousand faces*

Utterly impossible as are all these events they are probably as like those which may have taken place as any others which never took person at all are ever likely to be.

—James Joyce, *Finnegans Wake*

We arrive in this universe through no choice of our own, at a time and place not of our choosing. For a few moments, like cosmic fireflies, we will travel with other humans, with our parents, with our sisters and brothers, with our children, with friends and enemies. We will travel, too, with other life-forms, from bacteria to baboons, with rocks and oceans and auroras, with moons and meteors, planets and stars, with quarks and photons and supernovas and black holes, with slugs and cell phones, and with lots and lots of empty space. The cavalcade is rich, colorful, cacophonous, and mysterious, and though we humans will eventually leave it, the cavalcade will move on. In the remote future, other travelers will join and leave the cavalcade. Eventually, though, the cavalcade will thin out. Gazillions of years from today, it will fade away like a ghost at dawn, dissolving into the ocean of energy from which it first appeared.

What is this strange crowd we travel with? What is our place in the cavalcade? Where did it set out from, where is it heading, and how will it finally fade away?

Today, we humans can tell the story of the cavalcade better than ever before. We can determine with remarkable accuracy what lurks out there, billions of light-years from Earth, as well as what was going on billions of years ago. We can do this because we have so many more pieces of the jigsaw puzzle of knowledge, which makes it easier to figure out what the whole picture may look like. This is an astonishing, and very recent, achievement. Many of the pieces of our origin story fell into place during my own lifetime.

We can build these vast maps of our universe and its past partly because we have large brains, and, like all brainy organisms, we use our brains to create internal maps of the world. These maps provide a sort of virtual reality that helps us find our way. We can never see the world directly in all its detail; that would require a brain as big as the universe. But we can create simple maps of a fantastically complicated reality, and we know that those maps correspond to important aspects of the real world. The conventional diagram of the London Underground ignores most of the twists and turns, but it still helps millions of travelers get around the city. This book offers a sort of London Underground map of the universe.

What makes humans different from all other brainy species is language, a communication tool that is extraordinarily powerful because it allows us to share our individual world maps and, in so doing, form maps much larger and more detailed than those created by an individual brain. Sharing also allows us to test the details of our maps against millions of other maps. In this way, each group of humans builds up an understanding of the world that combines the insights, ideas, and thoughts of many people over thousands of years and many generations. Pixel by pixel, through this process of collective learning, humans have built increasingly rich maps of the universe during the two hundred thousand years of our existence as a species. What this means is that one small part of the universe is beginning to look at itself. It's as if the universe were slowly opening an eye after a long sleep. Today, that eye is seeing more and more, with the help of global exchanges of ideas and information; the precision and rigor of modern science; new research instruments, from atom-smashing particle colliders to space-based telescopes; and networks of computers with colossal number-crunching powers.

The story these maps tell us is the grandest story you can imagine.

As a child, I could not make sense of anything unless I could place it on some sort of map. Like many people, I struggled to link the isolated fields I studied. Literature had nothing to do with physics; I could see no connection between philosophy and biology, or religion and mathematics, or economics and ethics. I kept looking for a framework, a sort of world map of the different continents and islands of human knowledge; I wanted to be able to see how they all fitted together. Traditional religious stories never quite worked for me because, having lived in Nigeria as a child, I'd learned very early that different religions offer different, and often contradictory, frameworks for understanding how the world came to be as it is.

Today, a new framework for understanding is emerging in our globalized world. It is being built, developed, and propagated collectively by thousands of people from multiple scholarly fields and in numerous countries. Linking these insights can help us see things that we cannot see from within the boundaries of a particular discipline; it lets us view the world from a mountaintop instead of from the ground. We can see the links connecting the various scholarly landscapes, so we can think more deeply about broad themes such as the nature of complexity, the nature of life, even the nature of our own species! After all, at present we study humans through many different disciplinary lenses (anthropology, biology, physiology, primatology, psychology, linguistics, history, sociology), but specialization makes it difficult for any individual to stand back far enough to see humanity as a whole.

