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Edwin Hubble: A Biographical Retrospective

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A minor but intriguing drama was playing itself out on both sides of the Atlantic in the summer of 1919. Comfortably settled into rooms near the Great Gate of Trinity College, in Cambridge, Major Edwin Hubble was the recipient of a series of increasingly agitated letters postmarked Pasadena, California. Their author was the great solar astronomer and scientific entrepreneur George Ellery Hale, who beseeched Hubble to sail to America posthaste and to exchange his military uniform for the business suit of an astronomer. "Please come as soon as possible," a nervous Hale wrote. "We expect to get the 100-inch telescope into commission very soon, and there should be abundant opportunity for work by the time you arrive."[1]

The Missouri-born Hubble, who had worked mightily to rid himself of a telltale accent, was thirty years old and scarcely bursting with promise. Aside from his military service, he had never held a regular job save for a year spent teaching Spanish and mathematics at New Albany High School in Indiana. Yet he comported himself with an aristocratic air, making it appear that Hale was somehow his inferior. This impression went well beyond their correspondence. Hubble had entered the good graces of the wealthy English astronomer H. F. Newall whose home, Madingley Rise, was located near Cambridge Observatory. Newell had proposed Hubble for membership in the prestigious Royal Astronomical Society, whose outcome was a foregone conclusion. When a delegation of visiting American astronomers was wined and dined by members of the Society two months later, Hubble was seated near the head of the table next to Frank Dyson, the Astronomer Royal. The astronomers Walter Adams, Charles St. John, and Frederick H. Sears were the first from Mount Wilson to take the measure of the tall, crisply dressed major whose prominence was hardly commensurate with any scientific achievements. Galling it must have been to encounter a fellow American who affected an English accent during the period of inflated nationalism following a world war.

Despite his Christian upbringing, Edwin Hubble was a man who believed in destiny—particularly his own—though it was not something he communicated to others in so many words. The closest he came was in two letters to his mother, Virginia James Hubble, written in 1910 during his Rhodes Scholar days at Oxford, when he had donned plus-fours, a Norfolk jacket and cape. "I sometimes feel that there is within me to do what the average man would not do if only I find some principle for whose sake I could leave everything else and devote my life."[2] As one who read the classics in his spare time, he realized that the path traced out by the gods would be anything but easy: "Work, to be pleasant, must be toward some great end; an end so great that dreams of it, anticipation of it, overcomes all aversion to labour."[3]

Having taken his own good time, Hubble finally boarded a ship for New York some four months after Hale's initial plea that he come home. On reaching the East Coast, he took a train to San Francisco, where he received his formal discharge at the Presidio.

Reluctant to forfeit the cachet of his uniform, Hubble was still in full dress when he reached Pasadena in early September. Towering above the valley floor, and accessible only by a zigzagging dirt road, stood 5,714-foot Mount Wilson. Hale had spent his first night on the peak in the summer of 1903, and remembered falling asleep watching the stars pass over a gaping hole in the roof of an abandoned cabin. Having worked his will on the Wisconsin skies above Williams Bay, where he had conceived and overseen the construction of the great Yerkes 40-inch refractor, Hale subsequently raided the observatory of its best astronomers and technicians, then headed for the West Coast and the pristine firmament above the Pacific.

Hale, a consummate salesman, persuaded John D. Hooker, a Los Angeles businessman enamored of astronomy, to underwrite the purchase of a 100-inch glass disk for the most powerful telescope in the world. In return, Hooker would receive the honor of having the magnificent instrument christened his namesake. This promising beginning was followed by a second and far greater coup in early 1910, when Hale persuaded his friend Andrew Carnegie to come visit the mountain. Looking more like a sawed-off Ernest Hemingway than a titan of industry, the Scotsman posed for a photograph with Hale in front of the newly installed 60-inch telescope, the world's largest at the time. Aware of Carnegie's sensitivity about his diminutive stature, the diplomatic Hale made certain that his friend was standing up slope before the shutter clicked. When Carnegie was interviewed about his experience by the press, he spoke of 60,000 new stars already discovered on the mountain, causing the University of Chicago astronomer Forest Ray Moulton to quip that one might as well claim to have "discovered 60,000 new gallons of water in Lake Michigan."[4] No matter, the check for $10 million was in the mail.

