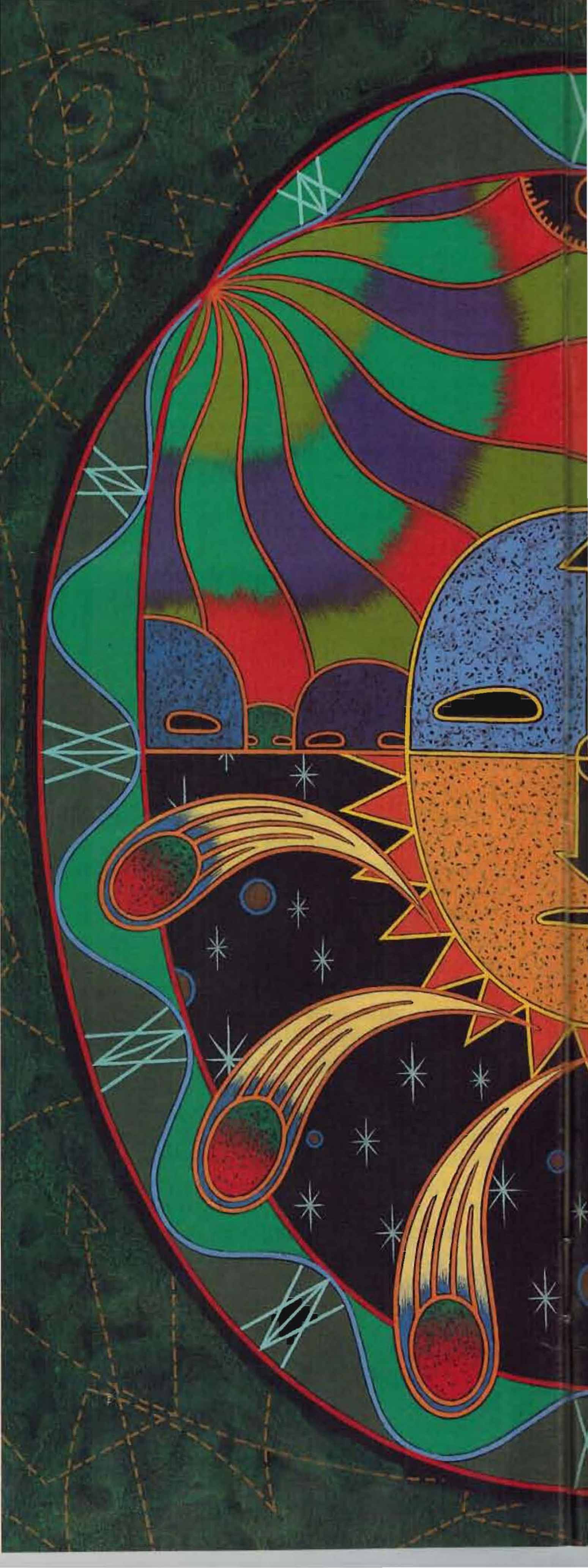
WHEN THE UNIVERSE BEGAN, WHAT TIME WAS IT?

To learn how the cosmos blossomed out of a subatomic point, theorists must first settle a fundamental question of chronology: Is there some hypothetical clock that can track the sequence of events, or is time, at the smallest of physical scales, irrelevant?

BY

MARCIA BARTUSIAK

ILLUSTRATIONS: STÉPHAN DAIGLE



TIME

is an elusive notion. Poets often think of time as a river, a free-flowing stream that carries us from the radiant morning of birth to the golden twilight of old age. It is the span that separates the delicate bud of spring from the lush flower of summer.

• • • • • • • • Physicists think of time in somewhat more practical terms. For them, time is a means of measuring change—an endless series of instants that, strung together like beads, turn an uncertain future into the present and the present into a definite past. The very concept of time allows researchers to calculate when a comet will round the sun or how a signal traverses a silicon chip. Each step in time provides a peek at the evolution of nature's myriad phenomena.

