

# ABOUT TIME

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*From Sun Dials to Quantum Clocks,  
How the Cosmos Shapes Our Lives – and  
We Shape the Cosmos*

ADAM FRANK



ONE WORLD

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*Prologue*

BEGINNINGS AND ENDINGS

ROCHESTER, NEW YORK, USA • APRIL 16, 2007, 3:20 P.M.

The girl in the third row raises her hand and I know I'm in trouble.

The lecture hall is packed with students. In front, the perennially scribbling pre-meds have put down put their pens. Usually desperate for any fact that might appear on the exam, this term's crop of grade hunters have stopped blindly transcribing everything I say and are, for the first time all year, simply listening. In the way back, the line of identical frat boys with their matching baseball caps are actually paying attention to the lecture rather than hiding behind their newspapers or whispering to the cute sorority girls clustered around them.

This is the class I cherish. From years of teaching I know this is the subject everyone cares about. I am deep into the cosmology lecture of my Astronomy 101 class. Today it's all Big Bang and cosmic origins, and the students are wide-eyed. For this one hour, the windows of the universe will open up for them. For this one hour, they will climb out of their day-to-day concerns about grades and careers and getting laid and briefly stand in wonder at the deepest questions their species has learned to ask . . . *and answer*:

I don't expect these students to pay such rapt attention to my other lectures: the ones on stellar evolution, the history of astronomy or comparative planetology. But with the Big Bang I know their attention will be fixed for long enough to briefly catch a glimpse of our communal place in the fabric of creation. And, within this hour, I also know that

sooner or later someone is going to break the spell and ask that one damn question.

“Professor?” she calls out. Sophie is her name. She is one of the students on fire with the subject this year—earnest, intelligent, alive to the big mysteries an astronomy class naturally washes up against. *OK, I think, here it comes.* I tell her to go ahead.

“But Professor,” she begins, “what happened *before* the Big Bang?”

The usual vertigo closes in. *Yeah, I think, that’s a good question. What the hell did happen before the Big Bang?* There is a long pause as the class waits expectantly. As if I, or anyone else, really have the answer.

**4:08 p.m.** I have lost them. Looking across the hall, I can see the mystery has dissipated. The real world has returned. The class is supposed to end at 4:15. Still in the thick of the lecture, I have already strayed too close to that imaginary deadline that marks the end of class. My story of cosmic creation has lost its urgency and become a death march of facts and details. The beginning of time and the nature of time both have become abstractions. Time and the cosmos shrink, congealing into the urgencies of *now*: the next class, the homework review session, the hoped-for hour at the gym, the coffee appointment with friends.

It is still too early for them to gather up their books and begin the shifting and rustling that mark the end of class. Instead, the students sit and feel the minutes collapse slowly—so slowly—into an ooze of boredom. They are caught in a purgatory of waiting, an empty place mediated only by their devices and technology. Some watch the minutes tick off on their open laptops. Others fill the wait by sending instant messages to friends across the quad or across the continent. Others see the abstraction of time become concrete on their mobile phones, each little box connected to a global cadence of milliseconds passing through waves of electromagnetic energy and information. While I continue to lecture about time and the universe, the students feel their own experience of both weighing down on them. If only they knew how closely connected their personal worlds were to the sweep of cosmic history I am recounting. And if only they understood how much it was all about to change.

## IT'S ABOUT TIME

This book tells two stories that are braided so tightly they cannot be separated, even if they have never been told together before. Like my cosmology lecture that April day in 2007, the twin narratives I am about to unfold encompass the grandest conception of the universe we human beings have been able to imagine and explore. At the same time they embrace our most intimate and most personal experience of the world—the very frame of human life.

This book is about time, both cosmic and human.

The subject of time can transport us to the deepest levels of reflection. By looking out into the depths of space, we are always looking back in time and so, on its largest scale, our science of the universe is also, always, a story about the depths of time. There are many books—philosophical, technical and popular—on the nature of time as we experience it. There are just as many books telling the story of cosmic time by recounting the grand story of scientific cosmology. But there are few instances where we stop to ask how our stories about the universe's time are intimately wedded to the texture of time in our daily lives. Now there is a compelling reason to recount the braided narratives of cosmic history and human time as a unified whole: *the Big Bang is all but dead, and we do not yet know what will replace it.*

There are those who will tell you that cosmology—the study of the universe entire—has become an exact science. They will tell you that this grand and all-embracing field has, in the last fifty years, moved from the realms of philosophical speculation into the purest domains of science via exacting confrontations between theoretical models and high-resolution data. You should know that they are right. For the first time in the long march of human thinking we are now, finally, able to construct a detailed and verifiable account of cosmic history.