Construction of the 100-inch Hooker reflector was nearing completion even as Europe was engulfed in war. The glassworks at St. Gobain in Paris had produced a giant disk weighing some 5 tons and measuring 101 inches across by 13 inches thick. The nerve-racking task of grinding its 7,800 square inches of surface had taken nearly five years to complete, yet so fine was the craftsmanship that every square inch produced the same focal length to within one part in some 90,000.[5] Upon its surface would fall not 60,000 points of light but an estimated 3 billion. The English poet Alfred Noyes would soon commemorate Hale's feat in his epic *Watchers of the Skies*:

> *Where was the gambler that would stake so much —*
> *Time, patience, treasure, on a single throw?*[6]

Back at Yerkes Observatory another young gambler was champing at the bit. Only months before the 100-inch mirror was moved safely to the mountaintop, Congress had declared war on Germany. Hubble, twenty-seven and an inveterate Anglophile, was itching to get into the fray. Abetted by the rising tide of patriotism, he pressured his dissertation advisor and director of Yerkes, Edwin Brant Frost, into moving up the date of his oral examinations. The aging astronomer was uneasy to say the least, but he yielded when Hubble informed him that he was applying for a commission in the Officers Reserve Corps. The document in question, titled "Photographic Investigations of Faint Nebulae," contained all of 17 pages, forcing Hubble himself to admit that it "seems so skimpy."

The work was little based on observations undertaken with the main telescope, for "seeing time" on the 40-inch was largely reserved for astronomers higher in the pecking order than Hubble. Fortunately, the brilliant but mentally unstable George Ritchey, who Hale had been forced to replace during the meticulous grinding of the 100-inch mirror, had designed and built a 24-inch reflector before departing for Mount Wilson. It was on this generally neglected instrument that Hubble cut his teeth as an astronomer.

Hubble took the first of hundreds of glass plates in the autumn of 1915. He described the object, known to astronomers as NGC (*New General Catalogue*) 2261, as the "finest example of a cometary nebula in the northern skies."[7] It, together with some 17,000 similar formations, had already been catalogued. At least 130,000 more were calculated to be within telescopic range. What most intrigued Hubble, who compared his plate with others taken years earlier, was that the nebula had since bowed to display a larger degree of convexity than before. He could only conclude that the object was quite near in astronomical terms, or he could never have observed its subtle change in shape. Displaying an ingrained caution that would one day become legendary, he wrote: "No attempt is here made to explain the phenomenon."[8] Nor did Hubble try to classify this and other nebulae according to type. It appeared that some of them are within our stellar system while others, such as the giant spirals with their enormous radial velocities and insensible proper motions, seemed to lie outside it. More distant still were numberless whiffs of light whose appearance on the photographic plates looked like spattered porridge. For the present there was little further to be done. All would have to await, Hubble concluded, the advent of "instruments more powerful than those we now possess."[9]

Two years later found Hubble in command of the most powerful telescope ever conceived. It was Christmas Eve 1919, and the mountain could be a lonely place, especially during the holidays. The astronomer Wendell Hoge, a victim of that loneliness, had poignantly made the following entry in the 1912 log of the 60-inch: "Merry Christmas to all the Universe."[10] Yet for Hubble, who preferred his own company to that of most others, such isolation was to be savored. What greater gift than to be sitting atop a mountain detached from a small planet circling a middling star, his fingers poised on the control paddles of the massive yet gentle giant?

To Hubble the process was every bit as much aesthetic as scientific. With the celestial map firmly fixed in his head, he waited patiently for the dark matter called night to steal in and fill the dome. The night assistant soon became invisible while the only trace left of Hubble was the Cheshire glow of his signature briar. Sounding like rolling thunder, the dome circled until its opening approached the field he was planning to photograph. Just as it was coming into focus he would suddenly shout the command to clamp the telescope, often catching the assistant off guard. The plate was then exposed as the astronomer settled in to wait and to wonder, periodically adjusting the instrument's position in an effort to capture light as old as creation itself. Few living astronomers can lay claim to this transforming experience, which is fast becoming part of the world we have lost.

