PANTHEON E BOOKS

THE DAY WE FOUND THE UNIVERSE

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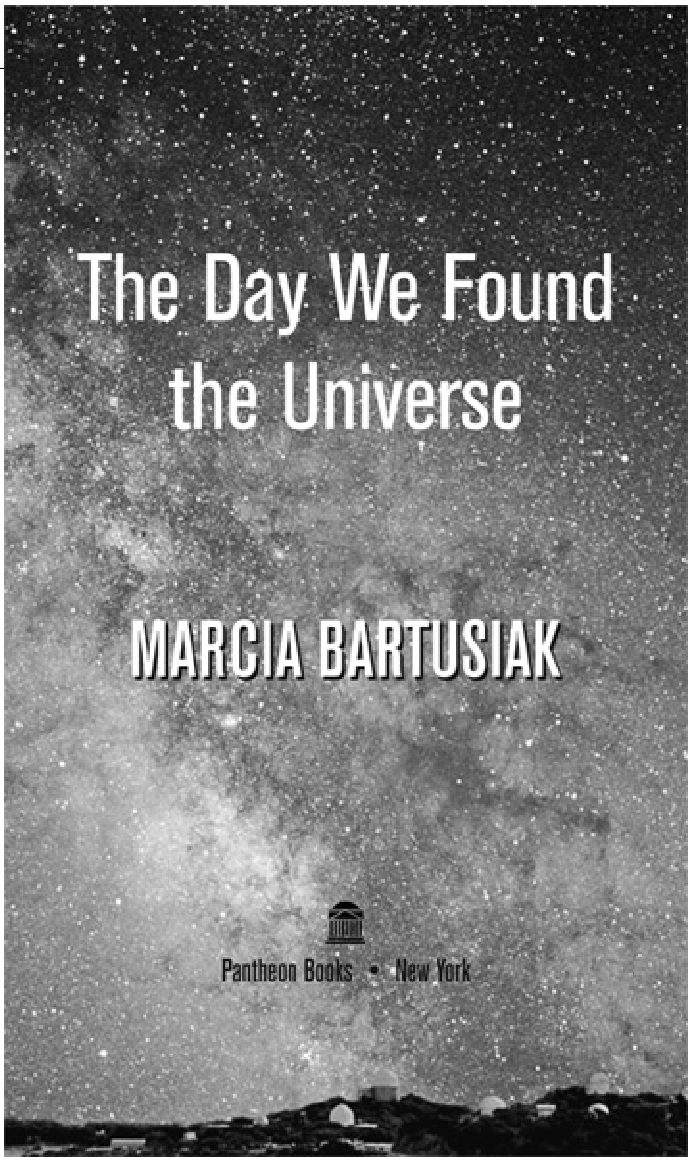
Thursday's Universe

Through a Universe Darkly

Einstein's Unfinished Symphony

Archives of the Universe



The Day We Found the Universe

MARCIA BARTUSIAK

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To Steve

The center of my universe, who shared
every light-year along the way

Preface

January 1, 1925

The twenties were not just roaring, they were blazing.

Moviegoers were flocking to the cinema to watch in amazement as Moses parted the Red Sea in Cecil B. DeMille's silent film epic *The Ten Commandments*, Greece overthrew its monarchy and proclaimed itself a republic, the first dinosaur eggs were discovered in Mongolia's Gobi Desert, and crossword puzzles became all the rage. It was the height of the Jazz Age, when Victorian ideals came tumbling down in a frenzy of flappers, Freudian analysis, and abstract art. While majestic ocean liners crossed the Atlantic in under five days, Clarence Birdseye introduced the public to the novelty of frozen food and a failed artist named Adolf Hitler published *Mein Kampf*. It was a world, wrote F. Scott Fitzgerald in his classic novel *The Great Gatsby*, "redolent of orchids and pleasant, cheerful snobbery and orchestras which set the rhythm of the year, summing up the sadness and suggestiveness of life in new tunes."

It was also an era of immense scientific fervor. On December 30, 1924, some four thousand scientists descended upon Washington, D.C., to attend the annual conference of the American Association for the Advancement of Science. Taking advantage of the three-day gathering, the American Astronomical Society held its meeting in the capital at the same time, with nearly eighty astronomers attending from across the United States. They lodged at the Powhatan, a plush eight-story hotel located on the corner of Eighteenth Street and Pennsylvania Avenue, where a room with private bath cost $2.50 a night and weary travelers could relax in its rooftop garden. Two blocks away Calvin Coolidge opened the doors of the White House to the visiting AAAS members. While notorious for being a man of few words, the thirtieth president of the United States was uncharacteristically chatty the day of the reception. "It has taken endless ages to create in men the courage that will accept the truth simply because it is the truth," Coolidge told his guests. "We have advanced so far that we do not fear the results of that process. We ask no recantations from honesty and candor… Those of us who represent social organization and political institutions look upon you with a feeling that includes much of awe and something of fear as we ask ourselves to what revolution you will next require us to adapt our scheme of human relations." Six months later high school biology teacher John Scopes would go on trial in Tennessee for illegally teaching Charles Darwin's theory of evolution.

The astronomers, though, were scarcely aware that Washington was host to the largest number of scientists ever assembled for an AAAS meeting. Their interest was intently focused on the astronomy program, which included talks on the atmosphere of Mars, how fast celestial objects could move, the temperature of Mercury, and the latest computed orbit of the eclipsing double-star system Algol.