• • • • • • • • In other words, time is a tool. In fact, it was the first scientific tool. Ancient astronomers meticulously tracked the sun's march across the Zodiac in order to mark off the seasons and determine when to plant and harvest. In this day and age, solar timepieces have been replaced by atomic clocks that, thanks to the steady

pulsing of hydrogen or other atoms, do not gain or lose a second in millions of years. Time can now be sliced into slivers as thin as one 10-trillionth of a second.

But what is being sliced? Unlike mass and distance, time cannot be perceived by our physical senses. We don't see, hear, smell, touch, or taste time. And yet we somehow measure it. Captivated by this conundrum, physicists are beginning to explore the very origins of time. And on first look, they are wondering whether time is a fundamental property of the universe at all. Maybe it is solely a personal experience, set up by our minds to distinguish then from now. As the joke goes, "Time is nature's way of preventing everything from happening all at once."

Such thoughts are more than philosophic. As a cadre of theorists attempt to extend and refine the general theory of relativity, Einstein's momentous law of gravitation, they have a problem with time. A big problem.

"It's a crisis," says mathematician John Baez, of the University of California at Riverside, "and the solution may take physics in a new direction." Not the physics of our everyday world. Stopwatches, pendulums, and hydrogen maser clocks will continue to keep track of nature quite nicely here in our low-energy earthly environs. The crisis arises when physicists attempt to merge the macrocosm—the universe on its grandest scale—with the microcosm of subatomic particles.

Gravity is the weakest of nature's forces: a toy magnet can easily pick up a paper clip against the gravitational pull of the entire earth. But gravity gains collective strength as masses accumulate and exert their effect over larger and larger distances. The force that causes one object to attract another eventually comes to control the motions of planets, stars, and galaxies. And the best description of how that happens is contained in Einstein's general theory of relativity, introduced in 1915. But the domain in which this theory works is limited; it does not apply to problems at the subatomic scale. For decades, physicists have struggled to discern how gravity acts on the level of elementary particles, a realm governed by the quite different set of rules laid down by quantum mechanics. Arranging this rather curious marriage—an all-embracing theory of "quantum gravity"—is one of physics' last great tasks.

There is a vital reason for physicists' dogged pursuit of this problem. They believe that quantum gravity was the dominant force at the birth of the universe, during the first tiny 10^{-43} second (one ten-millionth of a trillionth of a trillionth of a trillionth of a second). It was an instant when all the matter and energy in the universe was squeezed into a space far smaller than a proton. The microcosm and the macrocosm, in effect, were crushed together in a "singularity," a freakish state where density advances toward infinity and volume approaches zero.

By figuring out the physics of such a bizarre realm, theorists may at last find the key to the origins of the universe, how it came into existence. Simultaneously, they would be learning what lies at the heart of a black hole, the gravitational abyss that is thought to result when the core of an exploding star is crushed inward until its size becomes atomic rather than celestial.

A solution to this mystery, it turns out, lies in understanding the meaning of time: how it acts—and whether it even exists—at the moment of creation or deep within a black hole. Telling time, after all, involves picking out something in the world around you that is changing—the sun rising and setting, pendulums swinging—and tracking those changes to establish a chronology. With a clock, one can determine the sequence of events; and with a sequence of events, one can properly analyze the behavior of a system—in other words, "do the physics." But how do you register time, the most basic widget in a physicist's toolbox, when the entire mass of a stellar

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core is squeezed into a subatomic speck? Or when the entire visible universe is in such a state? What kind of clock could physicists possibly use to deal with the crushing and featureless conditions that marked the universe's birth, when quantum gravity was in control?

The problem is really a mathematical one but can be visualized in this crude way: Imagine you could somehow shift a magical gear into reverse and travel back some 15 billion years to that moment of creation. For most of the trip, a wristwatch would work just fine in keeping track of time. But upon reaching the very cauldron of creation, the watch would melt in a nanosecond. You could still keep track of time through the constant vibrations of individual atoms, the basis of atomic clocks. But go back far enough and even atoms cease to exist. Soon there is no longer any means of measuring the progress of events. During that primordial moment when the force of quantum gravity was strongest and the cosmos was tinier than a nuclear particle, there was essentially no room to place a clock, safe from interference, and gauge how the universe was evolving.

