From the Hill: The Story of

LOWELL OBSERVATORY

Rose Houk

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Third Edition

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Lowell Observatory
Flagstaff, Arizona

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Credits *(All photos property of Lowell Observatory unless noted below.)*
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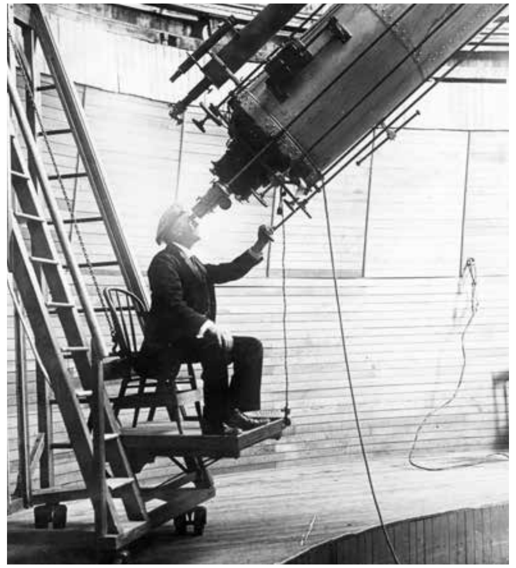


Lowell Observatory

invites the public to visit Mars Hill on the west side of Flagstaff, Arizona. The Steele Visitor Center is open daily all year, except on major holidays. Talks, tours, and exhibits are scheduled during daytime and nighttime programs. Night programs also feature viewings through the Clark twenty-four-inch and McAllister sixteen-inch telescopes, weather permitting. Visitors may also see historic instruments on display in the Rotunda Museum and Putnam Collection Center. The public is welcome to stroll among the oaks and pines on the peaceful campus, taking the short Pluto Walk to the Pluto Discovery Telescope, or the longer Galaxy and Universe Walks.

For information about public programs, summer camps, and special events, go to www.lowell.edu, or call (928) 774-3358. For advance reservations for group tours, call (928) 233-3280. Lowell Observatory is an independent, nonprofit research facility whose public program is supported primarily by admission fees and donations. Address: 1400 West Mars Hill Road, Flagstaff, Arizona, 86001.

Public outreach and education has always been a high priority for Lowell Observatory. One long-standing program includes travel to schools on the Navajo and Hopi Nations. Lowell astronomers visit classrooms and provide materials for fifth- through eighth-grade teachers and their schools. Traditional cultural knowledge is incorporated, and students are also invited on field trips to the observatory. University undergraduates and interns are also given on-the-job experience observing with Lowell telescopes under the guidance of professional staff.

Percival Lowell, founder of Lowell Observatory

More than century ago, a telegram

was fired off from the cosmopolitan eastern city of Boston to a backwoods lumber town in the Arizona Territory: "Site probably Flagstaff. Prospect for best seeing. Report climate . . . compared with Tucson."

The telegram was sent on April 10, 1894, by Percival Lowell to Andrew Ellicott Douglass. A young astronomer and son of an Episcopalian minister, A.E. Douglass was a man with a mission. He had been sent by Mr. Lowell to the western part of the country to find the best location for an astronomical observatory. All of Douglass's work was to be completed in time for a favorable view of Mars that was to occur one short month later. Douglass had already tested Tombstone, Tucson, Tempe, and Prescott and found them wanting in a most critical criterion for astronomical observing—the elusive quality of "seeing."

Flagstaff fulfilled both men's fondest wishes that spring. A.E. Douglass followed Percival Lowell's instructions; he set about building an observatory on a hill on the outskirts of the small town of Flagstaff, population a thousand souls, tucked into the ponderosa pine forest of northern Arizona.

Lowell Observatory has since become a household word in the world of astronomy. From its home on Mars Hill thorough searches for life on another planet have been conducted; Pluto, then our solar system's ninth planet, was discovered there; and pioneering observations that contributed to current concepts of the universe were also made at Lowell.

