



beyond the
big bang
*Einstein's
Evolving Universe*

By Marcia Bartusiak
Art by Moonrunner Design

On January 29, 1931, the world's premier physicist, Albert Einstein, and its foremost astronomer, Edwin Hubble, settled into the plush leather seats of a sleek Pierce-Arrow touring car for a visit to Mount Wilson in southern California. They were chauffeured up the long, zigzagging dirt road to the observatory complex on the summit, nearly a mile above Pasadena. Home to the largest telescope of its day, Mount Wilson was the site of Hubble's astronomical triumphs. In 1924 he had used the telescope's then colossal 100-inch mirror to confirm that our galaxy is just one of countless "island universes" inhabiting the vastness of space. Five years later, after tracking the movements of these spiraling disks, Hubble and his assistant, Milton Humason, had revealed something even more astounding: The universe is swiftly expanding, carrying the galaxies outward.

On the peak that bright day in January, the 51-year-old Einstein delighted in the telescope's instruments. Like a child at play, he scrambled about the framework, to the consternation of his hosts. Nearby was Einstein's wife, Elsa. Told that the giant reflector was used to determine the universe's shape, she reportedly replied, "Well, my husband does that on the back of an old envelope."

That wasn't just wifely pride. Years before Hubble detected cosmic expansion, Einstein had fashioned a theory, general relativity, that could explain it. In studies of the cosmos, it all goes back to Einstein.

Just about anywhere astronomers' observations take them—from the nearby sun to the black holes in distant galaxies—they enter Einstein's realm, where time is relative, mass and energy are interchangeable, and space can stretch and warp. His footprints are deepest in cosmology, the study of the universe's history and fate. General relativity "describes how our universe was born, how it expands, and what its future will be," says Alan Dressler of the Carnegie Observatories. Beginning, middle, and end—"all are connected to this grand idea."

At the turn of the 20th century, 30 years before Einstein and Hubble's rendezvous at Mount Wilson, physics was in turmoil. X-rays, electrons, and radioactivity were just being discovered, and physicists were realizing that their trusted laws of motion, dating back more than 200 years to Isaac Newton, could not explain how these strange new particles flit through space. It took a rebel, a cocky kid who spurned rote learning and had an unshakable faith in his own abilities, to blaze a trail through this baffling new territory. This was not the iconic Einstein—the sockless, rumpled character with baggy sweater and fright-wig coiffure—but a younger, more romantic figure with alluring brown eyes and wavy hair. He was at the height of his prowess.

Among his gifts was a powerful physical instinct, almost a sixth sense for knowing how nature should work. Einstein thought in images, such as one that began haunting him as a teenager: If a man could keep pace with a beam of light, what would he see? Would he see the electromagnetic wave frozen in place like some glacial swell? "It does not seem that something like that can exist!" Einstein later recalled thinking.

He came to realize that since all the laws of

physics remain the same whether you're at rest or in steady motion, the speed of light has to be constant as well. No one can catch up with a light beam. But if the speed of light is identical for all observers, something else has to give: absolute time and space. Einstein concluded that the cosmos has no universal clock or common reference frame. Space and time are "relative," flowing differently for each of us depending on our motion.

Einstein's special theory of relativity, published a hundred years ago, also revealed that energy and mass are two sides of the same coin, forever linked in his famed equation $E = mc^2$. (E stands for energy, m for mass, and c for the speed of light.) "The idea is amusing and enticing," wrote Einstein, "but whether the Almighty is . . . leading me up the garden path—that I cannot know." He was too modest. The idea that mass could be transformed into pure energy later helped astronomers understand the enduring power of the sun. It also gave birth to nuclear weapons.

But Einstein was not satisfied. Special relativity was just that—special. It could not describe all types of motion, such as objects in the grip of gravity, the large-scale force that shapes the universe. Ten years later, in 1915, Einstein made up for the omission with his general theory of relativity, which amended Newton's laws by redefining gravity.

General relativity revealed that space and time are linked in a flexible four-dimensional fabric that is bent and indented by matter. In this picture, Earth orbits the sun because it is caught in the space-time hollow carved by the sun's mass, much as a rolling marble would circle around a bowling ball sitting in a trampoline. The pull of gravity is just matter sliding along the curvatures of space-time.

Einstein shot to the pinnacle of celebrity in 1919, when British astronomers actually measured this warping. Monitoring a solar eclipse, they saw streams of starlight bending around the darkened sun. "Lights All Askew in the Heavens. Stars Not Where They Seemed or Were Calculated to be, but Nobody Need Worry," proclaimed the headline in the *New York Times*.