So when I tell you that the Big Bang is dead, I am not referring to the story that begins with a universe far hotter and far denser than what we see today. I do not mean the story of a universe expanding, of matter cooling and congealing over billions of years into stars and galaxies.

That story, the scientific narrative of cosmic evolution over the last 13.7 billion years is, for all intents and purposes, secure.

It is the beginning, the genesis, that stands ready to be replaced. The singular and all-important moment of creation at the beginning of the Big Bang—the beginning of time and existence—is poised to be swept aside. In other words, it's the bang in the Big Bang that we, in our endless quest to understand the world, are ready to abandon. That single moment of creation with no before has been done in by the very precision of the science that gave the idea a measure of reality.

Now it appears that science is ready to go beyond, and before, the Big Bang. Cosmology is waiting at the precipice of its next great revolution. The only question is where—or, better yet, when—do we go from here? We are ending the beginning and beginning down another path.

Cosmology and its impending reformation form the first narrative line of this book. If we are to understand how our grandest theories of the universe are about to change, we must first understand how we got to the Big Bang in the first place. Along the way we will encounter the most potent ideas of modern physics from Einstein's theory of relativity to the powerful but paradoxical realm of quantum mechanics and subatomic physics. In this first story we will explore cosmological foundations so that, when the moment comes, we will be ready to imagine the range and meaning of the Big Bang's bizarre alternatives.

And this is all about time. The roots of cosmology cannot be reworked without a new conception of time, including its origins and its physical nature. In Big Bang cosmology physicists imagined time to simply begin, like God firing up the engine on his cosmic Porsche. Alternative cosmologies, hovering just across the horizon, must replace that vision with something new.

Time, however, is slippery stuff. In both our abstract ideas about time and our attempts to understand its direct experience we are always walking on thin ice. Our scientific theorizing about time must always, at some point, meet our concrete, day-to-day movement through it. But where is that point? If the science of cosmology is about to re-imagine time, then how will that affect the way we experience time from moment to moment?



That question forms the heart of this book's second narrative. If the first story leads us to the precipice of modern cosmology, the second story tells what might be called the social history of time—a history of lived time. And in that second story there awaits a radical truth: as our ideas about cosmology and cosmic time have changed, human time has changed too. The industrial revolution, with its roots in the scientific discoveries of Newton and its radical reformation of human life, is perhaps the most potent and obvious example of the binding of human and cosmic time. Throughout the 1700s, new universal laws of physics pioneered by Newton reworked human conceptions of the heavens. Then, in time, Newton's mechanics became the blueprint for machines unlike anything human culture had built before, laying the ground for the triumph of industrialism. As workers filed into their new punch-clock lives of efficient production their world echoed the new clockwork universe of planets clicking through their orbits governed by economical rules of gravity and motion. Human time and cosmic time had been partnered in mutual transformation. But the two times—cosmological and human—had always been intertwined, and there was never an age when they could be cleanly separated.

The brute facts of time and nature are simple—the day lasts from sunrise to sunset—but from that point onward the simplicity ends. Our sense of social and personal time has been transformed and rebuilt in the many revolutions since we awoke to self-consciousness fifty thousand years ago. From hunter-gatherer tribes to the development of agriculture to the industrial revolution, our encounters with time have been reshaped again and again. Yet unrealized, the resonance between human and cosmic time is the essential instrument in this story of transformation. Cultures need a cosmology to understand their place in the greater framework of creation. But cosmologies—mythological or scientific—are collaborative creations that spring from the collective efforts and resources of entire cultures. When cultural time and cosmic time change, they change together. In an era dominated by scientific advancements, the simple assumption would be that new technologies lead the way, creating new cosmological narratives that also reshape culture. As we will see, the truth is far richer. The imperatives of changing culture or

changing cosmology are always pushing back and forth on each other. At some moments in history one side takes the lead in changing time, and at other moments it's the other side that surges forward to initiate change. But always and again, time—both cosmic and human—has changed in ways that we have yet to fully comprehend.

