THE YEAR OF ALBERT EINSTEIN

HIS DIZZYING DISCOVERIES IN 1905 WOULD FOREVER CHANGE OUR UNDERSTANDING OF THE UNIVERSE. AMID ALL THE CENTENNIAL HOOPLA, THE TRICK IS TO SEPARATE THE MAN FROM THE MATH

BY RICHARD PANEK

OVER FOUR MONTHS, March through June 1905, Albert Einstein produced four papers that revolutionized science. One explained how to measure the size of molecules in a liquid, a second posited how to determine their movement, and a third described how light comes in packets called photons—the foundation of quantum physics and the idea that eventually won him the Nobel Prize. A fourth paper introduced special relativity, leading physicists to reconsider notions of space and time that had sufficed since the dawn of civilization. Then, a few months later, almost as an afterthought, Einstein pointed out in a fifth paper that matter and energy can be interchangeable at the atomic level—specifically, that $E=mc^2$, the scientific basis of nuclear energy and the most famous mathematical equation in history.

No wonder 2005 has been designated worldwide as a celebration of all things Einstein. International physics organizations have proclaimed this centenary as the World Year of Physics, and thousands of scientific and educational institutions have followed their lead. Images of Einstein have become even more common than usual, discussions of his impact a cultural drumbeat. "His name is synonymous with science," says Brian Schwartz, a physicist at the City University of New York Graduate Center. "If you ask kids to show you what a scientist looks like, the first thing they'll draw is wild white hair."

In many ways, Einstein's "miracle year" inaugurated the modern era, with its jumpy, discordant points of view and shocks to established truths. But the time, generally, was one of great cultural and social upheaval. Also in 1905, Sigmund Freud published his essay "Jokes and their Relation to the Unconscious" and an account of one of his first psychoanalyses. Pablo Picasso switched from his Blue Period to his Rose Period. James Joyce completed his first book, *Dubliners*. Still, no one's rethinking of universal assumptions was more profound than Einstein's.

Largely for that reason, Einstein today is more myth than man, and the essence of that myth is that the workings of his mind are beyond the reach not only of most mortals but even of most physicists. As with many myths, there's some truth to it. "I learned general relativity three times," says Spencer Weart, director of the Center for History of Physics at the American Institute of Physics. "It's that difficult, subtle, different."

But there's also a good deal of exaggeration to the myth. Right from the start, long before he was Einstein the Inscrutable, the most prescient of his fellow physicists understood what he'd accomplished and its larger significance. He'd reinvented physics, which is just another way of saying he'd reinvented the way we all—physicists and nonphysicists alike—conceive of our place in the cosmos.

SPECIFICALLY, he'd reinvented relativity.

In a 1632 treatise, Galileo Galilei set forth what would become the classic version of relativity. He invited you, his reader, to imagine yourself on a dock, observing a ship moving at a steady rate. If someone at the top of the ship's mast were to drop a rock, where would it land? At the base of the mast? Or some small distance back, corresponding to the distance that the ship had covered while the rock was falling?

The intuitive answer is some small distance back. The correct answer is the base of the mast. From the point of view of the sailor who dropped the rock, the rock falls straight down. But for you on the dock, the rock would appear to fall at an angle. Both you and the sailor would have equal claim to being right—the motion of the rock is relative to whoever is observing it.

Einstein, however, had a question. It had bothered him for ten years, from the time he was a 16-year-old student in Aarau, Switzerland, until one fateful evening in May 1905. Walking home from work, Einstein fell into conversation with Michele Besso, a fellow physicist and his best friend at the patent office in Bern, Switzerland, where they were both clerks. Einstein's question, in effect, added a complication to Galileo's imagery: What if the object descending from the top of the mast wasn't a rock but a beam of light?

His choice wasn't arbitrary. Forty years earlier, the Scottish physicist James Clerk Maxwell had demonstrated that the speed of light is constant. It's the same whether you're moving toward the source of light or away from it, or whether it's moving toward or away from you. (What changes isn't the speed of the light waves, but the number of waves that reach you in a certain length of time.) Suppose you go back to the dock and look at Galileo's ship, only now the height of its mast is 186,282 miles, or the distance that light travels in a vacuum in one second. (It's a tall ship.) If the person at the top of the mast sends a light signal straight down while the ship is moving, where will it land? For Einstein as well as Galileo, it lands at the base of the mast. From your point of view on the dock, the base of the mast will have moved out from under the top of the mast during the descent, as it did when the rock was falling. This means that the distance the light has traveled, from your point of view, has lengthened. It's not 186,282 miles. It's more.