With this new insight into gravity, physicists at last were able to make actual predictions about the universe's behavior, turning cosmology into a science. Einstein was the first to try. Yet as events showed, even Einstein was a fallible genius. A misconception about the nature of the

universe led him to propose a mysterious new gravitational effect—a notion he soon rejected. But he may have been right for the wrong reasons, and his "mistake" may yet turn out to be one of his deepest insights.

For Newton, space was eternally

at rest, merely an inert stage on which objects moved. But with general relativity, the stage itself became an active player. The amount of matter within the universe sculpts its overall curvature. And space-time itself can be either expanding or contracting.

When Einstein announced general relativity in 1915, he could have taken the next step and declared that the universe was in motion, more than a decade before Hubble directly measured cosmic expansion. But at the time, astronomers conceived of the universe as a large collection of stars fixed forever in the void. Einstein accepted this immutable cosmos. Truth be told, he liked it. Einstein was often leery of the most radical consequences of his ideas.

But because even a static universe would eventually collapse under its own gravity, he had to slip a fudge factor into the equations of general relativity—a cosmological constant. While gravity pulled celestial objects inward, this extra gravitational effect—a kind of antigravity—pushed them apart. It was just what was needed to keep the universe immobile, "as required by the fact of the small velocities of the stars," Einstein wrote in 1917.

Twelve years later, Hubble's discovery of other galaxies racing away from ours, their light waves stretched and reddened by the expansion of space-time, vanquished the static universe. It also eliminated any need for a cosmological constant to hold the galaxies steady. During his 1931 California visit, Einstein acknowledged as much. "The red shift of distant nebulae has smashed my old construction like a hammer blow," he declared. He reputedly told a colleague that the cosmological constant was his biggest blunder.

With or without that extra ingredient, the basic recipe for the expanding universe was Einstein's. But it was left to others to identify one revolutionary implication: a moment of cosmic creation. In 1931 the Belgian priest and astrophysicist Georges Lemaître put the fleeing galaxies into reverse and imagined them cons ago merged in a fireball of dazzling brilliance—a

"primeval atom," as he put it. "The evolution of the world can be compared to a display of fireworks that has just ended: some few red wisps, ashes and smoke," wrote Lemaître. From this poetic scenario arose today's big bang.

Many were appalled by this concept. "The notion of a beginning . . . is repugnant to me," said British astrophysicist Arthur Eddington in 1931. But evidence in its favor slowly gathered, climaxing in 1964, when scientists at Bell Telephone Laboratories discovered that the cosmos is awash in a sea of microwave radiation, the remnant glow of the universe's thunderous launch. Ever since then the image of the big bang has shaped and directed the work of cosmologists as strongly as Ptolemy's celestial spheres influenced astronomers in the Middle Ages.

Freedman and others confidently peg the universe's current rate of expansion, as well as its age. A birthday cake for the universe would require some 14 billion candles.

Astronomers have found some strange objects in this expanding universe—and these too are Einstein's children. In the 1930s a young Indian physicist, Subrahmanyan Chandrasekhar, applied special relativity and the new theory of quantum mechanics to a star. He warned that if it surpassed a certain mass, it would not settle down as a white dwarf at the end of its life (as our sun will). Instead gravity would squeeze it down much further, perhaps even to a singular point. Horrified, Eddington declared that "there should be a law of Nature to

Now Einstein's "biggest blunder" is starting to loom

In 1980 Alan Guth, now at the Massachusetts Institute of Technology, gave the big bang a boost, adding new particle physics to Einstein's flexible space-time. He realized that for its first trillionth of a trillionth of a trillionth of a second, the infant cosmos could have undergone a supercharged expansion—an instant of "inflation"—before settling into more measured growth.

Inflation would have helped smooth out the matter and energy in the universe and flattened its overall space-time curvature, just as satellites have found by making precise measurements of the cosmic microwaves. And these days some theorists believe inflation wasn't a flash in the pan. In an ongoing process of creation, space-time could be inflating into new universes everywhere and all the time—an infinity of big bangs.

Within our own universe, the high priests of astronomy have continued the cosmological quest initiated by Einstein and Hubble, first at Mount Wilson, then at the 200-inch telescope on California's Palomar Mountain, 90 miles to the south. How fast is the universe ballooning outward? they asked. How old is it? "Answering those questions," says Wendy Freedman, director of the Carnegie Observatories, "turned out to be more difficult than anyone anticipated."

Only at the turn of this century, with the help of a space telescope aptly named Hubble, did

prevent a star from behaving in this absurd way!"