On Wednesday, the second day of the meeting, the astronomers were taken by glass-topped buses to the U.S. Naval Observatory, in the northwest sector of the town, for a tour of the facility and a buffet luncheon in its stately main hall. Later that evening, New Year's Eve, "occurred an event which was marked on the program and celebrated by a number of the faithful," *Popular Astronomy* recounted. As the clock struck twelve, astronomers happily changed to civil reckoning for determining the start of a day. No longer would the astronomical day begin at high noon, a tradition launched in the days of Ptolemy that often led to great bookkeeping confusion. Instead, it now began at midnight, just as it did for everyone else. "It will probably be remembered and noted long after other astronomical happenings of the current year are forgotten," stated the magazine.

But a presentation made on Thursday, New Year's Day, ultimately overshadowed all other events at the meeting.

Looking out their hotel windows that inaugural morning of 1925, convention-goers discovered a blanket of snow covering the city, enough to give holiday sleds a good tryout, reported the *Washington Post.* Despite the ongoing snowstorm, however, the astronomers kept to their schedule and walked the short distance to the newly constructed Corcoran Hall, on the nearby campus of George Washington University, for a joint session with the mathematicians and physicists of the AAAS. They first heard a talk on stellar evolution, followed by a lecture posing the question "Is the Universe Infinite?" which led to a lively discussion among the conferees. Then right before the noon break, a paper modestly titled "Cepheids in Spiral Nebulae" was presented to the assembled audience. Those not familiar with astronomy likely imagined it was a minor technical work, of interest only to a specialist. But the astronomers in the room immediately grasped its significance. For them, it was electrifying news. Despite its lackluster title, this paper was no less than the culmination of a centuries-long quest to understand the true nature and extent of the cosmos. January 1, 1925, was the day that astronomers were officially informed of the universe's discovery.

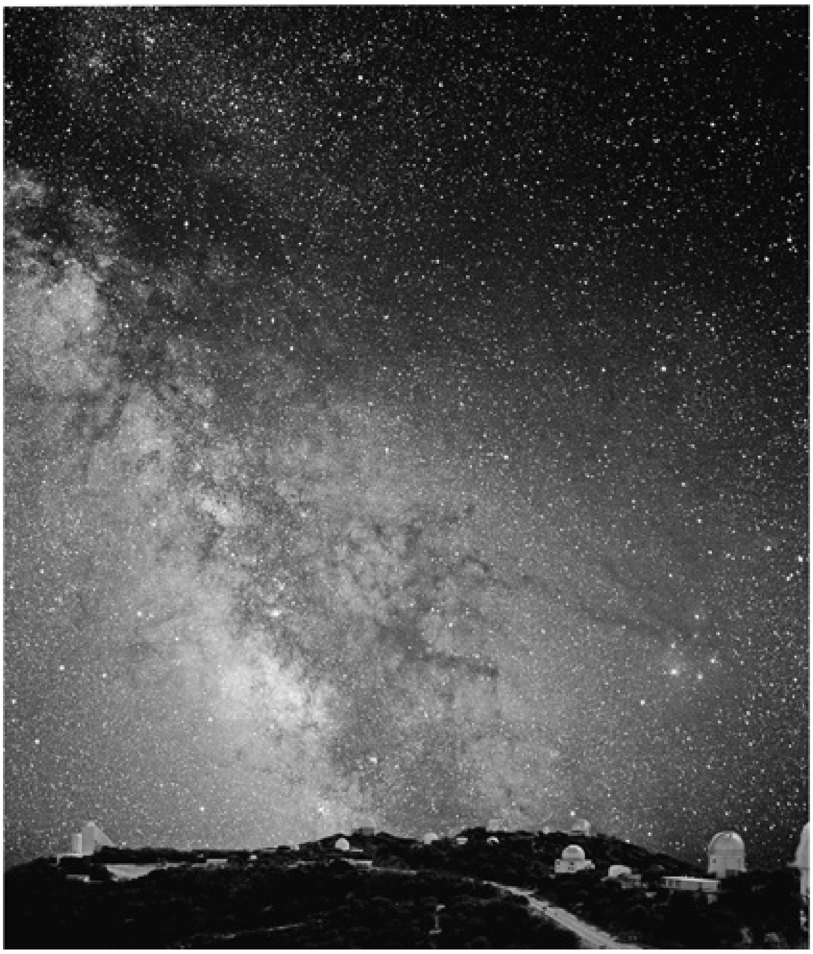
The author of the paper was thirty-five-year-old Edwin Hubble, a staff astronomer at the Mount Wilson Observatory, in southern California. Hubble had aimed Mount Wilson's 100-inch reflector, the largest telescope in its day, toward a pair of celestial clouds known as Andromeda and Triangulum, the only spiral nebulae in the nighttime sky that can be seen with the naked eye. By having access to significant telescopic power, Hubble was at last able to resolve individual stars in the outer regions of the two mistlike clouds, and to his surprise and delight some turned out to be Cepheids, special stars that methodically dim and brighten as if they were slow-blinking cosmic stoplights.

The signals revealed that our galaxy, the Milky Way, was not alone. The Cepheids were telling Hubble that the Andromeda and Triangulum nebulae were very distant, situated far beyond our galactic borders. Our celestial home was suddenly humbled, becoming just one of a multitude of galaxies residing in the vast gulfs of space. In one fell swoop, the visible universe was enlarged by an inconceivable factor, eventually trillions of times over. In more familiar terms, it's as if we had been confined to one square yard of Earth's surface, only to suddenly realize that there were now vast oceans and continents, cities and villages, mountains and deserts, previously unexplored and unanticipated beyond that single plug of sod. Hubble directed our eyes to billions of other galaxies—other Milky Ways formerly unknown—scattered like separate atoms through space and time, as far outward as telescopes could peer. Indications of the Milky Way's true place in the universe had been cropping up for years, but the evidence was indirect, conflicting, and controversial. Hubble stepped into the fray and finally provided the decisive proof. He confirmed an idea to everyone's satisfaction that beforehand had been on far shakier ground.