This dilemma summarizes the problem of time in physics. Either theorists come up with a "quantum clock," a means of understanding and dealing with the passage of time in that minuscule province where gravity and the quantum world mingle (at least on paper), or they do away with the concept of time altogether.

"The problem of time is one of the deepest issues in physics that must be addressed," says theoretical physicist Christopher Isham of Imperial College in London. And more than timekeeping is at stake here. There will be no Theory of Everything—no peek at "the mind of God," as the Cambridge University cosmologist Stephen Hawking so famously put it in *A Brief History of Time*—until this mystery is resolved. Time plays such an integral role in most laws of physics that physicists are starting to worry: without a sense of time, a definable clock at the moment of creation, will it be possible to explain all of nature's varied forces with one unified law? The question has been lurking in the background, like some crazy relative hidden away in the attic, as physicists seek that Holy Grail.

NEWTON'S CLOCK TAKES A LICKING

Time became a key word in the language of physics during the seventeenth century, notably when Isaac Newton wove the passage of time directly into his equations, as in *force = mass x acceleration*. Today, it is difficult for any physicist to examine the universe without thinking of time in much the same way as the illustrious Briton did more than 300 years ago. Most of the laws of physics continue to be written in the style of Newton; they are designed to show how things change from one moment to the next. Each event under study, such as the path of a ball thrown into the air or the thermodynamics of a melting ice cube, is broken down into a series of freeze-frames that, run like a movie, show how nature works.

NEWTON: A MINUTE IS A MINUTE.

Newton had placed a clock upon the mantel of the universe. This Newtonian timepiece ticked and tocked, chiming like some cosmic Big Ben, in step with all celestial inhabitants, no matter what their speed or position. That meant that a clock situated at the edge of the universe or zipping about the cosmos at high velocities would register the same passage of time, identical minutes and identical seconds, as an earthbound clock. More important, the Newtonian clock was never affected by the events going on around it. Time was aloof and absolute, alike for all as galaxies collided, solar systems formed, and moons orbited planets. Time led an independent existence, separate from nature itself.

This comfortable notion of time held until the beginning of this century, but then it was shattered with a jolt. Albert Einstein uncovered a glitch in Newton's cozy clockwork. With his special theory of relativity, published in 1905, Einstein showed that a clock at rest and a clock in motion do not necessarily agree with one another. Each registers a different flow of time. This effect is well documented: a muon particle (a heavy electron) racing in from space at near the speed of light, for instance, lives many times longer than a muon at rest on earth. What Einstein did was transform time into a true physical entity, one that was changed by what was going on around it. With special relativity, physicists learned that time is not absolute, as Newton had us think. Time, it turns out, is in the eye of the beholder and in the beholder's surroundings.

SPECIAL RELATIVITY

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Three years after this revelation appeared in print, Einstein's teacher Hermann Minkowski took Newton's clock off the mantelpiece and rolled it out like cookie dough to form the cosmic landscape called space-time. Minkowski, wanting to better explain some of special relativity's

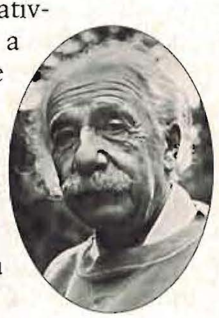
PHOTOS: BETTMANN ARCHIVE

unusual properties, glued space and time together to form a seamless canvas, a new absolute framework in which time becomes physically connected to space. If you think of the space-time coordinates as the interwoven threads of a blanket, tweaking one set of threads will affect all the others: travel near the speed of light and space will shrink as time expands. "Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows," remarked Minkowski. Time alone can no longer be separated from the mix.

In 1915, with his revolutionary general theory of relativity, Einstein shook up the classical, Newtonian view of time even further. He took the novel image of space-time and warped it, and in so doing was able to explain the origin of gravity, long a mystery. According to Newton, rocks fell to earth and planets orbited the sun because these objects were somehow held by invisible tendrils of force. Why should this be so? No one knew. But with Einstein's insight, the tendency of one object to attract another object became a simple matter of geometry. It was the natural consequence whenever a mass distorted the space-time canvas. A massive body—the sun, for example—indents the mat (much the way our bodies can sink into a flexible mattress), and nearby objects must then circle it because they are caught, like cosmic marbles, in the deep space-time basin carved out by the sun.