Ask a friend what time it is and he might look at his watch and respond that it is 1:17 p.m. But what is 1:17 p.m.? What is the meaning of such an exact metering of minutes? There is nothing innate, objective or God-given about this kind of time. As we shall see, mechanical clocks did not appear until the fourteenth century, and they did not even have minute hands (an invention that would take approximately another three hundred years to appear). Did 1:17 p.m. even exist one thousand years ago for peasants living in Dark Ages Europe, Song Dynasty China or the central Persian Empire? Was there such a thing as 1:17 p.m. in the long millennia before the vast majority of human beings had access to any form of timekeeping device?

But 1:17 exists for you. As a citizen of a technologically advanced culture replete with omnipresent time-metering technologies, you have felt 1:17 in more ways than you probably want to think about.

How often have you found yourself on time for a train, a bus or an appointment that was scheduled as an exact block on your electronic calendar? Then, somehow, a delay appeared. The bus was late, the train had not yet arrived, the appointment was pushed back. Suddenly you are forced into the purgatory of waiting. Through the mediation of your watch or your mobile phone (with its automatically updating time-zone compliant chronometer), you feel those minutes crawl past just as my students felt the weight of their minutes until the lecture ended: 1:11, 1:15, 1:17. They drag on breeding frustration, boredom and anger. For you, those minutes are real.

Measured against the long arc of human evolution, this experience of time is something new and very radical. You feel time in a way that nobody did a thousand years ago. In 2000 BCE or 850 CE there was no culturally agreed-upon 1:17 p.m. For the vast majority of human existence, there was only “after lunch” or “in the afternoon”.

It's a new time that we have created in our hyperdigital, telepresent,

instant-messaged society. Connected simultaneously to all points of a GPS-mapped globe, we struggle to get that last batch of e-mails sent out before the 2:30 meeting, only to watch helplessly as a new batch appears. It's a new time we have invented, and it appears to have left us with no time at all.

If the time we live by is something new in human evolution, is it real? If other cultures moved through each moment of their days in entirely different ways, then how concrete is 1:17 p.m., with all the import, urgency and meaning we ascribe to it? As we shall see, the time we imagine for the cosmos and the time we imagined into human experience turn out to be woven so tightly together that we have lost the ability to see each of them for what it is.

Our cosmologies are soaked in time and have shaped the worlds of culture and experience. Our cultures are soaked in time and have shaped our grandest imaginings of cosmology, from myth down to the exacting science and technologies we encounter today. This braiding of science and culture is a story that we are unused to telling. It is easy to think of science as some kind of lumbering giant picking up brute facts and handing them to us in the form of revolutionary technologies (mobile phones, atomic weapons, antibiotics). But the knife-sharp separation of science from other human endeavours such as art, politics and spiritual longing is too abstract to be true or helpful. We want to glimpse the ways our science shapes, and is shaped by, experience and the culture it creates. That task demands we ask the deepest questions of all about the nature of time, the cosmos and their beginnings.

## FROM HERE TO THE BEGINNITY: THE STORY OF SCIENTIFIC COSMOLOGY

The story of modern cosmology starts now and moves in reverse. That is how we astronomers and physicists have learned to piece together the story of the Big Bang. We begin with what we see around us—galaxies flying apart, carried along with the flow of space and time—an expanding universe. Then we imagine running the film of that expansion

backwards. The galaxies crowd together rather than rush apart. Space becomes dense, the galaxies dissolve, and atoms are slammed into each other, reaching towards infinite density. The heat released drives the temperature of the entire universe towards impossible heights, until we are back at that singular moment—the unimaginable beginning when time itself was born.

The first cosmologies were the myths of our distant ancestors. In their stories of sky gods and mother goddesses, one finds the same explanatory impulse that drives our modern scientific efforts. What is new in our scientific and technological versions of the cosmological narrative is the all-important ability to test our stories against the data. We can ask the universe if we are right and see if it agrees. But Big Bang cosmology is not really one story; it is many. It is an interlocking web of scientific narratives about the nature of reality. Forged in earthbound laboratories, astronomical observatories and the imaginations of theoretical physicists across the last five hundred years, it is a culmination, one of our greatest achievements as a culture. If we are to understand the Big Bang—its triumphs, its failures and the horizon of possibilities that could replace it—we will have to cover a broad landscape of physics and astronomy. We must obtain a complete view of where we are now so that we may be prepared to imagine what comes next.