The search for origin stories that can link different types of knowledge is as old as humanity. I like to imagine a group of people sitting around a fire as the sun was setting forty thousand years ago. I picture them on the southern shore of Lake Mungo, in the Willandra Lakes Region of New South Wales, where the oldest human remains in Australia have been found. Today, it is the home of the Paakantji, Ngyiampaa, and Mutthi Mutthi people, but we know that their ancestors lived in this region for at least forty-five thousand years.

In 1992, the remains of an ancestor (referred to as Mungo 1) discovered by archaeologists in 1968 were finally returned to the local Aboriginal community. This person was a young woman who had been partially cremated.[1] Half a kilometer away, remains were found of another person (Mungo 3), probably a man, who died at about age fifty. He had suffered from arthritis and severe dental erosion, probably caused by drawing fibers through his teeth to make nets or cords. His body had been buried with care and reverence and sprinkled with powdered red ocher brought from two hundred kilometers away. Mungo Man was returned to Lake Mungo in November 2017.

Both people died about forty thousand years ago, when the Willandra lakes, which are now dry, were full of water, fish, and shellfish and attracted multitudes of birds and animals that could be hunted or trapped.[2] Life was pretty good around Lake Mungo when they were alive.

In my imagined twilight conversations around the fire, there are girls and boys, older men and women, and parents and grandparents, some wrapped in animal furs and cradling babies. Children are chasing one another at the edge of the lake while adults are finishing a meal of mussels, freshly caught fish and yabbies, and wallaby steak. Slowly, the conversation becomes serious and is taken over by one of the older people. As on many long summer days and cold winter nights, the older people are retelling what they have learned from their ancestors and teachers. They are asking the sort of questions that have always fascinated me: How did the landscape, with its hills and lakes, its valleys and ravines, take shape? Where do the stars come from? When did the first humans live, and where did they come from? Or have we always been here? Are we related to goannas and wallabies and emus? (The answer of both the Lake Mungo people and modern science to that last question is a decisive “Yes!”) The storytellers are teaching history. They are telling stories about how our world was created by powerful forces and beings in the distant past.

Told over many nights and days, their stories describe the big paradigm ideas of the Lake Mungo people. These are the ideas with long legs, the ideas that can stay the course. They fit together to form a vast mosaic of information about the world. Some of the children may find parts of the stories too complex and subtle to take in at first hearing. But they hear the stories many times in different tellings, and they get used to them and to the deep ideas inside the stories. As the children get older, the stories get under their skin. They come to know them intimately and better appreciate their beauty and their subtler details and meanings.

As they talk about the stars, the landscape, the wombats and the wallabies, and the world of their ancestors, the teachers build a shared map of understanding that shows members of the community their place in a rich, beautiful, and sometimes terrifying universe: *This* is what you are; *this* is where you came from; *this* is who existed before you were born; *this* is the whole thing of which you are a small part; *these* are the responsibilities and challenges of living in a community of others like yourself. The stories have great power because they are trusted. They *feel* true because they are based on the best knowledge passed down by ancestors over many generations. They have been checked and rechecked for accuracy, plausibility, and coherence using the rich knowledge of people, of stars, of landscapes, of plants and animals available to the Mungo community and to their ancestors and neighbors.

We can all benefit from the maps our ancestors created. The great French sociologist Émile Durkheim insisted that the maps lurking within origin stories and religions were fundamental to our sense of self. Without them, he argued, people could fall into a sense of despair and meaninglessness so profound, it might drive them to suicide. No wonder almost all societies we know of have put origin stories at the heart of education. In Paleolithic societies, students learned origin stories from their elders, just as later scholars learned the core stories of Christianity, Islam, and Buddhism in the universities of Paris, Oxford, Baghdad, and Nalanda.

Yet, curiously, modern secular education lacks a confident origin story that links all domains of understanding. And that may help explain why the sense of disorientation, division, and directionlessness that Durkheim described is palpable everywhere in today's world, in Delhi or Lima as much as in Lagos or London. The problem is that in a globally connected world, there are so many local origin stories competing for people's trust and attention that they get in one another's way. So most modern educators focus on parts of the story, and students learn about their world discipline by discipline. People today learn about things our Lake Mungo ancestors had never heard of, from calculus to modern history to how to write computer code. But, unlike the Lake Mungo people, we are rarely encouraged to assemble that knowledge into a single, coherent story in the way that globes in old-fashioned classrooms linked thousands of local maps into a single map of the world. And that leaves us with a fragmented understanding of both reality and the human community to which we all belong.