Less enamored of the mountain than Hubble, though a brilliant astronomer in his own right, was Harlow Shapley, who could frequently be heard complaining about the numbing cold and lack of sleep. Shapley had preceded Hubble's arrival on Mount Wilson by five years and had virtually laid claim to the Milky Way galaxy, which he equated with the universe itself. However, Shapley's daunting and meticulous study of double stars or binaries, whose distances he had plotted by calculating light curves and rough stellar masses, caused him to reject the generally accepted belief that the Milky Way was only some 30 million light-years in diameter, the figure championed by the Dutch astronomer Jacobus Cornelius Kapteyn. It was Shapley's conclusion that Earth was far removed from the Milky Way's cyclopean eye, and that the distances to the binaries were "pretty darned big."

More recently, Shapley had turned his attention to the study of Cepheid variables, pulsating stars whose surfaces, he postulated, ebb and flow in great cauldron-like waves. The secrets of these intriguing objects were first plumbed by Henrietta Leavitt, a research assistant at Harvard College Observatory. Leavitt had proven that Cepheids can be treated as celestial timepieces, which alternately brighten and dim like clockwork. Employing photographic plates from Harvard's observatory in Peru, she further determined that the longer a Cepheid's period, the brighter its image on the glass exposure, a discovery of profound implications. Henceforth, Cepheids of similar periods could be looked upon as virtual twins, no matter their apparent brightness or location in the sky. As "standard candles" they were nothing less than beacons for calculating distances across the void.

Working on the 60-inch reflector while awaiting the completion of the more powerful Hooker, Shapley scoured the mottled globular clusters for the glimmer of yet unseen variables. By 1918 he had succeed in plotting the period-luminosity relation of 230 pulsating Cepheids, whose cycles ranged from 5 hours to 100 days. Putting pen to paper in a blizzard of publication after four grueling years on the mountain, he created a new and audacious galactic model—one that would do for the Milky Way what Copernicus had done for the solar system nearly four centuries earlier.

Having discerned that more than 40% of the 100 or so globular clusters then known were concentrated in 3% of the sky's area, Shapley reasoned that this massive gathering marked the center of the galaxy, which, in turn, could mean only one thing. Our planet is but a tiny part of a solar system located on the very fringes of the Milky Way, whose diameter had inflated to ten-fold that of the puny Kapteyn universe. In a word employed by Copernicus the cosmos was "*immensum*," a staggering 300,000 light-years across.

More than satisfied, Shapley came down from the mountain in March of 1921 to become director of Harvard College Observatory, a seeming just reward for what he considered his greatest scientific achievement. Yet his grandiose model of the universe would survive all of five years.

The German scientist and metaphysician Immanuel Kant imagined a system whereby countless stars are gathered together in a common plane or thin disk, like those of the Milky Way, yet so far removed from Earth that the individual components are indistinguishable with a telescope. They would appear as a feebly illuminated spot—circular if its plane is perpendicular to the line of sight; elliptical if viewed obliquely. Thus to Kant the nebulae were nothing less than countless systems of countless suns so distant that they are the weakest candles in the heavens, albeit galaxies not unlike our own. Embracing the principle of the uniformity of nature, the harness maker's son is credited with postulating the theory of island universes, a term coined by the explorer Alexander von Humboldt in the mid-nineteenth century.

Kant's contemporary, the great William Herschel, dictated a description of every chalk-colored web and pinwheel to his gifted sister Caroline as the objects drifted by the lens of his fixed telescope. Embracing Galileo's belief that faintness means distance, Herschel thought it likely that the nebulae could be massive aggregates of stars no different than the Milky Way, some of which "may well outvie [it] in grandeur."[11] Still, who could say for certain?