That's where Einstein begins to depart from Galileo. The speed of light is always 186,282 miles per second. Speed is simply distance divided by, or "per," a length of time. In the case of a beam of light, the speed is always 186,282 miles per second, so if you change the distance that the beam of light travels, you also have to change the time.

You have to change the time.

"Thank you!" Einstein greeted Besso the morning after their momentous discussion. "I have completely solved the problem."

According to Einstein's calculations, time itself wasn't constant, an absolute, an immutable part of the universe. Now it was a variable that depended on how you and whatever you're observing are moving in relation to each other. "Every other physicist assumed that there was a universal world clock that kept time," says Schwartz. "Einstein completely removed that idea." From the point of view of the person on the dock, the time it took the light to reach the ship's deck was longer than a second. That means the time on board the ship appeared to be passing more slowly than on the dock. The reverse, Einstein knew, would also have to be true. From the sailor's point of view, the dock would be moving, and therefore a beam of light sent down from a tall post on land would appear to him to travel a bit farther than it would to you on the dock. To the sailor, the time onshore would appear to be passing more slowly. And there we have it: a new principle of relativity.

"Henceforth, space by itself, and time by itself, are doomed to fade away into mere shadows," the German mathematician Hermann Minkowski declared in 1908.

Other physicists had done calculations that showed a similar difference in measurement of time between two observers, but they always added some version of "but not really." For them, a difference in time might be in the math, but it wasn't in the world. Einstein, however, said there is no "really." There is only what you on the dock can measure about time on board the moving ship and what the sailor can measure about time on board the moving ship. The difference between the two is in the math, and the math *is* the world. Einstein's insight was that because these perceptions are all that we can ever know, they are also, in terms of taking the measure of the universe, all that matter.

THIS WAS PRETTY HEADY STUFF for a 26-year-old clerk who only a couple of weeks earlier had submitted his doctoral thesis to the University of Zurich. Einstein would keep his day job at the patent office until 1909, but his obscurity was over, at least among physicists. Within a year of completing his relativity paper, his ideas were being debated by some of the most prominent scientists in Germany. In 1908 physicist Johann Jakob Laub traveled from Würzburg to Bern to study with Einstein, exclaiming that to find the great man still laboring in a patent office was one of history's "bad jokes." But Einstein wasn't complaining. His "handsome" pay, as he wrote a friend, was sufficient to support a wife and 4-year-old son, Hans Albert, and his schedule left him "eight hours of fun in the day, and then there is also Sunday." Even on the job, he found plenty of time to daydream.

During one such daydream, Einstein experienced what he would later call "the most fortunate thought of my life."

He knew that his 1905 special relativity theory applied only to the relationship between a body at rest and a body moving at a constant velocity. What about bodies moving at changing velocities? In the fall of 1907, he saw a vision in his mind's eye not unlike a beam of light descending from a mast: a man falling off a roof.

What's the difference? Unlike the beam of light, which moves at a constant velocity, the falling man would be accelerating. But in another sense, he would also be at rest. Throughout the universe, every scrap of matter would be exerting its exquisitely predictable influence on the man, through gravity. This was Einstein's key insight—that acceleration and gravitation are two ways of describing the same force. Just as someone on board Galileo's ship would have as much right to think of the dock leaving the ship as the ship leaving the dock, so the man in free fall from the roof would have as much right to think of himself being at rest while the earth hurtles toward him. And there we have it: another principle of relativity, called general relativity.

"Einstein always took what everyone else thought to be two completely different scenarios of nature and saw them as equivalent," says Gerald Holton of Harvard, a leading Einstein scholar. Space and time, energy and mass, and acceleration and gravitation: as Holton says, "Einstein was always confronting the question, Why should there be two different phenomena with two different theories to explain them when they look to me like one phenomenon?"

After his 1907 vision, however, another eight years would pass before Einstein worked out the equations to support it. (See sidebar, p. 112.) Einstein told friends that when he finally figured out the math to demonstrate general relativity in 1915, something burst inside him. He could feel his heart beating erratically, and the palpitations didn't stop for days. He later wrote a friend, "I was beyond myself with excitement."

BY THEN, Einstein was a professor at the University of Berlin, and the Great War was raging across the Continent. For word of Einstein's achievement to reach the wider world of physicists, it was going to have to travel across enemy lines. Einstein carried his writings on general relativity to the Netherlands, and from there a physicist friend forwarded them across the North Sea to England, where they eventually reached Arthur Eddington, perhaps the only astronomer in the world with the political clout and scientific prominence sufficient to mobilize wartime resources and to put general relativity to the test.