THINGS *begin to go a little crazy when you attempt to blend the law of gravity—which requires no special clock—with the subatomic rules of quantum mechanics.*

General relativity treats time very differently from the way it's handled in other areas of physics. Under Newton, time was special. Every moment was tallied by a universal clock that stood separate and apart from the phenomenon under study. In general relativity, this is no longer true. Einstein declared that time is not absolute—no particular clock is special—and his equations describing how the gravitational force works take this into account. His law of gravity looks the same no matter what timepiece you happen to be using as your gauge. "In general relativity time is completely arbitrary," explains Imperial College's Isham. "The actual physical predictions that come out of general relativity don't depend on your choice of a clock." The predictions will be the same whether you are using a clock traveling near the speed of light or one sitting quietly at home on a shelf.

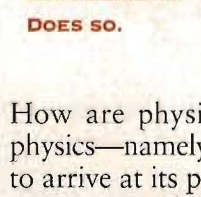


EINSTEIN: GOD DOESN'T PLAY DICE.

The choice of clock is still crucial, however, in other areas of physics, particularly quantum mechanics. It plays a central role in Erwin Schrödinger's celebrated wave equation of 1926. The equation shows how a subatomic particle, whether traveling alone or circling an atom, can be thought of as a collection of waves, a wave packet that moves from point to point in space and from moment to moment in time.

According to the vision of quantum mechanics, energy and matter are cut up into discrete bits, called quanta, whose motions are jumpy and blurry. They fluctuate madly. The behavior of these particles cannot be worked out exactly, the way a rocket's trajectory can. Using Schrödinger's wave equation, you can only calculate the probability that a particle—a wave packet—will attain a certain position or velocity. This is a picture so different from the world of classical physics that even Einstein railed against its indeterminacy. He declared that he could never believe that God would play dice with the world.

You might say that quantum mechanics introduced a fuzziness into physics: You can pinpoint the precise position of a particle, but at a tradeoff; its velocity cannot then be measured very well. Conversely, if you know how fast a particle is going, you won't be able to know exactly where it is. Werner Heisenberg best summarized this strange and exotic situation with his famous uncertainty principle. But all this action, uncertain as it is, occurs on a fixed stage of space and time, a steadfast arena. A reliable clock is always around—is always needed, really—to keep track of the goings-on and thus enable physicists to describe how the system is changing. At least, that's the way the equations of quantum mechanics are now set up.



SCHRÖDINGER: DOES SO.

And that is the crux of the problem. How are physicists expected to merge one law of physics—namely gravity—that requires no special clock to arrive at its predictions, with the subatomic rules of quantum mechanics, which continue to work within a universal, Newtonian time frame? In a way, each theory is marching to the beat of a different drummer (or the ticking of a different clock).

That's why things begin to go a little crazy when you attempt to blend these two areas of physics. Although the scale on which quantum gravity comes into play is so small that current technology cannot possibly measure these effects directly, physicists can imagine them. Place quantum particles on the springy, pliable mat of space-time, and it will bend and fold like so much rubber. And that flexibility will greatly affect the operation of any clock keeping track of the particles. A timepiece caught in that tiny submicroscopic realm would probably resemble a pendulum clock laboring amidst the quivers and shudders of an earthquake. "Here the very arena is being subjected to quantum effects, and one is left with nothing to stand on," explains Isham. "You can end up in a situation where you have no notion of time whatsoever." But quantum calculations depend on an assured sense of time.