Shapley's most outspoken critic was the congenial and bespectacled Heber Curtis of

Mount Hamilton's Lick Observatory. Curtis was dubious about Shapley's construct, not least because of the contribution made to it by Shapely's colleague and friend, Adriaan van Maanen. Also of Mount Wilson, van Maanen claimed to have detected rotational movements in several of the most photographed spiral nebulae, including M33, M51, M81, and M101. He calculated the rate of motion at about one hundred-thousandth of a revolution per year. Though this figure may seem small, indeed infinitesimal, when projected on a cosmic scale, it seemed to sound the death knell of Kant's island universe theory. The stellar rim of a spiral only 500,000 light-years from Earth would have to rotate at an incredible 30,000 miles per second. Spirals at far greater distances would not only approach but exceed the speed of light.

Try as he might, Curtis could find no confirmation of any such rotations in plates from van Maanen's arsenal—and Shapley's. After debating this and other issues before a meeting of the National Academy of Sciences in April 1920—the so-called Great Debate, which failed to live up to its billing—both Curtis and Shapley came away more convinced than ever of the validity of their respective positions.

Or so Shapley claimed for his part. Yet not long after the exchange he handed some plates of the great Andromeda nebula, M31, to Milton Humason, the former mule skinner and janitor whom Shapley had helped train to use the telescopes on Mount Wilson. He instructed Humason to examine them on the stereocomparator. As he was blinking the plates, the night assistant marked the locations in ink of images never before discerned, and which Humason believed to be Cepheid variables located beyond the Milky Way. As Humason told the story to astronomer Allan Sandage years later, Shapley was having none of it. He drew a handkerchief from his pocket and wiped the plates clean of Humason's telltale marks, all the while lecturing him on the points he had scored in the Great Debate.[12]

Hubble, who had impressed his fellow Rhodes Scholars by reading Kant in German, had lately embarked on an ambitious scheme encompassing the nature, form, and classification of the nebulae without tipping his hand regarding the Great Debate. On the night of October 4, 1923, he was on his ninth run of the year with the 100-inch telescope, having homed in on a spiral arm of M31. The seeing was rated at less than 1, the worst possible without closing the dome, the kind of conditions that would frequently cause him to dismiss the night assistant, who lost no time making for a boiling cup of coffee and a warm bed. Despite the poor conditions, the 40-minute exposure yielded a "suspected" nova, which Hubble intended to confirm the next night. The viewing had markedly improved, and he increased the exposure time by five minutes, just to be sure. Plate H335H confirmed his suspicions. What was more, a careful examination of the plate revealed two more stars, both of which the astronomer concluded were novae as well.

His run over, the knickers-wearing father of triplets caught the truck bound for the observatory offices on Pasadena's Santa Barbara Street, where he began searching the files for previous photographs of the "novae." He was startled to find that one of the objects on plate H335H—destined to become the most famous ever taken on Mount Wilson—was not a nova at all but a Cepheid variable. He first plotted the light curve of the object, determining that it had a period of 31.415 days. Then, by exploiting Shapley's distance-measuring techniques, he found that it was at least 300,000 parsecs from Earth, the equivalent of one million light-years, easily more than three times the diameter of Shapley's universe. Hubble took out his marking pen and, near the top of the mind-altering plate, crossed out "N" for nova, and in bold capital letters printed "VAR!" for variable, followed by an exclamation point.

Hubble waited four months, during which he discovered and calibrated the distance of a second Cepheid and a half dozen more novae, before writing to Shapley of his celestial tour de force. There was never any love lost between the two Missourians, who were as different as night and day: Shapley, the studied hick who despised Hubble's highhanded airs, English garb, and posturing, not to mention his spoken "Oxford"; Hubble, the patrician who hated Shapley's "Missouri tongue" and thought him a coward for having opposed the Great War. Rubbing it in, Hubble proved that his written Oxford could be as annoying as the spoken variety: "I have a feeling that more variables would be found by a careful examination of long exposures. Altogether next season should be a merry one and will be met with due form and ceremony."[13] Hubble's tone was reminiscent of another letter he had written to his mother from Oxford: "It is always great fun to look a man in the eyes and best him by sheer self-possession."[14]