It was the astronomical news of the century and yet Hubble, astonishingly, was not present—at this, his moment of triumph. Instead, the staid and respected Princeton University astronomer Henry Norris Russell stood in for Hubble that morning and relayed his findings to the conferees. From all accounts, Hubble was neither sick nor detained by family matters. He might have been put off by the long and wearying cross-country train ride, but the reason for his absence was possibly more idiosyncratic. Hubble, a former legal scholar trained in weighing evidence, was concerned that by the time of the astronomy meeting he hadn't countered every feasible argument against his finding. At his own observatory, in fact, a colleague had gathered the strongest ammunition against his conclusion, evidence Hubble couldn't yet refute. This loose end bothered him immensely. What Hubble craved was an airtight case—no stone unturned, no question left unanswered—before stepping up to the podium himself. Being caught in a scientific error was Hubble's greatest nightmare. Back in California the young astronomer was fretfully asking himself, Could I possibly be wrong?

With the stunning pictures of our resplendent cosmos now so widely circulated, such a part of the routine imagery that surrounds us daily, it's difficult to remember that less than a hundred years ago astronomers' conception of the universe was very different than it is today. There were no quasars, no distant galaxies, no exotic black holes or wildly spinning neutron stars. No one even knew for sure how the Sun could keep generating its tremendous energies over billions of years. What was called “the universe” consisted of a single, disk-shaped collection of stars that cuts a magnificent swath across the celestial sky. With Earth located within this great stellar assembly, we peer outward through the disk and perceive it as a band (much the way a plate looks viewed from its side). Known since ancient times as the Milky Way because of its ghostly white visage, our galaxy a century ago was not just the sole inhabitant of the cosmos. It *was* the cosmos—a lone, star-filled oasis surrounded by a darkness of unknown depth.

A few voices of dissent could be heard, arguing against this perspective. A growing number of small spiraling clouds were being sighted in the heavens; these faint celestial objects were lurking wherever a telescope gazed away from the Milky Way into deep space. Were these spiral nebulae close to us or were they farther off? No one knew, because at the turn of the twentieth century astronomers didn't yet have the means to determine their distance with assured accuracy. The only thing they could do was speculate. Some looked at these nebulae, shaped like springs unwinding, and thought, “Ah, nearby solar systems in the making.” Others observed the same tiny clouds and imagined them as a host of sister Milky Ways so distant that their stars melded into faint and misty whiteness. That would mean the Milky Way was not special at all but merely one island of stars caught in the midst of a far larger archipelago. But the majority of astronomers rejected this strange—even frightening—concept. That other galaxies existed seemed inconceivable, and so they fiercely clung to what they perceived to be their pivotal place in the cosmos. Nicolaus Copernicus may have moved Earth and its inhabitants from the hub of the solar system in the sixteenth century, but humanity remained comforted by the notion that it retained a privileged position in the very heart of the Milky Way, the sole galaxy. They rested easy knowing they resided in the very center of the universe. There was no hard-and-fast evidence to suggest otherwise.



The Milky Way over the Kitt Peak National Observatory, Arizona *(Photo by Michael R. Cole, UrbanImager)*

That contentment was shattered, though, as astronomy underwent a spectacular transformation, starting in the waning years of the nineteenth century. “This was an era of extraordinary change in every phase of human life on this planet,” recalled Edwin Frost, an astronomer who had personally witnessed the transition at the Yerkes Observatory in Wisconsin. “[It] was truly a Victorian age drawn to a close with the end of the century.” When Frost was growing up in the 1880s, Europe was the touchstone in matters of literature, painting, and science. “Even steel rails for the trunk-lines were imported from Britain as late as my college days,” he said. “Then Andrew Carnegie and others found that rails could be made better and cheaper in America… The child was rapidly getting out of its infancy.” Discoveries and inventions were on the rise. Seemingly overnight, there were electric lights, heating by coal, hot-air furnaces, indoor bathrooms, and automobiles smoothly traveling down asphalt-paved roads.

Astronomy blossomed within this atmosphere of teeming innovation. Cameras became standard equipment on telescopes, enabling observers to gather light over an entire night and so generate images of faint stars and nebulae never before seen. And spectroscopes, devices that separate starlight into its component colors, allowed astronomers to figure out what the stars and other celestial objects were truly made of. Suddenly the very chemistry of the heavens was in their grasp. Meanwhile, prominent industrialists, enriched by the bounty of the Gilded Age, provided the money that allowed big dreamers to construct the large telescopes they had so long desired.

Given the swift emergence of these technological improvements, dry textbook accounts, reduced to a discovery's most essential elements, make it appear as if Hubble's historic achievement had taken place overnight. He goes to the world's largest and best-equipped telescope and, voilà, he reveals a cosmos populated with myriad galaxies spread over space as far as the telescopic eye could see. The Milky Way suddenly becomes a minor player in a much larger drama, and Hubble is anointed cosmology's “prime architect” for making this astounding breakthrough. But that is not the case at all. In reality, Hubble stood on the shoulders of a series of astronomers farsighted enough to tackle a problem others had been ignoring. Answers did not arrive in one eureka moment, but only after years of contentious debates over conjectures and measurements that were fiercely disputed. The avenue of science is more often filled with twists, turns, and detours than unobstructed straightaways.

Astronomers trained in the older, classical ways, who dwelled on calculating the motions of the planets and measuring the positions of stars to the third decimal place, had not been distressed at all by the mystery of the spiral nebulae. They figured that once the matter was resolved it would not greatly change their perception of the overall structure and contents of the heavens. Simon Newcomb, the dean of American astronomy in the late nineteenth century, remarked at an observatory dedication in 1887 that “so far as astronomy is concerned…we do appear to be fast approaching the limits of our knowledge… The result is that the work which really occupies the attention of the astronomer is less the discovery of new things than the elaboration of those already known, and the entire systemization of our knowledge.”