A Modern Origin Story

And yet... in bits and pieces, a modern origin story is emerging. Like the stories told at Lake Mungo, our modern origin story has been assembled by ancestors and tested and checked over many generations and millennia.

It is different, of course, from most traditional origin stories. This is partly because it has been built not by a particular region or culture but by a global community of more than seven billion people, so it pools knowledge from all parts of the world. This is an origin story for all modern humans, and it builds on the global traditions of modern science.

Unlike many traditional origin stories, the modern origin story lacks a creator god, though it has energies and particles as exotic as the pantheons of many traditional origin stories. Like the origin stories of Confucianism or early Buddhism, the modern story is about a universe that just is. Any sense of meaning comes not from the universe, but from us humans. "What's the meaning of the universe?" asked Joseph Campbell, a scholar of myth and religion. "What's the meaning of a flea? It's just there, that's it, and your own meaning is that you're there."[3]

The world of the modern origin story is less stable, more turbulent, and much larger than the worlds of many traditional origin stories. And those qualities point to the limitations of the modern origin story. Though global in its reach, it is very recent and it has the rawness and some of the blind spots of youth. It emerged at a very specific time in human history and is shaped by the dynamic and potentially destabilizing traditions of modern capitalism. That explains why in many forms it has lacked the deep sensitivity to the biosphere that is present in the origin stories of indigenous peoples around the world.

The universe of the modern origin story is restless, dynamic, evolving, and huge. The geologist Walter Alvarez reminds us how big it is by asking how many stars it contains. Most galaxies have something like 100 billion stars, and there are at least that many galaxies in the universe. That means that there are (deep breath) 10,000,000,000,000,000,000,000 (10^{22}) stars in the universe.[4] New observations in late 2016 hinted that there may be many more galaxies in the universe, so feel free to add a few more zeros to this number. Our sun is a pretty ordinary member of that huge gang.

The modern origin story is still under construction. New sections are being added, existing parts still have to be tested or tidied up, and scaffolding and clutter need to be removed. And there are still holes in the story, so, like all origin stories, it will never lose a sense of mystery and awe. But in the past few decades, our understanding of the universe we live in has become much richer, and that may even enhance our sense of its mystery because, as the French philosopher Blaise Pascal wrote: "Knowledge is like a sphere; the greater its volume, the larger its contact with the unknown."[5] With all its imperfections and uncertainties, this is a story we need to know, just as the Lake Mungo people needed to know their origin stories. The modern origin story tells of the heritage all humans share, and so it can prepare us for the huge challenges and opportunities that all of us face at this pivotal moment in the history of planet Earth.

At the heart of the modern origin story is the idea of increasing complexity. How did our universe appear, and how did it generate the rich cavalcade of things, forces, and beings of which we are a part? We don't really know what it came out of or if anything existed before the universe. But we do know that when our universe emerged from a vast foam of energy, it was extremely simple. And simplicity is still its default condition. After all, most of our universe is cold, dark, empty space. Nevertheless, in special and unusual environments such as on our planet, there existed perfect Goldilocks conditions, environments, like Baby Bear's porridge in the story of Goldilocks, that were not too hot and not too cold, not too thick and not too thin, but just right for the evolution of complexity.[6] In these Goldilocks environments, increasingly complex things have appeared over many billions of years, things with more moving parts and more intricate internal relations. We should not make the mistake of assuming that complex things are necessarily better than simple things. But complexity does matter to us humans, because we are very complex, and the dynamic global society we live in today is one of the most extraordinarily complex things we know. So understanding how complex things emerged and what Goldilocks conditions allowed them to emerge is a great way of understanding ourselves and the world we live in today.