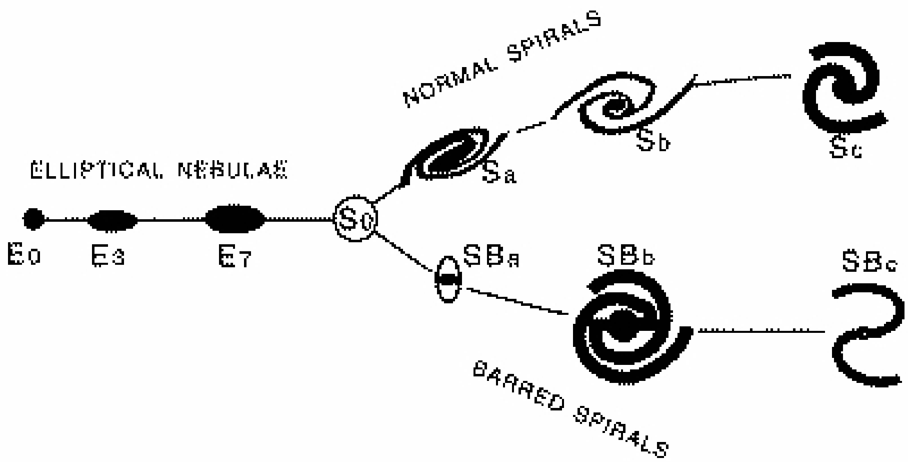
Hubble's boorishness aside, Shapley well knew who was king of the mountain, as would everyone else soon enough. The Andromeda nebula was nothing less than a separate galaxy composed of stars by the millions, if not more. Graduate student Cecilia Payne happened to be in Shapley's Harvard Observatory office when he opened and read Hubble's letter. He then passed it across his desk to Payne, remarking with the flair of a tragedian: "Here is the letter that has destroyed my universe."[15]

Shapley's capitulation was further signaled in an October 1924 letter to Hubble. Now that Hubble had proven the existence of independent star systems, would it not be more accurate to rename them "galactic nebulae" or perhaps "galaxies," the term Shapley himself preferred?[16] But there was no budging Hubble, who clung to his own nomenclature, calling them "nongalactic nebulae." Indeed, they would remain so on the mountain until his death in 1953.

Hubble's mastery of the 100-inch had recently enabled him to complete another observational program of the first order—this one an act of synthesis some four years in the making. Astronomers from William Herschel to Heber Curtis had long labored to establish a classification scheme of the various galactic nebulae, as well as the types of stars with which they are associated. By April 1921 Hubble had come up with a tentative scheme of his own and was sufficiently emboldened to forward a copy to Lick Observatory astronomer William H. Wright. In the cover letter he admitted to "a few anomalies, but on the whole the progression is surprisingly definite."[17] At the same time, he made it clear that he was by no means proposing a theory of galactic evolution.

Another year passed during which Hubble reinforced his model with new photographs taken with the 60- and 100-inch reflectors. Then, in 1922, he gained a seat on the International Astronomical Union's fourteen-member Commission on Nebulae and Star Clusters. Here was the opportunity he had been waiting for, but when he presented his model to the commission it was relegated to the status of an unpublished report. Others, including certain members of the commission itself, had put forth their own classification schemes. Only Vesto Melvin Slipher, the acting director of Lowell Observatory, thought Hubble's model worthy of being printed.

At this point a frustrated Hubble decided to go it alone. After carefully redrafting his paper, he sent it off to the *Astrophysical Journal*, which published it under the title: "A General Study of Diffuse Galactic Nebulae." So far, so good, yet neither Hubble himself nor his fellow astronomers as yet looked upon his scheme as definitive. Then came word that the commission had decided to compile a new catalogue on the nebulae employing photographic



HUBBLE'S CLASSIFICATION OF THE NEBULAE

plates as opposed to traditional visual observations. Still, the project could not advance short of a international consensus on a classification scheme.