There was no such law. Chandrasekhar had opened the door for others to contemplate the existence of the most bizarre stars imaginable. First there was a naked sphere of neutrons just a dozen miles wide born in the throes of a supernova, the explosion of a massive star. A neutron star's density would be equivalent to packing all the cars in the world into a thimble. Then there was the peculiar object formed from the collapse of an even bigger star or a cluster of stars—enough mass to dig a pit in space-time so deep nothing can ever climb out.

Einstein himself tried to prove that such an object—a black hole, it was later christened—could not exist. Like Eddington, he loathed what would be found at a black hole's center: a point of zero volume and infinite density, where the laws of physics break down. The discoveries that might have forced him to acknowledge his theory's strange offspring came after his death in 1955.

Astronomers identified the first quasar, a remote young galaxy disgorging the energy of a trillion suns from its center, in 1963. Four years later, much closer to home, observers stumbled on the first pulsar, a rapidly spinning beacon emitting staccato radio beeps. Meanwhile spaceborne sensors spotted powerful x-rays and gamma rays streaming from points around the sky.

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All these new, bewildering signals are believed to pinpoint collapsed objects—neutron stars and black holes—whose crushing gravity and dizzying spin turn them into dynamos. With their discovery, the once sedate universe took on an edge; it metamorphosed into an Einsteinian cosmos, filled with sources of titanic energies that can be understood only in the light of relativity.

Even Einstein's less celebrated ideas have had remarkable staying power. As early as 1912 he realized that a faraway star can act like a giant spyglass, its gravity deflecting passing light rays and magnifying objects behind it. He eventually concluded that this tiny effect defied "the resolving power of our instruments" and had "little value."

With today's telescopes, astronomers are seeing galaxies and galaxy clusters act as powerful

effect—now called dark energy—is big enough, it could also drive the acceleration. "The need came back, and the cosmological constant was waiting," says Adam Riess of the Space Telescope Science Institute, one of the discoverers of the acceleration. "It's totally an Einsteinian concept."

So is a prediction of general relativity that, if confirmed, could open new insights into the cosmos: ripples in space-time called gravity waves. To detect them, physicists have built three giant sensors, in south-central Washington State, Louisiana, and south of Pisa, Italy. In each one, laser beams run up and down miles-long pipes to measure the slight stretching and squeezing of space-time expected if a gravity wave passes by.

By triangulating these measurements, scientists might trace gravity waves back to their sources.

Starting to look like one of his greatest successes.

gravitational lenses, offering a peek at galaxies farther out. Since the light-bending depends on the mass of the lens, the effect also lets observers weigh the lensing galaxies. They turn out to have far more mass than can be seen. It's part of the universe's mysterious dark matter, the roughly 90 percent of its mass that can't be found in stars, gas, planets, or any other known form of matter.

A cosmic web of dark matter is now thought to have governed where galaxies formed. Dark matter is the universe's hidden architecture, and gravitational lensing is one of the few practical ways to "see" it. An effect Einstein thought insignificant has become a key astronomical tool.

Theorists have also dusted off his discarded cosmological constant to explain a startling new discovery, and now Einstein's "biggest blunder" is starting to look like one of his greatest successes. Astronomers had assumed that gravity is gradually slowing the expansion of the universe. But in the late 1990s two teams, measuring the distances to faraway exploding stars, found just the opposite. Like buoy markers spreading apart on ocean currents, these supernovae revealed that space-time is ballooning outward at an accelerating pace.

For Einstein, the cosmological constant was a way to steady the universe. But if its repulsive

Only stunningly violent events could cause space-time to shudder—a supernova, for example, or the titanic collision of two neutron stars or black holes. "If two black holes collided, gravity waves would be the only signals to come out," says Adalberto Giazotto, a scientist with the Pisa project.

The mighty jolt of cosmic birth probably also generated gravity waves, which would still be resonating through the cosmos. These remnant ripples could hold direct evidence of the fleeting moment when physicists believe all of nature's forces were united. If so, Einstein's gravity waves could at last offer clues to something he tried and failed to develop: a "theory of everything." Physicists are still seeking such a theory—a single explanation for both the large-scale force of gravity and the short-range forces inside the atom.

Catching these faint echoes of the big bang is a major goal of NASA's next generation of space astronomy missions, a plan the agency has tagged "Beyond Einstein."

Beyond Einstein? Not by a long shot. Einstein might be startled by the universe as we understand it today. But it is unmistakably his. □

HOW DOES EARTH WARP SPACE-TIME? A satellite holding the world's most perfect sphere is giving Einstein's predictions a tough test. Learn about Gravity Probe B and NASA's Beyond Einstein program at nationalgeographic.com/magazine/0505.