More complex things appeared at key transition points, and I will refer to the most important of these as *thresholds*. The thresholds give shape to the complicated narrative of the modern origin story. They highlight major turning points, when already existing things were rearranged or otherwise altered to create something with new, "emergent" properties, qualities that had never existed before. The early universe had no stars, no planets, and no living organisms. Then, step by step, entirely new things began to appear. Stars were forged from atoms of hydrogen and helium, new chemical elements were created inside dying stars, planets and moons formed from blobs of ice and dust using these new chemical elements, and the first living cells evolved in the rich chemical environments of rocky planets. We humans are very much part of this story, because we are products of the evolution and diversification of life on planet Earth, but in the course of our brief but remarkable history, we have created so many entirely new forms of complexity that, today, we seem to dominate change on our world. The appearance of something new and more complex than what preceded it, something with new emergent properties, always seems as miraculous as the birth of a baby, because the general tendency of the universe is to get less complex and more disorderly. Eventually, that tendency toward increasing disorder (what scientists term *entropy*) will win out, and the universe will turn into a sort of random mess without pattern or structure. But that's a long, long way in the future.

Meanwhile, we seem to live in a vigorous young universe that is full of creativity. The birth of the universe—our first threshold—is as miraculous as any of the other thresholds in our modern origin story.

Timeline

This timeline gives some fundamental dates for the modern origin story using both approximate absolute dates and recalculated dates, as if the universe had been created 13.8 years ago instead of 13.8 billion years ago. This second approach makes it easier to get a sense of the chronological shape of the story. After all, natural selection did not design our minds to cope with millions or billions of years, so this shorter chronology should be easier to grasp.

Most of the dates given for events that happened more than a few thousand years ago were established only in the past fifty years using modern chronometric technologies, of which the most important is radiometric dating.

EVENT: THRESHOLD 1: Big bang: origin of our universe
APPROXIMATE ABSOLUTE DATE: 13.8 billion years ago
DATE DIVIDED BY 1 BILLION: 13 years, 8 months ago

EVENT: THRESHOLD 2: The first stars begin to glow
APPROXIMATE ABSOLUTE DATE: 13.2 (?) billion years ago
DATE DIVIDED BY 1 BILLION: 13 years, 2 months ago

EVENT: THRESHOLD 3: New elements forged in dying large stars
APPROXIMATE ABSOLUTE DATE: Continuously from threshold 2 to the present day
DATE DIVIDED BY 1 BILLION: Continuously from threshold 2 to the present day

EVENT: THRESHOLD 4: Our sun and solar system form
APPROXIMATE ABSOLUTE DATE: 4.5 billion years ago
DATE DIVIDED BY 1 BILLION: 4 years, 6 months ago

EVENT: THRESHOLD 5: Earliest life on Earth

APPROXIMATE ABSOLUTE DATE: 3.8 billion years ago
DATE DIVIDED BY 1 BILLION: 3 years, 9 months ago

EVENT: The first large organisms on Earth
APPROXIMATE ABSOLUTE DATE: 600 million years ago
DATE DIVIDED BY 1 BILLION: 7 months ago

EVENT: An asteroid wipes out the dinosaurs
APPROXIMATE ABSOLUTE DATE: 65 million years ago
DATE DIVIDED BY 1 BILLION: 24 days ago

EVENT: The hominin lineage splits from the chimp lineage
APPROXIMATE ABSOLUTE DATE: 7 million years ago
DATE DIVIDED BY 1 BILLION: 2.5 days ago

EVENT: *Homo erectus*
APPROXIMATE ABSOLUTE DATE: 2 million years ago
DATE DIVIDED BY 1 BILLION: 17 hours ago

EVENT: THRESHOLD 6: First evidence of our species, *Homo sapiens*
APPROXIMATE ABSOLUTE DATE: 200,000 years ago
DATE DIVIDED BY 1 BILLION: 100 minutes ago

EVENT: THRESHOLD 7: End of last ice age, beginning of Holocene, earliest signs of farming
APPROXIMATE ABSOLUTE DATE: 10,000 years ago
DATE DIVIDED BY 1 BILLION: 5 minutes ago

EVENT: First evidence of cities, states, agrarian civilizations
APPROXIMATE ABSOLUTE DATE: 5,000 years ago
DATE DIVIDED BY 1 BILLION: 2.5 minutes ago