Within ten years James Keeler, director of the Lick Observatory, in California, proved Newcomb was exceedingly shortsighted. Against everyone's advice, Keeler got a troublesome reflecting telescope—the first of its kind at high elevation—back in working order and demonstrated its power with singular panache. Even though the telescope's mirror was relatively small, it allowed him to estimate that there were tens of thousands of faint nebulae arrayed over the celestial sky, ten times more than had been known before. In the 1910s Lick astronomer Heber Curtis followed up on Keeler's findings and gathered additional evidence to suggest that these many spiraling nebulae were nothing less than separate galaxies. At the same time, a few hundred miles south at Mount Wilson, near Los Angeles, Harlow Shapley resized the Milky Way, measuring it as far larger than previously thought and shoving our Sun off to the side, away from the galaxy's hub. As Shapley liked to put it, “The solar system is off center and consequently man is too.”

The story of our universe's discovery centers mightily on Shapley and Hubble, scientific knights who jousted with each other for years over the universe's true structure. These archrivals shared similar backgrounds and yet couldn't have been more different in temperament and tactics. Both were born in rural Missouri and both came to astronomy through unusual routes: Hubble as a discontented high school teacher, Shapley as a crime reporter. And each, after obtaining his doctoral degree, was selected by the visionary George Ellery Hale to work at the Mount Wilson Observatory, the greatest astronomical venue in its day. Each pursued a question that few others were asking. For Shapley, it was our precise location within the Milky Way; for Hubble, our place in the universe at large.

Their work took place during a crucial moment of transition. While European astronomers were diverted by World War I and its resulting turmoil, American astronomers were free to push forward on the question of the spiral nebulae. Figuring out the universe's exact configuration became an American obsession, its participants drawn from the Lick, Mount Wilson, and Lowell observatories, newly built in the western United States. The world's older observatories had no chance at all, for at the Lick and Mount Wilson observatories, in particular, astronomers had access to advanced telescopes situated on prime high-elevation sites, a combination essential to cracking the mystery.

Hubble gets deserved credit for providing the last, painstaking turn of the lock. “Hubble's drive, scientific ability, and communication skills enabled him to seize the problem of the whole universe, make it peculiarly his own, contribute more to it than anyone before or since, and become the recognized world expert of the field,” wrote astronomer Donald Osterbrock, archivist Ronald Brashear, and physicist Joel Gwinn for a centennial celebration of Hubble's birth.

By 1929, just five years after his initial finding on the galaxies, Hubble made an even more astounding discovery. He and his colleague Milton Humason gathered the key evidence that opened the door to proving that the universe was expanding, with the galaxies continually riding the wave outward. Space-time was in motion! Half the work to reach this startling conclusion was actually performed on an Arizona mountaintop a decade earlier by Vesto Slipher, a Lowell Observatory astronomer whose vital role in arriving at this finding is now largely forgotten outside the halls of academia. Such is the power of Hubble's legend. It pushed the contributions of others into the shadows as the years progressed. This book intends to shine the spotlight once again on the entire cast of characters who contributed to revealing the true nature of the universe and laid the groundwork for Hubble's success.

Knowledge of the cosmic expansion was a transforming event. It allowed astronomers to escape the confines of their home galaxy, letting them explore a far larger cosmological vista. The Milky Way was now fleeing outward, giving theorists free rein to contemplate the universe's very origin. They mentally put the cosmic expansion into reverse and imagined the galaxies drawing closer and closer to one another, until they ultimately combined and formed a compact fireball of dazzling brilliance. In this way, they realized that the universe had emerged in the distant past from an enormous eruption—the Big Bang. No longer was our cosmic birth a matter of metaphysical speculation or a biased whim; it had become a scientific principle that could be tested and probed.

This new cosmic outlook came about through a unique convergence—the perfect storm—of sweeping developments. Not only did a burgeoning economy provide the money—and new technologies the instruments—to make these discoveries, but newly introduced ideas in theoretical physics supplied some answers. No less a scientific figure than Albert Einstein had arrived on the scene with a novel theory of gravity that provided a unique explanation for the universe's bewildering behavior.

A dynamism entered into the universe's workings. Einstein's equations introduced the idea that space and time are woven into a distinct object, whose shape and movement are determined by the matter within it. His general theory of relativity anticipated the universe's expansion and turned its study into an intellectual and theoretical adventure. Early globetrotters had crossed the oceans in search of terra firma—solid land, new continents—previously unknown to them and ready for exploration. With his relativistic vision of space-time as a pliable fabric that can bend and stretch, Einstein allowed astronomers to recast the ancient search into a quest for *cosmos firma*. Glued together by the genius physicist, space and time became cosmic real estate to be appraised, mapped, and scrutinized, with Hubble serving as its first surveyor.

Hubble eventually summarized his cosmological findings in a work titled *Realm of the Nebulae*, which is part history, part college textbook, and part professional memoir. This book was labeled a “classic” by his peers at the very time it was published in 1936. And Hubble's initial take still holds up in its broad outline. “[His] picture differs from today's only in details,” Caltech astronomer James Gunn noted decades after its publication. “One looks through the pages almost in vain for things that are known to be wrong. One finds a few…[but] we still determine the distances of the nearest galaxies by methods described [by Hubble]. We still mostly use Hubble's classification scheme. We still pay a great deal of attention to the questions Hubble asks.”

However, there is one glaring exception to Gunn's statement. Although Hubble's name is now strongly attached to the discovery of the expanding universe, he was never a vocal champion of that interpretation of his data. That was because there were other hypotheses in play in the 1930s and 1940s. Hubble was reluctant to choose sides, at a time when his newly mined data and Einstein's theory were so fresh. Hubble always coveted an unblemished record: the perfect wife, the perfect scientific findings, the perfect friends, the perfect life. His observations that the galaxies were fleeing outward were to him always *apparent* velocities. He wanted to protect his legacy in case a new law of physics sneaked in and changed the explanation. So far, it hasn't.