Once again Hubble turned to Slipher, who was now chairing the commission. He typed up his extensive notes in July 1923, including revisions of his initial scheme, added a series of photographic plates, and sent the material off to Slipher in Arizona. "The men at Mount Wilson," Hubble wrote, together with a visiting Henry Norris Russell from Princeton, "have looked over the notes and have expressed their approval." [18]

The diagram of Hubble's most recent scheme, which some likened to a "galactic tuning fork," had undergone marked changes from the one published in 1922. While the galactic nebulae remained the same, Hubble now separated the nongalactic nebulae into only two classes: what he had previously termed spindles, ovates, and globulars were subsumed under the categories of ellipticals and spirals. Amorphous in appearance, the ellipticals resembled blobs, which Hubble further divided according to their flatness or lack of same. Those whose shape was perfectly circular were termed E0 nebulae. Several steps removed were the E7 ellipticals, the flattest of their kind and resembling a lens or, to the sports-minded, a football.

More elegant to the astronomer's eye were the spirals whose double arms form cosmic pinwheels. These Hubble separated into two categories, normal spirals and the less common but distinctive barred spirals, so called because their arms originate from the end of a "bar" traversing their nuclei. Both types of spirals were then separated into subclasses based on the tightness of their arms. A normal spiral with tightly wound arms was given an Sa designation while SBa became the symbol for its counterpart in the barred category. Sc and SBc spirals are the most loosely wound of all.

Yet as every astronomer is quick to learn, all is not quite right in the heavens. Hubble was nagged by the anomalous nebulae that could not be easily fit into any of his three categories, forcing him to create the catchall term "irregular nebulae" for the "very few" clusters that otherwise eluded his synthesizing powers.

Although several of Hubble's peers in the IAU were impressed by his revised classification system, they ultimately voted against its adoption. His frustration mounting, Hubble chose to do what he had done before. "Extra-Galactic Nebulae," a seminal paper, appeared in volume 64 of the *Astrophysical Journal*. Thirty years later the gifted astronomer Walter Baade, who was Hubble's colleague at Mount Wilson, told a rapt audience at Harvard that the "systems that really present difficulties to Hubble's classification [are] so small [in number] that I can count them on the fingers of my hand."[19] So it would be until the deep field opened up by the *Hubble Space Telescope*—reaching back in time and across space some 13 billion years—revealed nascent galaxies in the throes of creation, like scattered snippets of cosmic DNA.

Percival Lowell's belief that the surface of the planet Mars was etched by giant canals had caused the astronomer to hire Vesto Melvin Slipher in 1901 for the purpose of verifying the waterways' existence. For years a deeply skeptical Slipher had held Lowell off with one hand while reaching for the stars with the other. Hubble and Slipher had first crossed paths in the autumn of 1914 on the campus of Northwestern University during the annual meeting of the American Astronomical Society. Hubble was heading for Williams Bay to begin his graduate work in astronomy and was in the audience when Slipher announced that the massive Andromeda spiral was blueshifted, barreling toward the Sun at the astonishing speed of 300 kilometers per second. Spectrograms and consequent radial velocities obtained for more than forty other nebulae and star clusters were even more confounding. Unlike Andromeda, most nebulae were redshifted, strong evidence that they were hurtling outward from the Sun at speeds as great as 1,100 kilometers per second.[20] When Slipher finished his paper the audience rose as one and accorded the astronomer a standing ovation, welcome praise indeed for one who was convinced that the velocities of the spirals were too great, their distances too vast, for them to be gravitationally bound to the Milky Way.

Others were considerably more skeptical. Among them was George Ritchey, whose work with the 60-inch reflector on Mount Wilson had produced a series of plates containing spiral nebulae, none of which seemed to possess sufficient matter to be classified as independent galaxies. Then, at some point in 1926, Slipher simply ran out of telescope, his 24-inch-refractor a casualty of the increasingly smaller and dimmer objects he was attempting to photograph. Nor had he succeeded in obtaining credible distances to the spiral nebulae, thus leaving the conundrum of expansion unresolved.