EVENT: Roman and Han Empires flourish
APPROXIMATE ABSOLUTE DATE: 2,000 years ago
DATE DIVIDED BY 1 BILLION: 1 minute ago

EVENT: World zones begin to be linked together
APPROXIMATE ABSOLUTE DATE: 500 years ago
DATE DIVIDED BY 1 BILLION: 15 seconds ago

EVENT: THRESHOLD 8: Fossil-fuels revolution begins

APPROXIMATE ABSOLUTE DATE: 200 years ago
DATE DIVIDED BY 1 BILLION: 6 seconds ago

EVENT: The Great Acceleration; humans land on the moon
APPROXIMATE ABSOLUTE DATE: 50 years ago
DATE DIVIDED BY 1 BILLION: 1.5 seconds ago

EVENT: THRESHOLD 9 (?): A sustainable world order?
APPROXIMATE ABSOLUTE DATE: 100 years in the future?
DATE DIVIDED BY 1 BILLION: 3 seconds to go

EVENT: The sun dies
APPROXIMATE ABSOLUTE DATE: 4.5 billion years in the future
DATE DIVIDED BY 1 BILLION: 4 years, 6 months to go

EVENT: The universe fades to darkness; entropy wins
APPROXIMATE ABSOLUTE DATE: Gazillions and gazillions of years in the future
DATE DIVIDED BY 1 BILLION: Billions and billions of years from now

PART I

Cosmos

it didn't have striking parallels to the modern idea, embedded in quantum physics, that space is never *entirely* empty but is full of possibilities.

Is there a sort of ocean of energy or potential from which particular forms emerge like waves or tsunamis? This is such a common concept that it is tempting to think our ideas about ultimate beginnings come from our own experiences. Every morning, we each experience how a conscious world, with shapes, sensations, and structures, seems to emerge from a chaotic unconscious world. Joseph Campbell writes: "As the consciousness of the individual rests on a sea of night into which it descends in slumber and out of which it mysteriously wakes, so, in the imagery of myth, the universe is precipitated out of, and reposes upon, a timelessness back into which it again dissolves."[5]

But perhaps this is too metaphysical. Maybe the difficulty is logical. Stephen Hawking argues that the question of beginnings is just badly put. If the geometry of space-time is spherical, like the surface of Earth but in more dimensions, then asking what existed before the universe is like looking for a starting point on the surface of a tennis ball. That's not how it works. There is no edge or beginning to time, just as there is no edge to the surface of Earth.[6]

Today, some cosmologists are attracted to another set of concepts that tug us back to the idea of a universe without a beginning or end. Perhaps our universe is part of an infinite multiverse in which new universes keep popping out of big bangs. This could be right, but at present we have no hard evidence for anything before our own, local big bang. It's as if the creation of our universe was so violent that any information about what it came out of was erased. If there are other cosmological villages, we can't yet see them.

Frankly, today we have no better answers to the problem of ultimate beginnings than any earlier human society had. Bootstrapping a universe still looks like a logical and metaphysical paradox. We don't know what Goldilocks conditions allowed a universe to emerge, and we still can't explain it any better than novelist Terry Pratchett did when he wrote, "The current state of knowledge can be summarized thus: In the beginning, there was nothing, which exploded."[7]

Threshold 1: Quantum Bootstrapping a Universe

The bootstrap for today's most widely accepted account of ultimate origins is the idea of a big bang. This is one of the major paradigms of modern science, like natural selection in biology or plate tectonics in geology.[8]

It wasn't until the early 1960s that the crucial pieces of the big bang story emerged. That's when astronomers first detected the cosmic microwave background radiation—energy left over from the big bang and present everywhere in today's universe. Though cosmologists still struggle to understand the moment when our universe appeared, they can tell a rollicking story that begins about (deep breath, and I hope I've got this precise) a billionth of a billionth of a billionth of a billionth of a billionth of a second after the universe appeared (around 10^{-43} of a second after time zero).