Einstein had theorized that a solar eclipse offered a rare opportunity to observe gravity's effect on light. As the daytime sky darkened, stars would become visible, and if indeed the sun's gravity pulled on the passing light, then those stars near the edge of the sun would appear to be out of position by a degree his equations predicted precisely. Eddington rallied his nation's scientific troops, and Great Britain's Astronomer Royal, Sir Frank Dyson, petitioned his war-depleted government to send two expeditions to observe the total eclipse on May 29, 1919—one to Sobral, Brazil, the other to Príncipe, an island off the west coast of Africa.

In late September, Einstein got a telegram saying that the eclipse results matched his predictions. In October, he accepted the congratulations of the most prominent physicists on the Continent at a meeting in Amsterdam. Then he went home to Berlin. As far as he knew, he'd gotten his due.

"REVOLUTION IN SCIENCE," the November 7 *Times* of London trumpeted. "New Theory of the Universe. Newtonian Ideas Overthrown." The preceding day, Dyson had read aloud the eclipse results at a rare joint session of the

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THE LAST WORD ON ENERGY

It may be the world s most famous equation, but what does $E=mc^2$ actually mean?

Shortly after completing his paper on special relativity, in 1905, Einstein realized his equations applied to more than space and time. From the point of view of an observer standing still relative to an object moving very fast approaching the speed of light the object would appear to be gaining mass. And the greater its velocity in other words the more energy that had been spent in getting it moving the greater its apparent mass. Specifically, the measure of its energy would be equal to the measure of its mass multiplied by the speed of light squared.

The equation didn t help scientists engineer an atomic bomb, but it does explain why smashing atoms can release mushroom clouds worth of power. The speed of light, or c, is a big number: 186,282 miles per second. Multiply it by itself, and the result is, well, a really big number: 34,700,983,524. Now multiply that number by even an extraordinarily minute amount of mass, such as what one might find in the nucleus of an atom, and the result is still an extraordinarily tremendous number. And that number is E, energy.

Prompted by two nuclear physicists, Einstein wrote to President Franklin D. Roosevelt on August 2, 1939, that extremely powerful bombs of a new type were now conceivable. Historians tend to think the letter played a strictly subsidiary role in the decision of the Allied powers to pursue the nuclear option, says physics historian Spencer Weart. But the fact that Einstein and, indirectly, his equation played any role whatsoever has forever linked a lifelong pacifist and utopian with mankind s ability to destroy itself.

Einstein later realized that his assessment that German scientists would be capable of building an atomic bomb the opinion that drove him to write to FDR was mistaken. If I had known that these fears were groundless, he wrote to a friend late in life, I would not have taken part in opening that Pandora s box. But open it now was, never to close, as Einstein himself had acknowledged elliptically, almost poetically, back in August 1945, when he first heard the news about Hiroshima. *Oh, Weh* using the German word for pain. And that s that.

A NEW VIEW OF GRAVITY

Einstein s vision of a man falling from a roof marked the beginning of a great struggle

Once while Einstein was working on the equations for general relativity, which would take him eight years to complete, he went mountain-climbing with the French-Polish chemist Marie Curie. Seemingly oblivious to the crevasses as well as to her difficulty in understanding his German, Einstein spent much of the time talking about gravitation. You understand, Einstein said to her, suddenly gripping her arm, what I need to know is exactly what happens in an elevator when it falls into emptiness.

In Einstein s imagination, the man suspended midway between roof and earth was now inside an elevator. In a certain set of circumstances, the passenger would have no way of knowing whether he was experiencing gravity or upward acceleration. If the elevator were standing on the surface of the earth, the man would feel gravity s force there, which causes falling objects to accelerate at a rate of 32 feet per second squared. But if the elevator were accelerating through deep space at that same rate, he would experience precisely the same downward force.

Einstein imagined a beam of light piercing the elevator. If the elevator were rising relative to the source of light, the beam would enter at a certain height on one side of the elevator and appear to curve on its way to a lower height on the opposite wall. Einstein then imagined that the elevator were stationary on the surface of the earth. Since he postulated that the two circumstances are the same, Einstein concluded that the same effect would have to hold true for both. In other words, gravity must bend light.

He wouldn t have the math to support this idea until 1915, and he wouldn t have the proof until the eclipse expeditions of 1919. But by then he was so confident of his calculations that when a student asked what he would have done if he d heard the eclipse observations hadn t validated his math, Einstein told her, Then I would have been sorry for the dear Lord. The theory *is* correct.