While Lowell Observatory treasures its history, it is far more than a quaint home of nineteenth-century science. Today a multitude of telescopes still point at the night sky, as the observatory's staff of scientists continues wide and varied research into basic questions about our solar system, and other planets and stars and galaxies far beyond. Observers and instrument makers ably aid that research. Lowell Observatory also serves as a training ground for university students in astronomy.

Percival Lowell dedicated the last twenty-two years of his life to work at his observatory. He was there when he died in 1916 and is buried in a mausoleum that looks out toward the towering San Francisco Peaks. His philosophy as an astronomer is etched in the gray New England granite of his tomb: "To see into the beyond requires purity . . . and the securing it makes him perforce a hermit from his kind . . . . He must abandon cities and forego plains . . . only in places raised above and aloof from men can he profitably pursue his search."

Percival Lowell made a fine choice in his selection of a place—high above the cities and the plains—where he would carry out the final passion of his life and where his endowment would allow others to do likewise.

A.E. Douglass at the Clark Telescope

Flagstaff It Is

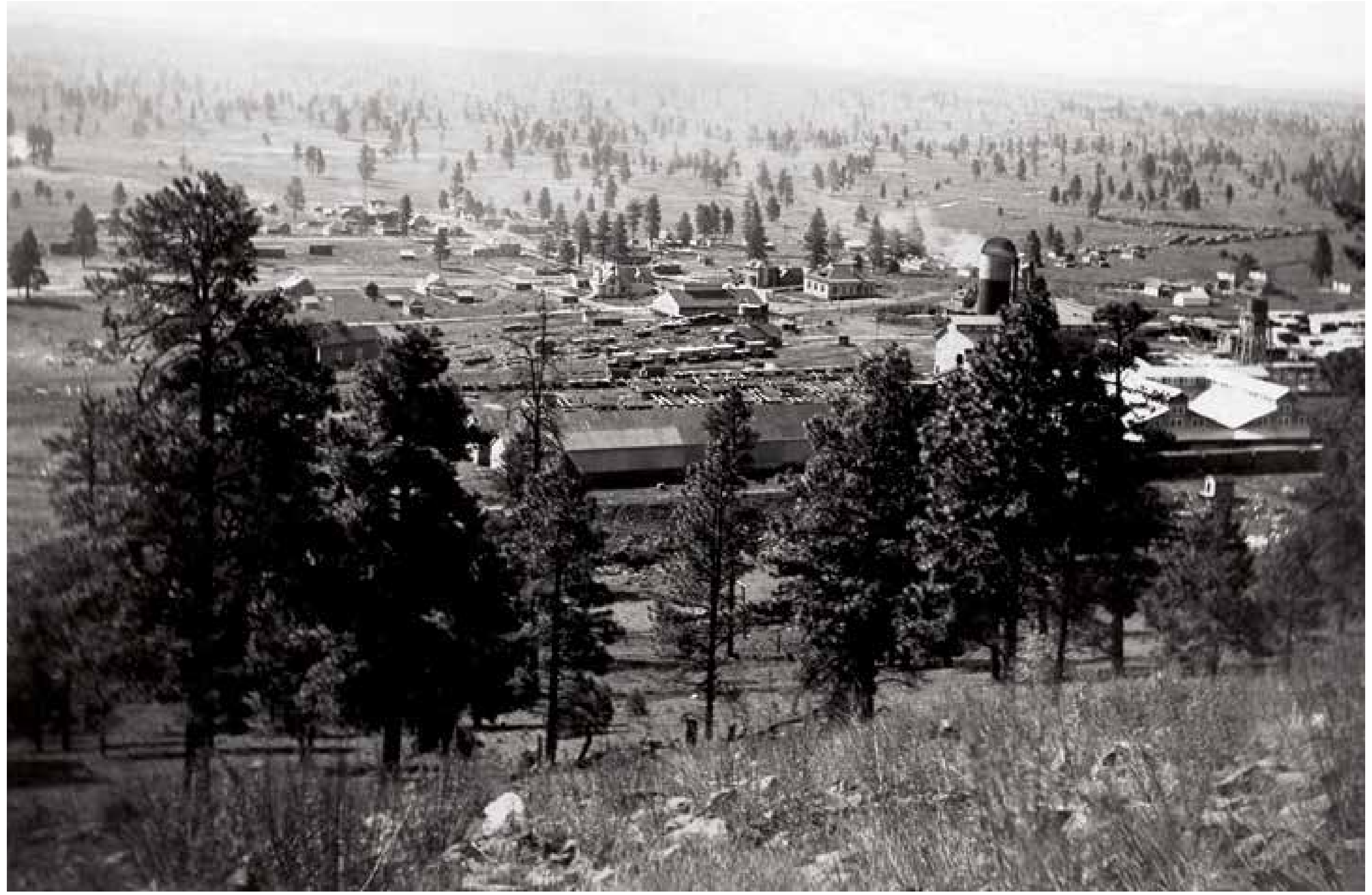
Early telescope on Mars Hill

A.E. DOUGLASS started his search for the site of Percival Lowell's observatory in March 1894 in southern Arizona. He first tried Tombstone, then moved on to Tucson, where he found not only bad weather but troublesome mosquitoes as well. In daily dispatches to his employer in Boston, he reported vital statistics of each place he sampled—rainfall, altitudes, winds, and the "seeing."

"Seeing" is an intrinsic quality of the air, concerned not so much with clarity as with steadiness. Heavenly objects, when seen through the turbulence of Earth's atmosphere, are given to wobbling in the eyepiece of a telescope. For astronomers, the more this pesky problem of atmospheric turbulence can be avoided the better, hence the emphasis on good seeing.