The bare-bones story goes like this: Our universe began as a point smaller than an atom. How small is that? Our species' minds evolved to deal with things at human scales, so they struggle with things this tiny, but it might help to know that you could squeeze a million atoms into the dot at the end of this sentence.[9] At the moment of the big bang, the entire universe was smaller than an atom. Packed into it was all the energy and matter present in today's universe. All of it. That is a daunting idea, and at first it might appear plain crazy. But all the evidence we have at present tells us that this strange, tiny, and fantastically hot object really existed about 13.82 billion years ago.

We don't yet understand how and why this thing appeared. But quantum physics tells us, and particle accelerators—which speed up subatomic particles to high velocities by means of electric or electromagnetic fields—*show* us, that something really can appear in a vacuum from nothing, though grasping what this means requires a sophisticated understanding of *nothing*. In modern quantum physics, it is impossible to determine precisely the position and motion of subatomic particles. This means you can never say for sure that a particular region of space is empty, and that means that emptiness is tense with the possibility that something might appear. Like the "neither non-existence nor existence" of the Indian Vedas, this tension seems to have bootstrapped our universe.[10]

were arranged in new configurations.

At the earliest moment for which we have some evidence, a split second after the big bang, the universe consisted of pure, random, undifferentiated, shapeless energy. We can think of energy as the *potential for something to happen,* the capacity to *do* things or *change* things. The energies inside the primeval atom were staggering, many trillions of degrees above absolute zero. There was a brief period of super-rapid expansion known as *inflation*. Expansion was so fast that much of the universe may have been projected far beyond anything we will ever see. That means that what we see today is probably just a tiny part of our entire universe.

A split second later, rates of expansion slowed. The turbulent energies of the big bang settled down, and as the universe kept expanding, the energies were spread out and diluted. Average temperatures fell, and they have kept falling, so today, most of the universe is just 2.76 degrees Celsius above absolute zero. (Absolute zero is the temperature at which nothing even jiggles.) We don't feel the chill, nor do any of the other organisms on planet Earth, because we are warmed by the campfire of our sun.

In the extreme temperatures of the big bang, almost anything was possible. But as temperatures dropped, possibilities narrowed. Distinct entities began to emerge like ghosts within the chaotic fog of the cooling universe, entities that could not exist in the violent cauldron of the big bang itself. Scientists call these changes of form and structure *phase changes*. We see phase changes in our daily lives when steam loses energy and turns into water (whose molecules move about a lot less than steam molecules) and when water turns into ice (which has so little energy that its molecules just jiggle in place). Water and ice can exist only in a narrow range of very low temperatures.

Within a billionth of a billionth of a billionth of a billionth of a second after the big bang, energy itself underwent a phase change. It split into four very different species. Today, we know them as gravity, the electromagnetic force, and the strong and weak nuclear forces. We need to get acquainted with their different personalities, because they shaped our universe. Gravity is weak, but it reaches across vast distances and always pulls things together, so its power accumulates. It tends to make the universe more clumpy. Electromagnetic energy comes in negative and positive forms, so it often cancels itself out. Gravity, though puny, shapes the universe on a large scale. But electromagnetism dominates at the level of chemistry and biology, so it's what holds our bodies together. The third and fourth fundamental forces are known, unexcitingly, as the strong and weak nuclear forces. They reach over tiny distances, so they matter on a subatomic scale. We humans don't experience them directly, but they shape every aspect of our world because they determine what happens deep inside atoms.

There may be other species of energy. In the 1990s, new measures of the universe's rate of expansion showed that the rate is increasing. Borrowing an idea first floated by Einstein, many physicists and astronomers now argue that there may be a form of antigravity that is present in all of space, so its power increases as the universe expands. Today, the mass of this energy may account for as much as 70 percent of the total mass of the universe. But even if it is beginning to dominate our universe, we don't yet understand what this energy is or how it works, so physicists call it *dark energy.* The term is a placeholder. Watch this space, because understanding dark energy is one of the great challenges of contemporary science.