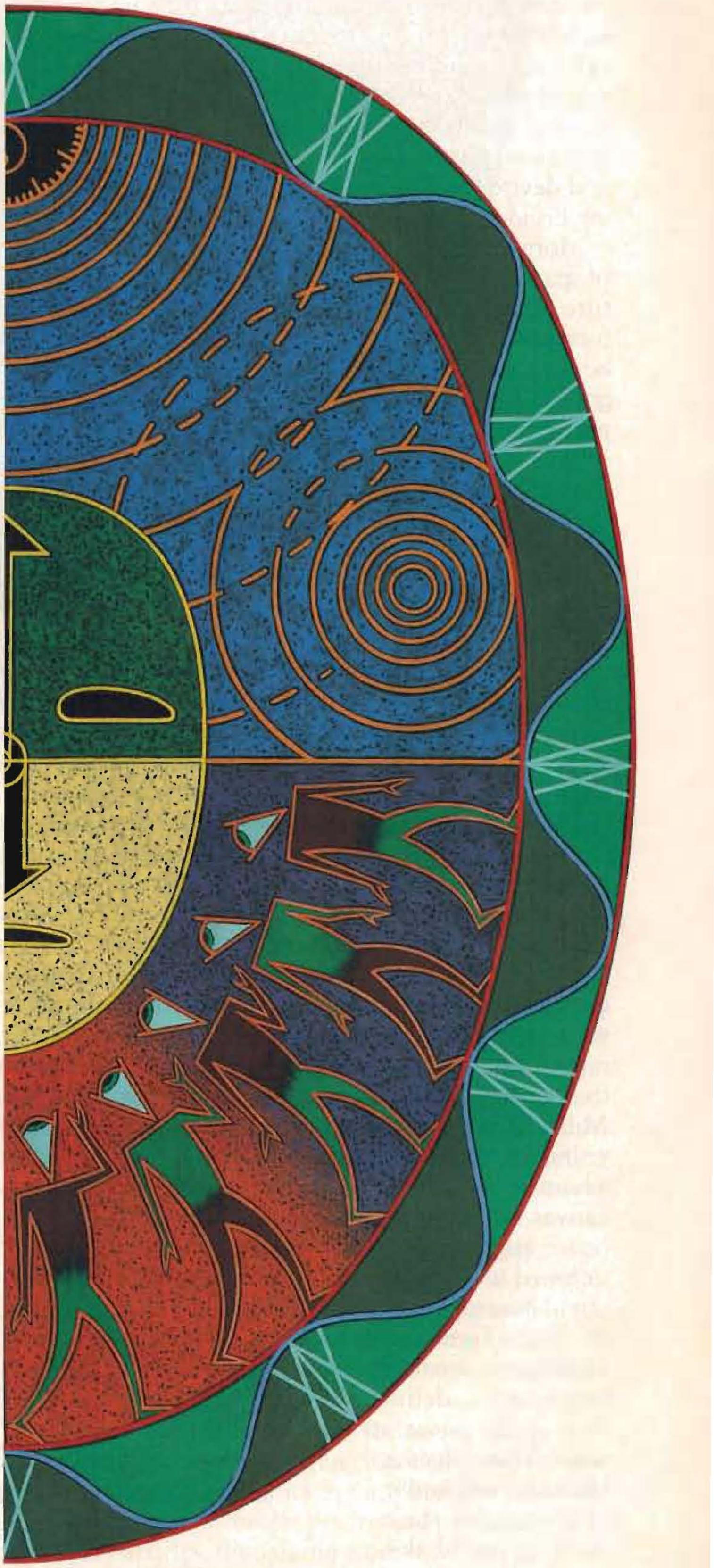
What to do? Different physicists answer the question differently.

CHANGES IN MATTER

For Karel Kuchař (pronounced KOO-cosh), a general relativist at the University of Utah, the key to measuring quantum time is to devise, using clever math, an appropriate clock—something he has been attempting, off and on, for nearly 30 years. Conservative by nature, Kuchař believes it is best to stick with what you know before moving on to more radical solutions. So he has been seeking what might be called the submicroscopic version of a Newtonian clock, a quantum timekeeper that can be used to describe the physics going on in the extraordinary realm ruled by quantum gravity, such as the innards of a black hole or the first instant of creation.

Unlike the clocks used in everyday physics, Kuchař's hypothetical clock would not stand off in a corner, unaffected by what is going on around it. It would be set within the tiny, dense system where quantum gravity rules and would be part and parcel of it. This insider status has its pitfalls: the clock would change as the system changed—so to keep track of time, you would have to figure out how to monitor those variations. In a way, it would be like having to pry open your wristwatch and check its workings every time you wanted to refer to it.