Hubble's recent work on Cepheids had enabled him to accumulate a wealth of distance measurements, but he was anything but content. Indeed, he wrote of his work to date as mere "reconnaissance." Elsewhere, I have characterized him as a great mariner in the making, a galactic voyager ready to leave behind familiar shoals and coasts and to strike out for the fabled Indies, supposedly somewhere far off in the murky distance.[21] At his side was the former bellboy, mule driver, failed orchardist, and janitor Milton Humason, whose grammar school education would brand him a pariah in every major observatory today. Yet such were Humason's skills that he commanded Hubble's absolute confidence, which would waver but once during the long, difficult voyage ahead.

From inside the dark and creaking dome the pair slipped into the vast ocean sea of space, or what Hubble would later call "the realm of the nebulae," to begin charting the period-luminosity relation for Cepheids and other stellar bodies. If, as he suspected, a nebula's speed of recession is truly an index of its distance, then the distances of nebulae far across the universe could be inferred by simply measuring their redshifts.

Of all the many plates they would take, the first was destined to be the most memorable. Humason was at the controls of the Hooker and spent two frigid nights photographing through a yellow prism, which blocked the ultraviolet light. The object was a faint nebula chosen because its redshift had eluded Slipher owing to its distance from Earth. After he developed the plate while still on the mountain, Humason scanned it with the aid of a magnifier for the H and K lines generated by calcium atoms in the nebula. They soon appeared, and though the spectrum was faint the telltale vertical marks were shifted to the right or red end, as expected. Humason phoned an anxious Hubble, who was waiting for him at Santa Barbara Street when the assistant astronomer finished his run. Hubble gathered the plate and, after confirming the redshift, calculated its speed of recession at 3,000 kilometers per second, some 1,800 kilometers per second greater than Slipher's largest value. When Humason was asked about his feelings at the moment of discovery years later, he claimed Byron as his model, though he seems not to have had the slightest clue as to who Byron was or what he had done.[22]

As Humanson soon learned, such Faustian arrogance came with a price. The freezing astronomer, his face grotesquely lit by red dark-vision lamps, perched like a Lilliputian on the small Cassegrain platform five stories above the observatory floor, coaxing and prodding the recalcitrant behemoth through moonless nights punctuated by staccato winds and the incessant ticking of the weight-driven clock. When the machinery balked, as it often did, he kept the image steady by forcing his shoulder against more than 100 tons of metal. If all else failed he literally climbed on to the instrument's giant frame, bending his body at painfully awkward angles for the sake of a plate steeping in light from nebulae time out of mind. "You had to stretch out into nothing," he reminisced about his efforts to obtain the long exposures.[23] A deceptively nonchalant Hubble, who was choreographing Humason's every move while putting in his own time on the mountain, dismissed his assistant's acrobatics as Milt's "adventures among the clusters."[24]

Mutiny was in the air. When Hubble pressed Humason to do even more, he recoiled at the prospect of additional pain and suffering. It took the intervention of Hale, who had been succeeded as director of Mount Wilson by Walter Adams, to keep Humason from jumping ship. Hale promised him a new spectrograph and camera, which would shorten the exposure time of plates from nights to hours. Furthermore, Hale was the person who had taken a chance on Humason, elevating him from obscurity to a trusted and highly valued colleague.

So they continued on, the former Rhodes Scholar and the grammar school dropout, forging ever deeper into uncharted waters. Giant spirals like M31, M33, M51, and M101—the very heat of Messier's catalogue—confirmed the redshifts. Galaxies in all directions appeared to be moving away from Earth, or Earth from them. Based on his calibration of Cepheids, Hubble established the first linear relation between the degree of spectral displacement and the calculated distance to the observed object: the greater the redshift, the more remote the source of light. Out of these efforts emerged the revolutionary paper of March 1929, which a cautious Hubble had held back for over a year. He titled it "A Relation Between Distance and Radial Velocity Among Extra-Galactic Nebulae."[25]

In a scant six pages Hubble worked a change in humankind's conception of the cosmos no less profound than that advanced by Copernicus, in 1543. Gone forever was the static universe; in its place was an expanding one, the rate of the mutual recession of its parts increasing with their relative distance.