Percival Lowell, acutely aware of the importance of seeing, bore it in mind constantly during the dogged search for an observatory site. The yardstick he and Douglass used to measure seeing was a scale devised by astronomer W.H. Pickering of the Harvard College Observatory, who was also involved in the founding of Lowell Observatory. Like the scoring in a diving contest, Pickering's scale of seeing progressed from one to ten, with ten being the most desirable.

Finding nothing above a seven in the southern part of the state, Douglass headed north, aiming always for a ten. On the evening of April 4, with Lowell's own portable six-inch telescope, Douglass launched a two-week series of observations in several places around Flagstaff. He sent reports almost daily to Lowell, including details about the town. Although Flagstaff lacked a river of any size, it did have a "good hotel for this part of the U.S. Ladies can stay there." More important, he found a site that offered especially good seeing. As time became more critical, Lowell wired Douglass stating Flagstaff as the tentative site. Following another week of reports from Douglass, Lowell made up his mind and telegraphed: "Flagstaff it is."



View from Mars Hill of small town of Flagstaff, circa 1896 to 1900

The observatory would be on site 11, situated on a low hill just west and 330 feet above town. Lowell then admonished Douglass, as he would often in the ensuing months, to push on with work on the observatory "as fast as possible."

Douglass wasted no time. Ground was broken on April 23 for the foundation of the dome that would house the telescope, to arrive later from Boston. Twenty-four juniper posts were sunk into the basalt boulders that cap the mesa, and the posts were covered with thin boards. The top of the dome would revolve on wheels set into a hardwood track, so that one man could move it easily with a set of block and tackle. The shutter opening in the roof was eight feet wide, covered with a canvas curtain that happened to work well in summer but behaved "mischievously" in winter.

Douglass was maintaining a hectic schedule, not only with construction but also with astronomical observations. While the telescope pier was being installed, he was sending Lowell drawings and reports of his search for the returning Gale's Comet. Douglass was also keeping close accounts of the money being spent, and finally had to ask Mr. Lowell to forward a thousand dollars to pay increasing expenses. His employer obliged, advising Douglass to take out two hundred dollars, a fourth of his salary.