The most common candidates for this special type of clock are simply "matter clocks." "This, of course, is the type of clock we've been used to since time immemorial. All the clocks we have around us are made up of matter," Kuchař points out. Conventional timekeeping, after all, means choosing some material medium, such as a set of particles or a fluid, and marking its changes. But with pen and paper, Kuchař mathematically takes matter clocks into the domain of quantum gravity, where the gravitational field is extremely strong and those probabilistic quantum-mechanical effects begin to



arise. He takes time where no clock has gone before.

But as you venture into this domain, says Kuchař, "matter becomes denser and denser." And that's the Achilles heel for any form of matter chosen to be a clock under these extreme conditions; it eventually gets squashed. That may seem obvious from the start, but Kuchař needs to examine precisely how the clock breaks down so he can better understand the process and devise new mathematical strategies for constructing his ideal clock.

More promising as a quantum clock is the geometry of space itself: monitoring space-time's changing curvature as the infant universe expands or a black hole forms. Kuchař surmises that such a property might still be measurable in the extreme conditions of quantum gravity. The expanding cosmos offers the simplest example of this scheme. Imagine the tiny infant universe as an inflating balloon. Initially, its surface bends sharply around. But as the balloon blows up, the curvature of its surface grows shallower and shallower. "The changing geometry," explains Kuchař, "allows you to see that you are at one instant of time rather than another." In other words, it can function as a clock.

Unfortunately, each type of clock that Kuchař has investigated so far leads to a different quantum description, different predictions of the system's behavior. "You can formulate your quantum mechanics with respect to one clock that you place in space-time and get one answer," explains Kuchař. "But if you choose another type of clock, perhaps one based on an electric field, you get a completely different result. It is difficult to say which of these descriptions, if any, is correct."

More than that, the clock that is chosen must not eventually crumble. Quantum theory suggests there is a limit to how fine you can cut up space. The smallest quantum grain of space imaginable is 10^{-33} centimeter wide, the Planck length, named after Max Planck, inventor of the quantum. (To give you an idea how tiny that is, if an atom were blown up to the size of our Milky Way galaxy, which spans some 100,000 light-years, this quantum grain would still be no bigger than a human cell.) On that infinitesimal scale, the space-time canvas turns choppy and jumbled, like the whitecaps on an angry sea. Space and time become unglued and start to wink in and out of existence in a probabilistic froth. Time and space, as we know them, are no longer easily defined. This is the point at which the physics becomes unknown and theorists start walking on shaky ground. As physicist Paul Davies points out in his book *About Time*, "You must imagine all possible geometries—all possible spacetimes, space warps and timewarps—mixed together in a sort of cocktail, or 'foam'. . . . "

Only a fully developed theory of quantum gravity will show what's really happening at this unimaginably small level of space-time. Kuchař conjectures that some property of general relativity (as yet unknown) will not undergo quantum fluctuations at this point. Something might hold on and not come unglued. If that's true, such a property could serve as the reliable clock that Kuchař has been seeking for so long. And with that hope, Kuchař continues to explore, one by one, the varied possibilities.

"FORGET TIME"

Kuchař has been trying to mold general relativity into the style of quantum mechanics, to find a special clock for it. But some other physicists trying to understand quantum gravity believe that the revision should happen the other way around—that quantum gravity should be made over in the likeness of general relativity, where time is pushed into the background. Carlo Rovelli is a champion of this view.

"Forget time," Rovelli declares emphatically. "Time is simply an experimental fact." Rovelli, a physicist employed by both the University of Pittsburgh and the University of Trento in Italy, has been working on an approach to quantum gravity that is essentially timeless. To simplify the calculations, he and his collaborators, Abhay Ashtekar and Lee Smolin of Pennsylvania State University, set up a theoretical space without a clock. In this way, they were able to rewrite Einstein's general theory of relativity, using a new set of variables so that it could more easily be interpreted and adapted for use on the quantum level.