Hubble was lucky in a way. The Hubble Space Telescope could easily have been given another name had certain events turned out differently: if someone had not prematurely died (Keeler), if someone else had not taken a promotion (Curtis), or if another (Shapley) was not mulishly wedded to a flawed vision of the cosmos. The discovery of the modern universe is a story filled with trials, errors, serendipitous breaks, battles of wills, missed opportunities, herculean measurements, and brilliant insights. In other words, it is science writ large.

The Little Republic of Science

An immense continent of rock known as the North American plate slid inexorably ove an oceanic slab of Earth's crust moving eastward. At the tectonic juncture, where th two gargantuan plates smashed together, the ocean floor plunged downward, th tremendous compression forging massive blocks of shale and sandstone. In due cours some of this material lifted upward from its depths, relentlessly rising toward the sky to for the Diablo Mountain Range—two hundred miles of peaks and vales stretching from the Sa Francisco Bay southward along California's coastline. As if readying for a performance, natur sculpted the landscape that, millions of years later, offered astronomers a unique observin platform for their studies of the cosmos. Situated on the eastern edge of the Pacific, this lof terrain became the perfect vantage point from which to make the first great discoveries twentieth-century astronomy.

One noticeable peak in the Diablo Range, some forty miles from the sea, was known early settlers as La Sierra de Ysabel. The first to record an ascent to its uppermost reache were William Brewer, a geologist who worked on California's first complete geologic survey, and Charles Hoffman, a topographer. Laurentine Hamilton, then a Presbyteria minister from San Jose, tagged along for the 1861 summertime adventure. While journeyin over the lower elevations the men used mules but struggled over the last three miles on foo With the two scientists burdened down by their heavy equipment, the minister was able sprint ahead, pushing through the chaparral, mesquite, and thick groves of scrub oak th filled the mountain's furrowed sides like well-sprinkled seasoning. Upon reaching the summi Hamilton waved his hat in the air and exclaimed, “First on top, for this is the highest point In honor of the achievement, Brewer graciously named the peak after his “noble and tru friend.

Within three decades Mount Hamilton was the site of a radical new endeavor astronomy. Fueled by America's escalating wealth, “the public mind in this country is no directed to the importance of original scientific research,” wrote Joseph Henry, head of th Smithsonian Institution, in 1874 to the noted English biologist Thomas Huxley, “and I thin there is good reason to believe that some of the millionaires who have risen from poverty wealth will in due time seek to perpetuate their names by founding establishments for th purpose in question.” In the vanguard to answer that call was San Francisco entrepreneu James Lick, who funded the world's first astronomical observatory permanently establishe at high elevation. Before this, professional telescopes were routinely constructed in relativel low-lying areas, near major cities or on university campuses for easy access.

In 1888, from its commanding perch atop Mount Hamilton, the Lick Observatory bega operating the largest telescope in its day, which featured a pair of imposing lenses a full yar wide to gather and magnify the celestial light. It was the same type of telescope throug which Galileo first peered, one that directed the light through two aligned pieces of glass, b the diameter of the Lick instrument was a couple of dozen times larger. Its founder spared n expense to house this giant refractor. The massive building was designed in a classical sty by Washington architect S. E. Todd. From afar, it appeared as if a European palace had bee magically transported to the American West. Inside its dome, hand-carved molding decorated the walls. The floors were curved wooden planks, polished to a sheen and stylish following the shape of the circular dome. Tourists traveled on stagecoach for hours for glimpse of this new wonder of the scientific world.

Unbeknownst to those visitors, though, the most innovative work at Lick was actual being done in more modest surroundings, about a quarter of a mile south of the showstoppin telescope, at the end of a mountain spur known as Ptolemy Ridge. There, in a far small dome that resembles a quaint medieval chapel, James Keeler labored to put a reflectin telescope into operation, which used a silvered mirror instead of a lens to magnify its imag It was an instrument that everyone warned him would be nothing but trouble. Big-lense refractors were the telescopes of choice in the late 1800s, but Keeler bravely broke from th tradition, establishing an approach in professional astronomy that eventually spread to ever major observatory throughout the world.

Lick Observatory, c. 1910. The 36-inch telescope is housed
in the big dome; the smaller Crossley-telescope dome is at the far left.
*(Mary Lea Shane Archives of the Lick Observatory, University Library,
University of California-Santa Cruz)*

Though now reduced to a minor figure in many histories of astronomy, Keeler was actual a forerunner to the birth of modern cosmology, a crucial player in helping launch the ne field. A man who could manipulate a spectroscope like no other, he pioneered uses for th new instrument at a time when astronomers were just beginning to apply the methods physics in their work. This specialty, newly tagged “astrophysics,” enabled observers at la to discern the chemical and physical natures of stars, planets, and nebulae.

In Keeler's time the universe was a far simpler place, at least to our modern-day eyes. Th cosmos consisted solely of a vast collection of stars, a disk-shaped distribution somewh flattened, with the Sun situated in an honored place near the center. Beyond that, said mo astronomers, was simply a void—possibly extending out to infinity.

But there were oddities in the celestial sky, difficult to explain. There were thes mysterious nebulae that through a telescope looked like watery whirlpools, mistlike clou exhibiting spiraling shapes. Astronomers were long acquainted with other types of nebula such as the vast and chaotic cloud in Orion and the ringlike nebulae, but these vaporo objects resided within the bounds of the Milky Way. The spiral nebulae, on the other han were solely found away from the milky band of our galaxy. Why did they prefer the mo open cosmic spaces, as if they were avoiding the stars? Astronomers didn't have a goo rational explanation for this unique distribution. Keeler, to his credit, made these nebulae h prime subject for investigation, at a time when the study of stars and planets was far mo attractive to astronomers. Before the introduction of photography, the number of nebulo clouds in the heavens was estimated to be in the thousands. Mounting a camera onto h reflecting telescope, Keeler began to realize there were likely tens of thousands. H discovery was a revelation, and in making this masterful leap in observing, Keeler opened u a vast new arena for astronomy.