Meanwhile, the fledgling town of Flagstaff—dubbed the Skylight City—guaranteed title to five acres of land for the observatory and pledged to build a wagon road to the top of the mesa.

May 28, 1894, was a monumental day in the history of Lowell Observatory. Percival Lowell himself arrived in Flagstaff. Borrowed eighteen- and twelve-inch telescopes were in place in the new dome, and all was in readiness to observe a "favorable opposition" of Mars—when it is opposite the sun and close to Earth.

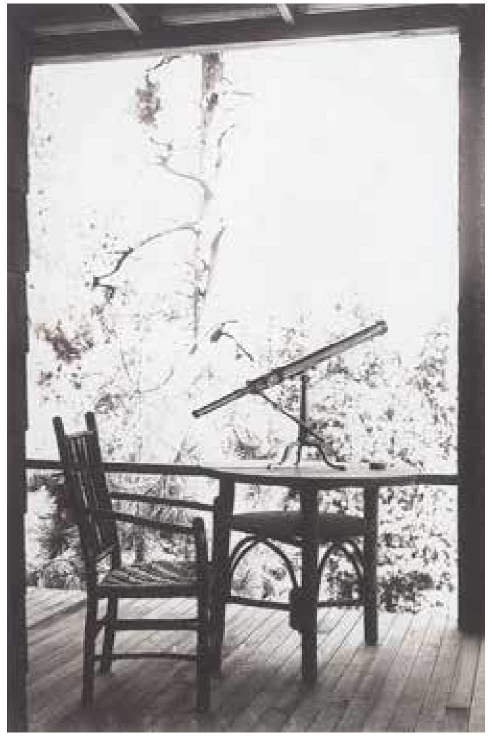
Observations of the planet began immediately and continued almost nightly for the next six months. But then things began to turn sour. Just as Lowell was leaving in December, Flagstaff's infamous wintry weather set in with a vengeance. Lowell later sent condolences to Douglass as the weather, along with the observing, grew grim beyond words.

At times snowfall was so heavy that Douglass had to climb a ladder and enter the telescope dome through the shutter, and he could toboggan on his snowshoes down the hill to the boarding house where he stayed. Handyman Stanley Sykes, who would become Lowell Observatory's instrument maker, related to Douglass his own scale of seeing, more appropriate to Flagstaff conditions: "10 is when you can see the moon, 5 is when you can still see the telescope, and 1 is when you can only feel the telescope but not see it."

By March Lowell said if such conditions continued he could "see little use in keeping up the observatory any longer." He was on the verge of returning the telescope, dismantling the dome, and relocating in Mexico. And that he did. By the middle of April 1895 Lowell Observatory officially closed—but only temporarily.

Percival Lowell continued an on-again, off-again search for an ideal observatory site. He looked all over the world—including not only Mexico, but also the Sahara Desert and the Andes Mountains as well. But even with imperfections, Flagstaff eventually won out because overall it was judged better than any other place Lowell had tried.

The Clark dome on Mars Hill with a weather station on ladder



Above, a well-dressed Percival Lowell. Below, Percival's first telescope on porch at the observatory