This was quite an accomplishment; finding a common vocabulary for these two diverse fields was a goal that relativists had been seeking for decades. The new formulation, which is creating a stir within the relativity community, may finally allow physicists to explore how gravity behaves on the subatomic scale. But is that really possible without any reference to time at all?

GETTING RID

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same adjustment as when Copernicus placed

the sun, not the earth, at the center

of the universe.

"First with special relativity and then with general relativity, our classical notion of time has only gotten weaker and weaker," answers Rovelli. "We think in terms of time. We need it. But the fact that we need time to

carry out our thinking does not mean it is reality."

Rovelli believes if physicists ever find a unified law that links all the forces of nature under one banner, it will be written without any reference to time. "Then, in certain situations," says Rovelli, "as when the gravitational field is not dramatically strong, reality organizes itself so that we perceive a flow that we call time."

Getting rid of time in the most fundamental physical laws, says Rovelli, will probably require a grand conceptual leap, the same kind of adjustment that sixteenth-century scientists had to make when Copernicus placed the sun, and not the earth, at the center of the universe. In so doing, the Polish cleric effectively kicked the earth into motion, even though back then it was difficult to imagine how the earth could zoom along in orbit about the sun without its occupants being flung off the surface. "In the 1500s, people thought a moving earth was impossible," notes Rovelli. Divorcing time from physics seems equally incredible. No wonder, then, that Rovelli is facing a bit of resistance to his idea. Kuchař, for one, is not yet convinced that time can be so easily dismissed. "We need rules to give the proper restraint to our imagination," he cautions.

But maybe, as Rovelli suggests, the true rules are timeless, including those applied to the subatomic world. Indeed, a movement has been under way to rewrite the laws of quantum mechanics, a renovation that was spurred partly by the problem of time, among other quantum conundrums. As part of that program, theorists have been rephrasing quantum mechanics' most basic equations to remove any direct reference to time.

The roots of this approach can be traced to a procedure introduced by the physicist Richard Feynman in the 1940s, a method that has been extended and broadened more recently by others, including James Hartle of the University of California at Santa Barbara and Murray Gell-Mann of Caltech.

Basically, it's a new way to look at Schrödinger's equation. As originally set up, this equation allows physicists to compute the probability of a particle moving directly from point A to point B over specified slices of time. The alternate approach introduced by Feynman instead considers the infinite number of paths the particle could conceivably take to get from A to B, no matter how slim the chance. Time is removed as a factor; only the potential pathways are significant.

Summing up these potentials (some paths are more likely than others, depending on the initial conditions), a specific path emerges in the end. Consider a ball being thrown across a street to your neighbor's house. There's a high probability it will take the shortest and straightest route, but others are possible. The ball could steeply arc, for instance; it could swerve to the right or to the left; there's even a minuscule chance it could go around the earth in the opposite direction and hit your neighbor's back door. Each path represents a potential outcome for the particle and contributes to the final result.

The process is sometimes compared to interference between waves. When two waves in the ocean combine, they may reinforce one another (leading to a new and bigger wave) or cancel each other out entirely. Likewise, you might think of these many potential paths as interacting with one another—some getting enhanced, others destroyed—to produce the final path. More important, the variable of time no longer enters into the calculations.

Hartle has been adapting this technique to his pursuits in quantum cosmology, an endeavor in which the laws of quantum mechanics are applied to the young universe to discern its evolution. Instead of dealing with individual particles, though, he works with all the configurations that could possibly describe an evolving cosmos, an infinite array of potential universes. When he

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sums up these varied configurations—some enhancing one another, others canceling each other out—a particular space-time ultimately emerges. In this way, Hartle hopes to obtain clues to the universe's behavior during the era of quantum gravity. Conveniently, he doesn't have to choose a special clock to carry out the physics: time disappears as an essential variable.

A Matter of Perception

Of course, as Isham points out, "having gotten rid of time, we're then obliged to explain how we get back to the ordinary world, where time surrounds us." Quantum gravity theorists have their hunches. Like Rovelli, many are coming to suspect that time is not fundamental at all. This theme resounds again and again in the various approaches aimed at solving the problem of time. Time, they say, may more resemble a physical property such as temperature or pressure. Pressure has no meaning when you talk about one particle or one atom; the concept of pressure arises only when we consider trillions of atoms. The notion of time could very well share this statistical feature.