The coming years would produce more papers and further confirmation of what Hubble had wrought. Slipher's pioneering displacements would seem puny when compared to the new velocities Hubble and Humason were adding at the rate of ten per month. Past Virgo, past Pegasus, past Pisces, Cancer, Perseus, Coma, and Leo, careening into the blackness of space at an incredible 19,700 kilometers per second—the astronomer and his assistant slowly but surely nibbling away at the speed of light. Humason uncorked a bottle of his famous Depression-era "Panther Juice" to mark their success. And later Hubble was overhead speaking to him on the telephone: "Now you are beginning to use the 100-inch the way it should be used."[26] Soon the unlikely duo would publish the jointly authored paper marking the highlight of their collaboration: "The Velocity-Distance Relation Among Extra-Galactic Nebulae."[27] Still, Hubble had good reason to believe that this sudden expansion of the cosmos was more the beginning of the journey than the end. Along the way, he would join other scientific immortals by having a law named after him, *Hubble's law* ($V = Hd$), a measure of the rate of expansion of the universe.

At night, when the waning moon is but a sliver in the distance, the great telescope stands ready to do its master's bidding. Like a birthing ghost, he emerges from the gloaming, tall, slender, confident in knickers and high-topped boots, hands thrust deep into the pockets of his trench coat, sparks rising from his briar into the cavernous dome. His face, much like his thoughts, borders on the opaque, as though glimpsed through a glass darkly.

He pauses for a moment, as if to contemplate what lies ahead, before ascending the steps and iron ladder leading to the observing platform. The dome is open to the chill air, the tops of the tall pines dimly visible against the darkening sky. The master mariner issues orders to the waiting night assistant seated at the console below. So many hours or so many degrees. There follows the metallic whining of the traverse, a series of loud clicks, a final heavy clanging of the Victorian machinery as the 100-inch is clamped. He withdraws a small magnifying glass from his pocket with which to examine the field at the eyepiece. Satisfied that all is well, he eases back into the lone bentwood chair and deliberately fills his pipe. The last traces of daylight have vanished, and the remaining lights are turned out, making way for the soft glow of the stars. Leaning over, he slides the cover from a photographic plate, slips it into its holding frame, and calls out the exposure time to the assistant. Then he tells him: "You can go if you like."[28] Taking control of the telescope himself, he is suddenly alone in the universe with his private thoughts and dreams.

Such solitude had been experienced years earlier by a young and obscure employee in the Swiss patent office at Berne. In the early 1930s, Albert Einstein, by then a Nobel Laureate, had come to Caltech to lecture and to take the measure of the American astronomer who had cast doubt on his belief that the universe is static. It did not take long for Einstein to correct this major blunder, which had provided no explanation for Hubble's redshifts. He modified his calculations on relativity to make theory conform to fact. Then, one afternoon as Hubble's wife Grace was driving the gnomish physicist around Pasadena, Einstein turned to her and issued a compliment for the ages: "Your husband's work," he said, "is beautiful."[29]

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Abbreviations

Manuscript Collections

AIP — American Institute of Physics, College Park, Maryland

HCOA — Director's Correspondence, Harvard College Observatory Archives, Harvard University, Cambridge, Massachusetts

HUB — Edwin Hubble Manuscript Collection, Henry Huntington Library, San Marino, California

MWODF — Mount Wilson Observatory Archives Director's Files, Henry Huntington Library, San Marino, California

SALO — Mary Lea Shane Archives of the Lick Observatory, University Library, University of California, Santa Cruz

YOA — Director's Papers, Yerkes Observatory Archives, Yerkes Observatory, Williams Bay, Wisconsin

Individuals

A.S. — Allan Sandage

B.S. — Bert Shapiro

G. E. Christianson

E.B.F. — Edwin B. Frost
E.P.H. — Edwin P. Hubble
G.B.H. — Grace Burke Hubble
G.E.H. — George Ellery Hale
H.S. — Harlow Shapley
J.F.L. — John F. Lane
M.L.H. — Milton L. Humason
V.H. — Virginia Hubble
V.M.S. — Vesto M. Slipher
W.H.W. — William H. Wright
W.S.A. — Walter S. Adams