Royal Society and the Royal Astronomical Society. The Royal Society president and the discoverer of the electron, J. J. Thomson, called Einstein's theory, in a quote that raced around the world, "one of the most momentous, if not the most momentous, pronouncements of human thought."

Only then, 14 years after Einstein's miracle year, did the range of Einstein's accomplishments begin to become common knowledge. Because the public learned about special relativity and general relativity at the same time, says Weart, the cult of Einstein coalesced quickly. "And then came quantum theory, and people went back and said, 'Oh, yeah, Einstein did that, too.'"

An accurate count of articles about Einstein around the world in 1919—that first year of fame—is probably impossible; an essay contest sponsored by *Scientific American* for the best explanation of relativity in layperson's terms attracted entries from more than 20 countries. "I have been so swamped with questions, invitations, challenges," Einstein wrote in a letter during this period, "that I dream that I am burning in Hell and that the postman is the Devil eternally roaring at me, throwing new bundles of letters at my head because I have not yet answered the old ones."

And all this celebrity, British astronomer W.J.S. Lockyer remarked, was for discoveries that "do not personally concern ordinary human beings; only astronomers are affected." The depth of the response could be due only to the historical moment—the aftermath of the Great War. "Here was something which captured the imagination," wrote Leopold Infeld, a Polish physicist and future collaborator of Einstein's: "human eyes looking from an earth covered with graves and blood to the heavens covered with the stars."

To many, Einstein became a symbol of postwar rapprochement and a return to reason. As Eddington wrote to him less than a month after the eclipse announcement, "For scientific relations between England and Germany this is the best thing that could have happened." Even today, that interpretation continues to resonate. "During that war when much of humanity devoted itself to senseless destruction," Holton has said, Einstein "revealed the outlines of the grand construction of the universe. That must count as one of the most moral acts of that time."

But some critics of relativity argued that Einstein was merely one more anarchist fueling the funeral pyres of civilization. A professor of celestial mechanics at Columbia University worried in the *New York Times* in November 1919 that the impulse to "throw aside the well-tested theories upon which have been built the entire structure of modern scientific and mechanical development" was of a piece with "the war, the strikes, the Bolshevist uprisings."

Einstein's own political leanings further complicated people's responses to his work. A visceral, lifelong anti-authoritarian, he had renounced his German citizenship at age 16 rather than subject himself to mandatory military service. Now, in the nascent Weimar Republic, Einstein, a Jew, found himself portrayed as a villain by swastika-sporting German nationalists and as a hero by internationalists. "This world is a curious madhouse," Einstein wrote a friend. "At present every coachman and every waiter argues about whether the relativity theory is correct. A person's conviction on this point depends on the political party he belongs to." The "arguments" soon descended into death threats, and Einstein briefly fled Germany for a speaking tour of Japan. After Hitler rose to power in 1933, Einstein abandoned Germany for good. He accepted an appointment to the Institute for Advanced Study in Princeton, where he lived in a modest house on Mercer Street until his death from a ruptured abdominal aneurysm at age 76 in April 1955.

Throughout his public years, Einstein embodied contradictions. A pacifist, he would advocate the construction of the atomic bomb. (See sidebar, p. 111.) He argued for a world without borders, and campaigned for the establishment of the state of Israel—so much so that in 1952 he was invited to be its president. He was a genius, puttering absent-mindedly around his house in Princeton, and he was a joker, sticking out his tongue for a photographer. But it wasn't simply these contradictions that distinguished him. It was their scale. They were all larger than life, and so therefore, the thinking went, must he be, too.

But he wasn't, as he well knew. His first marriage had ended in divorce, a second, to a cousin, in her death, nearly two decades before his. He fathered one illegitimate daughter, who is thought to have been given up for adoption and is lost to history, and two sons, Hans Albert and Eduard. One of them, Eduard, suffered from schizophrenia. Hans Albert taught engineering at UC Berkeley. Yet somehow Einstein *père* became a myth among men.

It was a fate Einstein hated. "I feel," he wrote a friend in 1920, "like a graven image"—as if there were something blasphemous in how his idolaters even then were beginning to fashion him. And maybe there was. Once the Nazis were defeated, Einstein would become not all things to all people but one thing to all people: a saint.