To understand the Big Bang and its looming alternatives, we must cover a terrain that has a wild topography of remarkable beauty and range, shaped by nature's deepest laws. Passing across that landscape, we will, in the chapters that follow, explore the foundations of modern physics—Einstein's theory of relativity, quantum and particle physics, thermodynamics and astrophysics. We will linger long enough with these fundamental ideas to gain a sense of how the universe has taken the form we see through our eyes and our telescopes.

Crossing this terrain will take us to the precipice we now face. For all their power, our two greatest theories of physics—quantum mechanics and Einstein's theory of gravity (called general relativity)—face a single great failing: they cannot talk to each other. The domains of the very small (quantum physics) and the domains of the very large (gravity) cannot be reconciled. After fifty years of trying, we still lack that holy

grail of physics, a theory of quantum gravity—a theory of space and time on scales so small entire universes could be bound in an atom. To understand the bang in the Big Bang, we need quantum gravity. Consequently, our cosmology remains incomplete.

The search for quantum gravity and the ideas it entails will form one part of our story. The problems and paradoxes that have plagued the Big Bang will form the other. To rescue Big Bang cosmology from its own best data, astronomers and physicists were forced to imagine events occurring in the early universe—the barest instants after creation—which have shaken the very concept of a “moment of creation”. Together with the attack on quantum gravity, the rescue of the Big Bang has led to a Wild West of new ideas that throw open the frontiers of space, time and creation. The last part of our story will be the exploration of these frontiers.

Could there have been not just one bang but recurring ones? Could our universe be only one in a long line of cycles? Could there be many bangs going off all the time, creating an infinite number of simultaneously existing universes—a multiverse of infinite possibilities? Perhaps, more radically still, our entire conception of time is wrong. Perhaps time is an illusion. Perhaps there is no passage from one moment to the next. Once we have gained a view of where we stand now, in the midst of our cherished but ill-fated Big Bang theory, we can explore these and other possibilities as we look to the future of cosmology and our concept of time itself.

## FROM THE BEGINNING TO BEING-HERE- NOW: THE STORY OF HUMAN TIME

Building cosmologies is an old, old business for us. Myths and religion have conceived of Big Bangs before. But that didn't make it any less of a surprise when scientists found that their own pathways of investigation led them towards  $t = 0$ , with its echoes of a biblical moment of creation. What many of them didn't know was that even alternative cosmological models had antecedents in mythology and religion.

The human engagement, construction and invention of time began with our mental awakening. Archaeologist Steven Mithen calls this, appropriately, the “Big Bang of consciousness”, and it remains as mysterious and enigmatic as the origin of the cosmos. Two thousand generations ago, deep in the cold of the last ice age, we humans awoke to the predicament of ourselves in time. In order to cope, we invented new forms of social organization and new ways of thinking that set the species on an unprecedented evolutionary trajectory. We invented culture and in doing so invented ourselves.

It began some seventy thousand to forty thousand years ago with the burying of the dead. Death has always been a portal to time’s great mystery. By ending time (at least as we know it) for the self, death acts as an invitation to consider time’s reality and its meaning. We felt this even in the early stages of our cultural development. Arranging the departed into huddled postures of repose, we lay our loved ones in graves with precious goods, such as beads and knives, that signified an awareness of death as time. Later, on cave walls and rock cliffs, we began to leave a permanent record of our interior response to the world in art that remains haunting to this day. In these caves covered in paintings of bison and mammoths, archaeologists have also found flutes made of bone, and carvings on bone fragments that seem to trace the phases of the moon. As a species, we awoke not only to symbolic expression through art but also to the explicit experience of time through internal rhythms expressed in music and external rhythms we noticed in the sky.

Personal time and cosmic time have been linked from the earliest origins of culture. When the development of agriculture followed the retreating glaciers, some twelve thousand years ago, a new sense of time emerged with it. Farming led to surplus and wealth, villages turned into towns, towns turned into cities, and cities grew into empires. In each stage, new encounters with time would emerge that were born directly from the material needs of the culture. It was through a direct, embodied engagement with the material world—what we made, how we made it and how that changed the way we organized ourselves—that time itself changed. Each culture shaped its day-to-day life through the

technologies it built and through its “institutional facts”—the invented social reality the technologies allowed and supported.