Keeler's celestial curiosity may have initially been sparked by a dramatic solar eclipse h witnessed in 1869 when he was eleven—its narrow path of totality creating a sensation as t Moon's shadow stretched across the United States. A few months later, his family moved fro Illinois to Mayport, Florida, where Keeler was homeschooled, surrounded by the stacks *Scientific Americans* to which his father subscribed. Ordering some lenses from an optic dealer who advertised in the magazine, young Keeler built his first telescope—a 2½-inc refractor with a cedar tube. He was soon spending long nights at his scope drawing sketch of lunar craters and the planets. He was riding the wave of a new American fancy.

Earlier in the nineteenth century astronomical research in the United States had been rather haphazard affair, until two key events dramatically altered the situation. In t autumn of 1833 people throughout the country witnessed a meteor storm, torrents shooting stars, like no other. It was described as a "constant succession of fire bal resembling sky rockets, radiating in all directions from a point in the heavens," which led this spectacular celestial fireworks show being called the "Falling of the Stars." A decade lat the public went agog once again over the Great Comet of 1843, proclaimed by Ya astronomer Denison Olmsted in that preelectric era as "the most remarkable in its appearan of all that have been seen in modern times." The comet was visible even in daylight, with nucleus as bright as the full Moon and a tail that stretched for nearly two million mile Together, the meteor blizzard and the comet sparked a huge surge of public interest in t heavens. It also made U.S. politicians woefully aware of their country's lack of first-ra scientific institutions to study such captivating phenomena. The English novelist Franc Trollope, who spent some time in America in the 1820s, had found it "extraordinary that people who loudly declare their respect for science, should be entirely without observatori Neither at their seats of learning, nor in their cities, does anything of the kind exist."

This deficiency was quickly remedied with the opening of observatories in both Cincinna Ohio, and Chapel Hill, North Carolina, and at colleges such as Yale, Harvard, and William The U.S. Naval Observatory, the country's first national observatory, also obtained its fir decent telescope. During this period before the Civil War, additional observatories quick sprang up, becoming the scientific facility de rigueur for major American cities and college These efforts at last fulfilled the vision of John Quincy Adams, America's sixth president, wh had long pushed for the country to erect a “lighthouse in the sky.” “Some Americans, haunte by a nagging sense of cultural inferiority and smarting from invidious comparisons wi Europe, fostered astronomical research as a matter of national pride,” writes historia Howard Miller. And once in place, these pioneering astronomical outposts stimulated continuing interest, especially among young boys like Keeler who dreamed of one day takin part in this new American endeavor.

Described by acquaintances as a “lankey green country boy” with a backwoods “cracke drawl,” Keeler came to develop special skills in building instruments, which enabled him t enter Johns Hopkins, America's first research university, just a year after the institutio opened in Baltimore, Maryland. Upon graduation in 1881, Keeler began work near Pittsburg at the Allegheny Observatory, headed up by Samuel P. Langley, the man who two decad later would almost beat the Wright brothers at getting a piloted, self-propelled aircraft flyin A year of graduate work in Germany in 1883–84 sharpened Keeler's expertise in spectr analysis. All this preparation turned out to be indispensable when he received an offer to jo the staff of the Lick Observatory, the revolutionary new mecca for astronomy in centr California.

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James Lick initiated a remarkable trend. He stood at the head of a long line of prosperou benefactors in the late nineteenth and early twentieth centuries who used the busine fortunes they accrued in the United States to construct some of the most productiv observatories in astronomical history. Given his largesse, Lick raised the stakes in astronom Before this, the most acclaimed observatories were in Europe and sponsored by eith universities or governments. With resources sparse, these institutions were often slow t adopt new techniques and instruments. At each observatory, surveys plugged along f decades, often using just one key telescope. But the Lick Observatory offered a new mod for research, one that ran at a quicker pace enriched by private capital. Lick made b telescopes the commemorative monument of choice among the American nouveaux riche Moreover, with these privately funded observatories being established from scratch, the were able to purchase the finest instruments and adopt the latest technologies. As consequence, astronomy advanced in the United States at a faster pace than in any oth country in the history of science. “Starting from essentially zero at the beginning of th nineteenth century,” says historian Stephen Brush, “the Americans had overtaken th Germans to jump into second place by the end of that century and were already challengi the British for the top spot.” Domination of the heavens appeared to go hand in hand wi economic riches.

Lick earned his riches. Born in 1796 to a rural Pennsylvania Dutch family, just as the ne republic of the United States was getting under way, he learned the trade of woodworking the side of his father. After making a fairly comfortable living running his own shop in Ne York City, Lick abruptly decided in 1821 to move to South America, bent on amassing fortune. There he became a master builder of fine-wood piano cases, a venture that prove highly lucrative in a culture where dancing and music were greatly valued. After twent seven years, though, living at first in Argentina, then Chile, and finally Peru, he decided t sell his varied business concerns and return to the United States. Arriving in San Francisco b ship in 1848, just as California was about to secede from Mexico, he came ashore wi $30,000 in gold doubloons and six hundred pounds of Peruvian chocolate made by his frien Domingo Ghirardelli.