Matter appeared within the first second after the big bang. Matter is the stuff that energy pushes around. Until just over a century ago, scientists and philosophers assumed that matter and energy were distinct. We now know that matter is really a highly compressed form of energy. The young Albert Einstein demonstrated this in a famous paper in 1905. That formula—energy (E) is equal to mass (m) times the speed of light (c) squared, or $E = mc^2$—tells us how much energy is compressed inside a given amount of matter. To figure out how much energy is locked up in a bit of matter, multiply the mass of the matter not by the speed of light (which is more than one billion kilometers per hour) but by the speed of light *times itself.* This is a colossal number, so if you uncompress a tiny bit of matter, you get a huge amount of energy. That's what happens when an H-bomb explodes. In the early universe, the opposite process occurred. Huge amounts of energy were compressed into tiny amounts of matter, like motes of dust in a vast fog of energy. Remarkably, we humans have managed to re-create such energies briefly, in the Large Hadron Collider outside Geneva. And, yes, particles do start popping out of that boiling ocean of energy.

And we're still in the first second...

The First Structures

Within the chaotic fog of energy just after the big bang, distinct forms and structures began to appear. Though the fog of energy is always there, the structures that emerged from it will give our origin story shape and a plotline. Some structures or patterns will last for billions of years, some for a split second, but *none* are conserved. They are evanescent, like waves on the ocean's surface. The first law of thermodynamics tells us that the ocean of energy is always there; it's conserved. The second law of thermodynamics tells us that all the forms that emerge will eventually dissolve back into the ocean of energy. The forms, like the movements of a dance, are *not* conserved.

Some distinct structures and forms emerged within a second of the big bang. Why? Why is the universe not just a random flux of energy? This is a fundamental question.

If our story had a creator god, explaining structure would be easy. We could just assume (as many origin stories do) that God preferred structure to chaos. But most versions of the modern origin story no longer accept the idea of a creator god because modern science can find no direct evidence for a god. Many people have *experiences* of gods, but those reported experiences are diverse and contradictory, and they cannot be reproduced. They are too malleable, too diffuse, and too subjective to provide objective, scientific evidence.

So the modern origin story has to find other ways of explaining the emergence of structures and forms. And that's not easy, because the second law of thermodynamics tells us that sooner or later, all structures will eventually break down. As the Austrian physicist Erwin Schrödinger wrote: "We now recognize this fundamental law of physics to be just the natural tendency of things to approach the chaotic state (the same tendency that the books of a library or the piles of papers and manuscripts on a nebulae? What exactly were they? Were they moving? Over time, astronomers have learned how to tease out more and more information about stars from the light they emit. That information includes their distance from us and whether they are heading closer or moving away.

One of the cleverest methods to study the movement of stars and nebulae uses the Doppler effect (named after the nineteenth-century Austrian mathematician Christian Andreas Doppler) to measure the speed at which stars or nebulae are moving toward or away from us. Energy travels in waves, and waves, like those at the beach, have a frequency. They reach peaks at a regular pace that you can measure. But the frequency changes if you move. If you get in the ocean and swim out, the frequency at which you encounter waves will seem to increase. The same thing happens with sound waves. If an object, such as a motorbike, is making a noise and moving toward you, the frequency of the sound waves will seem to increase, and your ears will interpret the higher frequency as a higher pitch. After it passes you, the pitch will seem to drop, because now the waves are being stretched out. The rider, of course, is not moving relative to the motorbike and keeps hearing the same pitch. The Doppler effect is the apparent change in frequency of electromagnetic emissions as objects move toward or away from each other.

The same principle works with starlight. If a star or galaxy is moving toward Earth, the frequency of its light waves will seem to increase. Our eyes interpret higher-frequency visible light as blue light, so we say it has shifted toward the blue end of the electromagnetic spectrum. But if it is moving away from Earth, the frequency of its light will seem to shift toward the red end of the spectrum; astronomers say it is redshifted. And we can tell how fast a star or galaxy is moving by measuring how much the frequency has shifted.

In 1814, a young German scientist, Joseph von Fraunhofer, created the first scientific spectroscope, a specialized prism that splits up the frequencies of starlight just as a glass prism splits light into the colors of the rainbow. Fraunhofer found that spectra from sunlight had thin dark lines at particular frequencies, like cosmological bar codes. Two other German scientists, Gustav Kirchhoff and Robert Bunsen, eventually showed in the lab that

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