If so, reality would then resemble a pointillist painting. On the smallest of scales—the Planck length—time would have no meaning, just as a pointillist painting, built up from dabs of paint, cannot be fathomed close up. At that range, the painting looks like nothing more than a random array of dots. But as you move back, the dots begin to blend together and a recognizable picture slowly comes into focus. Likewise, space-time, the entity so familiar to us, might take form and reveal itself only when we scrutinize larger and larger scales. Time could be simply a matter of perception, present on the large scale but not on the smallest scale imaginable. Physicists talk of the universe "congealing" or "crystallizing" out of the chaotic quantum jumble that lies at the heart of the Big Bang. Time is not a physical entity but rather a notion that emerges.

Hawking at Cambridge University sees such an effect in his own work on quantum cosmology. To arrive at this conclusion Hawking first had to circumvent the unique and complicated status of time in the space-time continuum. While time can be considered a fourth dimension, it is very different from length, width, and height. In space an object can move freely in any direction—but in time an object must always move forward into the future and away from the past. And this requirement makes the mathematics of quantum cosmology quite complicated. The equations are tough to handle.

Hawking decided to get rid of this restriction by treating time as just another dimension of space—a mathematical procedure (trick may be too strong a word) physicists often use to simplify what would otherwise be an intractable problem. The equation has been altered, but its solution can sometimes provide an inkling of the answer hidden in the more complicated equation.

In the 1930s, quantum theorists used a similar approach to figure out how radioactive elements can eject subatomic particles. By all the classical laws of physics, the protons and neutrons within an atom don't have enough energy to break free from the steely grip of an atomic nucleus. But physicists keenly grasped that, in the probabilistic world of the atom, there were small but real odds that a particle could acquire enough energy every once in a while to "tunnel" through its nuclear barriers and fly out of the atom.

Hawking's foray into that nebulous realm where general relativity meets quantum mechanics is suggesting that time, nonexistent at first, could have emerged in an analogous fashion, burrowing into the real world from a domain of timelessness. Thus, there is no reason to inquire what came before the Big Bang. To Hawking, that's as senseless a question as asking what is north of the North Pole.

There's another way to look at Hawking's result: Time simply loses all meaning as you travel back, closer and closer to the Big Bang singularity, akin to the way a compass starts gyrating and loses its ability to indicate a precise direction as you near the north or south magnetic pole. A compass is useful only when it's far from a magnetic pole; likewise, time may be discernible only after you get far enough away from the Big Bang singularity. Perhaps St. Augustine got it right when he wrote, in the fifth century, that "the world was made, not in time, but simultaneously with time."

Unfortunately, St. Augustine did not reveal by what means, and that is the mystery that is so vexing. Hawking's mathematical procedure offers a glimpse, not a final solution. Physicists as yet only recognize the problem, and sense what must happen, but are far from postulating a mechanism. That awaits a full theory of quantum gravity.

Quantum gravity theorists like to compare themselves to archeologists. Each investigator is digging away at a different site, finding a separate artifact of some vast subterranean city. The full extent of the find is not yet realized. What theorists desperately need are data, experimental evidence that could help them decide between the different approaches.

It seems an impossible task, one that would appear to require recreating the hellish conditions of the Big Bang. But not necessarily. For instance, future generations of "gravity-wave telescopes," instruments just now being built that are designed to detect ripples in the rubberlike mat of spacetime, might sense the Big Bang's reverberating thunder, relics from the instant of creation when the force of gravity first emerged. Such waves could provide vital clues to the nature of space and time.


HAWKING: TIME CAME LATER.

"We wouldn't have believed just 50 years ago that it would be possible to say what happened in the first 10 minutes of the Big Bang," points out Kuchař. "But we can now do that by looking at the abundances of the elements. Perhaps if we understand physics on the Planck scale well enough, we'll be able to search for certain consequences—remnants—that are observable today." If found, such evidence would bring us the closest ever to our origins and possibly allow us to perceive at last how space and time came to well up out of nothingness some 15 billion years ago.■