Wasting no time, Lick quickly put his incisive business acumen to work. He shrewdly use his gold to purchase real estate in San Francisco, then just a scrubby town with scarcely thousand inhabitants. When residents started heading to the hills to make their fortune in th California gold rush, Lick was there to provide them with a stake by buying up their tow land at bargain prices. He also bought a gristmill, greatly expanding it, and built California first great luxury hotel, the opulent Lick House, which occupied an entire city block (and wa later destroyed in the fire that tore through San Francisco after its horrific 1906 earthquake)

James Lick
(Mary Lea Shane Archives of the Lick Observatory, University Library, University of California-Santa Cruz)

Lick never married but still built a homestead at the south end of San Jose, where h lovingly cultivated rare plants and shrubs from around the world. The community considere him an eccentric miser; he dressed like a tramp and at times slept on a bare mattress laid o atop a piano crate. As a youth, he had gotten a girl pregnant, but her father, a prosperou miller, refused his offer to marry her, judging Lick too poor and socially inferior. The mille could hardly have imagined how astronomy, decades later, would benefit from this snobbis rebuff. Without a legitimate heir, Lick, in his old age, began to think of using some of h tremendous wealth (he had accumulated nearly $4 million, around $100 million in today dollars) to erect a gargantuan monument to himself. For Lick it was a chance at immortalit He particularly favored the idea of constructing a giant marble pyramid on the corner Fourth and Market streets in downtown San Francisco, a structure that would have surpasse Egypt's Great Pyramid of Giza in size.

But a few auspicious encounters revised this vainglorious plan. Lick had once spent a fe days with a visiting amateur astronomer and lecturer, George Madeira, who captivated hi with talks about astronomy's latest discoveries. They met again a few years later for som telescope viewing when Madeira allegedly asserted, “If I had your wealth, Mr. Lick, I wou construct the largest telescope possible to construct.” Around the same time Joseph Henr then head of the National Academy of Sciences as well as the Smithsonian, was visiting Sa Francisco and arranged a meeting with Lick to discuss how wealthy men could use the money to cultivate science. The following year, 1872, the Harvard naturalist Louis Agass gave a widely reported lecture at the California Academy of Sciences, where Agassiz echo Henry's refrain.

All these lessons struck a chord. Lick soon astonished the California Academy when h granted the institute, without prior notice, the gift of a downtown lot to build a museum ar more expansive headquarters. Academy president George Davidson, a geodetic surveyor ar astronomer, promptly called on Lick to thank him, initiating a friendship. When Lick wa later felled by a stroke and confined to a two-room suite at his hotel for nearly a yea Davidson regularly visited, engaging Lick with chats about the rings of Saturn, the belts o Jupiter, and other astronomical topics. Lick soon abandoned his scheme to build a pyram and decided instead to erect a telescope “superior to and more powerful than any telescop yet made,” right on his favored city spot, the corner of Fourth and Market.

An in-town telescope was never built (fortunately), largely due to Davidson's interventio As both an amateur astronomer and a geodeist, a profession that took him to towerin mountain sites, he had long been convinced that astronomy would best be served by takin its instruments to the highest elevations possible, where a telescope's resolution woul improve immensely in the clear, more rarefied atmosphere. Isaac Newton first pointed th out in the eighteenth century. “For the Air through which we look upon the Stars, is in perpetual Tremor,” he wrote in his *Opticks*. “… The only remedy is a most serene and qui Air, such as may perhaps be found on the tops of the highest Mountains above the gross Clouds.” And preferably in a region with a dry season, free of rain.

Over time Lick came to accept Davidson's compelling idea and in the fall of 187 authorized the funds to construct a state-of-the-art observatory in the arid Sierra Nevad Mountain Range at an elevation of 10,000 feet. Caught up in the excitement of this nov venture, Lick pledged $1 million, a princely sum. No observatory had ever been establishe in such a remote and elevated locale. In that decisive shift, astronomy would soon change a remarkable way, whisking the field away from its previous urban settings.

Over the next three years, Lick fiddled with the provisions of his trust, fired and hire assorted board trustees, reduced the price tag to a tightfisted $700,000, and changed his min on the telescope's location. Once set for a spot near Lake Tahoe by the Nevada border, th site was eventually shifted to Mount Hamilton, a shorter peak (4,200 feet high) just to th east of San Jose, where Lick could look up and proudly view it from his property. Davidso sorely disappointed by the lowered elevation and Lick's parsimonious ways, left the proje and refused to speak to his former benefactor ever again.

Davidson's snub mattered little in the end, for Lick soon passed away. He died on Octob 1, 1876, at the age of eighty. Only then did construction of the mountaintop observatory, a arduous and unprecedented endeavor, truly get under way: Congress at last approved transf of the public land, the local county built a road to the top, and the mountain peak wa certified by an expert as exceptional for its atmospheric stability. Mount Hamilton's shar knife-edged profile causes minimal disturbance as air flows in from the west. Fulfilling Lick decree, the largest refracting telescope in the world—one with lenses ten inches wider tha the previous record holder at the U.S. Naval Observatory—was installed in a magnificer domed building, designed in the Italian Renaissance style and large enough to accommoda the scope's lengthy tube. Massive hydraulic cylinders allowed an astronomer to raise or low the entire circular floor to keep him level with the telescopic eyepiece. The top thirty feet the mountain had been blasted away to provide a level space for the rambling comple which included housing, workshops, offices, and a library. The observatory operated as small town, with families living on-site and supplies brought up daily by wagon from Sa Jose. A visitor dubbed it the "little Republic of Science."

Lick became the new republic's patron saint, for his egotism never completely disappeare with his noble gift to astronomy, even after his death. In January 1887, as soon as th telescope base was complete, Lick's remains were brought up the mountain and reburied, h body resting directly under the grand instrument he funded, in the very base of the pi supporting the giant refractor. Tour groups still visit the tomb today. Davidson claimed cred (as did others) for the interment idea, first voiced when Lick was alive. He was surprised th old man agreed. At the time Davidson had suggested a cremation and burial of the ashes, which the former carpenter quickly replied, "No sir! I intend to rot like a gentleman."