But cultures (with their invented institutions) need justification and support. They need to set themselves against a cosmic background to give individual and collective lives meaning. The central theme of this book will be to explore the enigmatic entanglement that tied human time to the cosmological narratives of sky and stars, origins and final endings.

It is crucial to recognize that each grand change in human history has shifted more than merely ideas about time. Instead, it is the experience of time, its felt contours, that have been transformed. To understand that story, and to see how closely connected our direct encounters with time are to cosmological imaginings about it, we must travel a path parallel to the one we take in our exploration of physics and astronomy. A Palaeolithic farmer moved through his day and experienced time in a radically different way than did a merchant living in the great city of Babylon. The human encounter with time is fluid and malleable. It can and will change again.

Thus, our story of human time will begin fifty thousand years ago with our hunter-gatherer ancestors and move through experiences of the first farmers and city builders. It will take on new themes as the Renaissance begins and clocks are first introduced to town squares. With the industrial revolution, an entirely new form of time comes to dominate culture, and a new politics follows in its footsteps. As the twentieth century begins, the electrified world gives birth to yet another form of encountered time that presages our own wireless world. Then, with the dawn of the space age and the digital revolution, we arrive at our own home in the age of precision, just-in-time, never-enough-time.

By recounting the narrative of our time, in step with our emerging understanding of cosmic time, we will be in a better place to see where we are now and what other times we might create.

We must note that there were (and are) many trajectories of development for human culture. In this book we will focus on the broad sweep of history, science and time but in doing so we focus primarily on the trajectory of cultural development associated with the West.

This makes sense, of course, because science and scientific cosmology emerged from traditions born in what historian Ian Morris calls the “Western core”—Mesopotamia, Egypt, Greece and so on.<sup>1</sup> We should remain mindful, however, that the traditions that emerged in the Eastern core—China, Korea and others—had their own cultural uses for time and their own cosmological visions for it as well. Now that science has become truly global it may be that our future will see metaphors associated with these other traditions finding their way into cosmological theorizing and the cultural constructions of time. It is a possibility we must not lose sight of as we look forward.

## THE REDISCOVERY OF MAN

It’s only 9:00 a.m. in Lindos and the sun leans hard on my astronomer friend and me as we climb the narrow steps to the top of the cliff. We slept on the beach last night, knowing it would be the only way to reach the temple before the impossible heat and the crowds arrive.

Lindos is a small coastal town on the Greek island of Rhodes. Here, some twenty-five hundred years ago, on a granite promontory that rises dozens of metres above the sea, the Greeks built a temple to the goddess Athena. From the beach below it’s a staggering sight—an acropolis hanging in the air. Now, as we reach the top of the stairs and walk out onto the temple grounds, it’s overwhelming.

We came to this island not as sightseers but for a business that stretches as far back as this temple. All week we have been attending a conference on astronomy. My companion and I both study star formation—a branch of astronomy that focuses on the assembly of stars and planets from vast clouds of dusty interstellar gas. Along with 150 other astronomers, we gathered at a resort hotel on the other side of the island to share new data, new models and new insights into the early lives of stars very much like the one beating its light and heat down on us now. We must have looked odd to tourists, with our penchant for staying indoors all day, huddled in a dark meeting hall, staring at endless sets of PowerPoint slides.



Locating this conference in Rhodes was not an arbitrary choice for its organizers. Two thousand years ago the city of Rhodes was the home of Hipparchus, the greatest of ancient Greece's observational astronomers. In the days when this temple was home to priests servicing Athena's concerns on Earth, Hipparchus was busy in the city cataloging the starry skies.

I stand under the towering columns of the temple to shield myself from the ferocity of the sun and stare into an impossibly empty sky and an unyieldingly blue Aegean. Here, at a temple where each day would be metered by prayers to the gods, on an island where true astronomical investigation gained an early foothold, the glue binding human and cosmic time seems as concrete as the giant stone columns standing guard over the ocean.

What began here has been continuously reshaped in a long march leading directly to the cosmos my colleagues and I explored at last week's meeting. Now all of us—scientist and nonscientist alike—are about to start this march anew even if we do not recognize it. We are ready to end one kind of time and one kind of universe. We are ready to end the beginning and to begin again.