The halo of white hair helped. In 1919, when the world first made Einstein's acquaintance, his 40-year-old, slightly cocky visage only hinted at the caricature to come. But in time his hair flew, like a mind untethered, while the bags under his eyes deepened, as if from the burden of looking too hard and seeing too much. And as for those eyes—well, when Steven Spielberg was designing the title character of *E.T. the Extra-Terrestrial*, and he wanted his alien ambassador of good will to have eyes that were moist like a wise old man's yet twinkling with childlike wonder, he knew whose to use.

Long before the public beatified Einstein, his fellow physicists had begun to question his infallibility. When the Russian mathematician Aleksandr Friedmann in 1922 noted that, according to his calculations using Einstein's equations, the universe could be expanding or contracting, Einstein wrote a brief rebuttal saying Friedmann's math was mistaken. A year later Einstein acknowledged that the error had in fact been his, yet he remained unrepentant. Only after the American astronomer Edwin Hubble's 1929 discovery that other galaxies are receding from our own—that the universe is indeed expanding—did Einstein relent. He'd committed his "greatest blunder," he sighed.

Stubbornness would also dominate his attitude toward quantum mechanics, even though the field was partly an outgrowth of Einstein's 1905 paper on photons. Einstein frequently and famously objected to the central tenet of quantum theory—that the subatomic world operates according to statistical probabilities rather than cause-and-effect certainties. "God does not play dice with the universe," he often declared, and to the increasing exasperation of colleagues, he spent the last three decades of his life trying—without success—to find a grand unified theory that would banish such uncertainty.

"Einstein was single-minded, and you can see the good and the bad in that," says Michael S. Turner, a cosmologist at the University of Chicago and a director for mathematical and physical sciences at the National Science Foundation. "He was single-minded in reconciling general relativity with Newton's theory of gravity, and he hit a home run. But he was also single-minded about finding a unified field theory, and from 1920 on, his career was that of a mere mortal." Over the decades, experiments have repeatedly supported both the relativistic and the quantum interpretations of the cosmos. "Space is flexible," Turner says. "Time warps. And God plays dice."

In the half century since his death, astronomers have validated perhaps the most revolutionary prediction embedded within Einstein's equations—the big bang theory of the creation of the universe, a conclusion that seems inevitable if one "runs the film" of Hubble's expanding universe backward. And there have been other startling ramifications of relativity theory, such as black holes, which can be created by collapsed stars with masses so great that their gravitational force swallows everything in their vicinity, including light. As Weart says, quoting a maxim among physicists, "The general theory of relativity just dropped in 50 years ahead of its time."

Scientists are still asking questions that Einstein made possible: What powered the big bang? What happens to space, time and matter at the edge of a black hole? What mysterious energy is causing the acceleration of the universe's expansion? "This is really the golden age for Einstein's theory, quite apart from the centenary," says Clifford M. Will, a physicist at Washington University in St. Louis and the author of *Was Einstein Right?*

For his part, Einstein never quite knew what hit him. "I never understood why the theory of relativity with its concepts and problems so far removed from practical life should for so long have met with a lively, or indeed passionate, resonance among broad circles of the public," he wrote in 1942, at age 63. "What could have produced this great and persistent psychological effect? I never yet heard a truly convincing answer to this question."

Yet when Einstein attended the Hollywood première of *City Lights* in 1931, the movie's star and director, Charlie Chaplin, offered him an explanation: "They cheer me because they all understand me, and they cheer you because no one understands you." Maybe Einstein achieved his peculiar brand of immortality not in spite of his inscrutability but because of it. Social scientist Bernard H. Gustin has suggested that an Einstein assumes godlike status because he is "thought to come into contact with what is essential in the universe." Holton recently elaborated on this comment: "I believe this is precisely why so many who knew little about Einstein's scientific writing flocked to catch a glimpse of him, and to this day feel somehow uplifted by contemplating his iconic image."

The halo has helped maintain the myth, keeping Einstein a presence on magazine covers and newspaper front pages, on posters and postcards, coffee mugs, baseball caps, T-shirts, refrigerator magnets and, based on a Google search, 23,600 Internet sites. But what we're celebrating this year is more than a myth. In reinventing relativity, Einstein also reinvented nothing less than the way we see the universe. For thousands of years, astronomers and mathematicians had studied the motions of bodies in the night sky, then searched for equations to match them. Einstein did the reverse. He started with idle musings and scratches on paper and wound up pointing toward phenomena previously unimaginable and still unfathomable. "The general theory of relativity is one man's idea of what the universe ought to be like," says Einstein scholar Arthur I. Miller of University College, London. "And that's pretty much what it turned out to be." It's this legacy of Einstein's that the World Year of Physics is commemorating, this lasting contribution to the modern era: the triumph of mind over matter.