The choice for director of the new Lick Observatory was Edward Holden, a graduate West Point and an unaccomplished astronomer whose sole qualification seemed to be that h energy and initiative had once impressed Simon Newcomb, then America's most revere astronomer, while he was assisting Newcomb at the Naval Observatory. A proud an pompous man, Holden at least had a keen eye for talent. Aware of Keeler's outstanding wor at Allegheny, Holden hired him in 1886 to get the new mountaintop observatory and i equipment up and running. Of all Holden's hires, James Keeler was by far the best traine Bringing Keeler to the mountain was the best decision Holden ever made during h tumultuous directorship.

A Rather Remarkable Number of Nebulae

Keeler traveled to the Lick Observatory along a road that was a marvel of engineerin in its day. Although Mount Hamilton is less than a mile high, the journey from its bas to the top is more than twenty miles in length, with the roadway sinuously zigging ar zagging as it gradually ascends. There are some 360 switchbacks in all, and some wer even given special names, such as “the Tunnel,” “Crocodile Jaw,” and “Oh My Point branded by the oft-heard refrain as people sat atop the stagecoach and looked down in horr at the point's steep drop-off. The serpentine route was installed to maintain a gentle gradien so that stagecoach horses in the nineteenth century never needed to break their stride.

Upon reaching the top, Keeler was immediately enamored of the breathtaking scener “The view from the observatory peak is a very beautiful one, particularly in the spring, whe the surrounding hills are covered with bright green verdure, and the eye looks down upo acres of wild flowers,” he later wrote in a pamphlet for visitors. “To the west lies the lovel Santa Clara valley, shut in from the ocean by mountains somewhat lower than the M Hamilton range. Sometimes the entire valley is filled with clouds, rolling onward under clear sky and bright sun like a river of snow… The surrounding mountain tops project out the fog like black islands.” Often the ocean fog arrives at sunset, rolling in from the Pacific the Golden Gate, to the north, and Monterey Bay, to the south.

Not everyone on the mountain was enthusiastic about Keeler's arrival. The observatory superintendent, Thomas Fraser, was initially wary of the newcomer. “If he has the right rir all will be right,” said Fraser, “but if Stubern *[sic]* then things will go wrong and he will hav to leave that is all there is to it.” It didn't take long, though, for Fraser to be won over by th exceptional skill Keeler displayed as the telescope was being prepared for operation.

Its great lenses were finally installed on New Year's Eve 1887, but due to severe weath the staff could not test the telescope out until a few days later. Often in the wintertim storms would sweep over the mountain with winds gusting more than 60 miles per hou which would drift the snow about the dwellings more than ten feet high. Once the staff g back to the telescope, the trial run did not go well. To their horror the astronome discovered that Alvan Clark, the telescope maker, had misstated the instrument's require length. Much like the Hubble Space Telescope's initial mishap a century later, they couldr get it into focus. The telescope's tube should have extended fifty-six feet, but instead was s inches too long, forcing them to get out their tools and spend valuable days cutting the tub down to size. Clark's son, a partner in the telescope firm, was there for the trial, “a terrib old blow and grumbler,” Keeler told Holden. While Clark insisted that his firm's glass wa superb and the eyepieces “triumphs of art,” he declared the dome “worthless.”

With its tube shortened, the telescope was at last tried out on January 7, 1888, a cloudle night that was piercingly cold. With the dome frozen solid that evening, the handful of sta members and guests present could only passively observe the objects that happened to pa by the dome's slit, open toward the southeast. Yet, “no inconvenience was felt beyond th necessity of a little waiting,” recalled Keeler. He was pleased to find the clock runni smoothly and the mounting working well. The group first observed Rigel, a blue-white doub star, followed by the Orion nebula, its great streamers making it one of the most spellbindi sights through a telescope. “Here the great light-gathering power of the object glass wa strikingly apparent,” Keeler noted. Then, just after midnight, Saturn came into view. Keel reported that the planet was “beyond doubt the greatest telescopic spectacle ever beheld b man. The giant planet, with its wonderful rings, its belts, its satellites, shone with a splend and distinctness of detail never before equaled.” Everyone in the party took a loo Afterward Keeler spent some time studying Saturn more carefully, which led to Li Observatory's first discovery. He spied a fine, dark line in Saturn's outer ring, “a mere spide thread,” as he described it. It was a breach (now best known for historic reasons as the Enc Gap, after an early-nineteenth-century German astronomer) that had never before bee clearly seen. A superb drawing Keeler made of Saturn, based on his sketch of the planet th night, was displayed at the 1893 Chicago World's Fair.

James Keeler
(Mary Lea Shane Archives of the Lick Observatory, University Library, University of California-Santa Cruz)

Six feet tall with fair wavy hair, Keeler cut a fine figure. Despite his isolated upbringing rural Florida, he became a keen judge of human nature and was often called upon to hand personnel and scientific crises at the observatory, which he carried out with the cal discretion of an international diplomat. “He was tolerant, amused and unwilling to ta sides,” said Keeler's biographer Donald Osterbrock. “He always sought to put the be construction he could on anyone's activities, to emphasize the positive, and never to critici unless absolutely necessary. It was perhaps not the most courageous philosophy in the worl but it [took] him far.”

And as an astronomer, Keeler was outstanding, studying a range of subjects from sol eclipses to planetary features. Photography was still in its infancy, so Keeler continued make drawings that were praised by his colleagues as marvelous reproductions. “Beautif and accurate,” reported fellow Lick astronomer Edward E. Barnard in a notice to the Roy Astronomical Society. “… [Keeler] has a real artistic ability such as very few observe