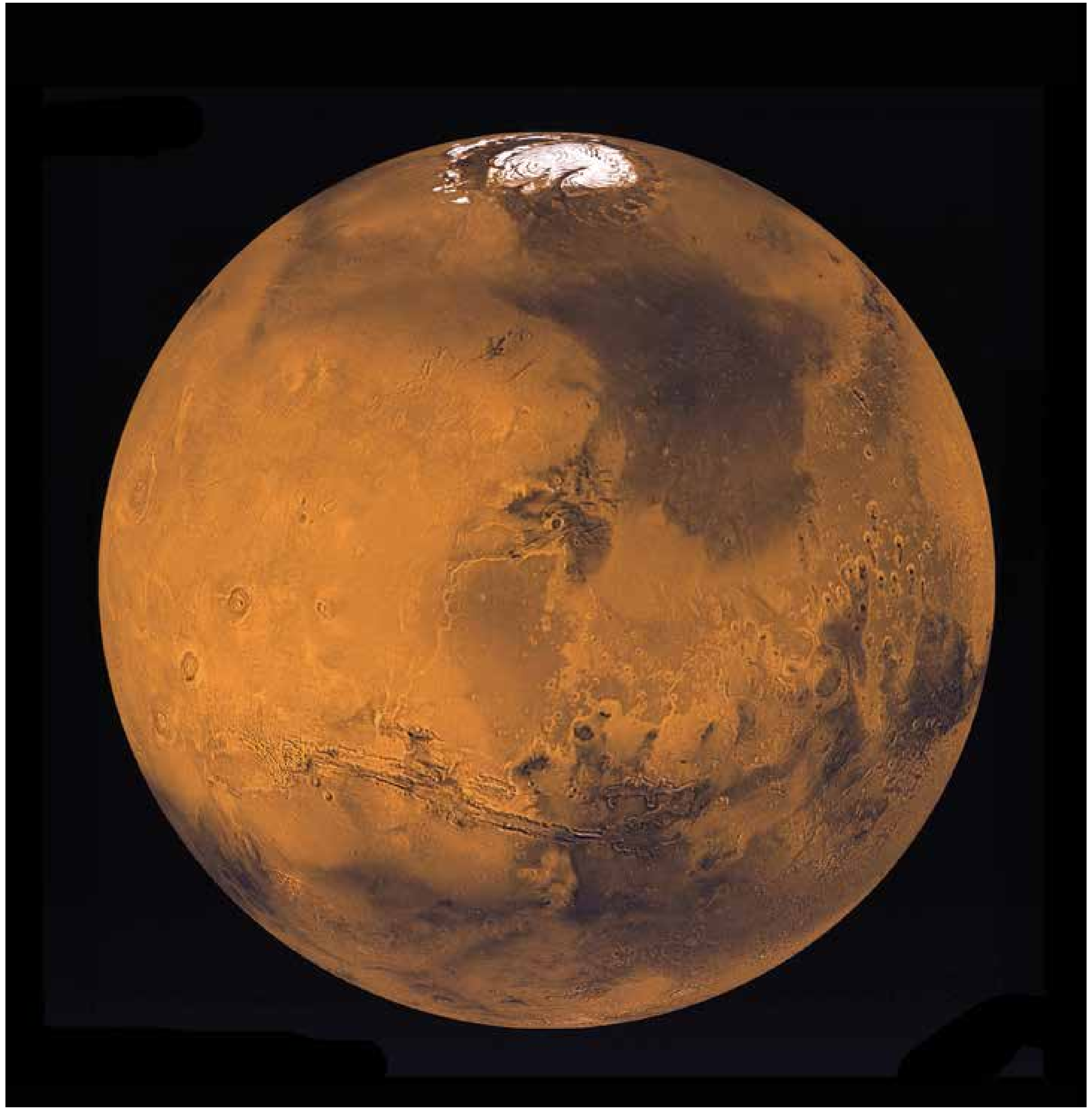
In the summer of 1896 A.E. Douglass was back in Flagstaff, and later that year a fine new twenty-four-inch refracting telescope and a handsome forty-foot dome to house it were brought to Flagstaff for testing, then sent to Mexico. It all returned to Mars Hill in the spring of 1897. The telescope was built by the famous firm of Alvan Clark and Sons, and the dome had been constructed by Godfrey Sykes, who worked with his brother Stanley in their "Makers and Menders" business in Flagstaff. Lowell arrived in July and installed the lens in the telescope, and again began immediate observations of Mars.

His subsequent work on Mars brought Percival to Flagstaff often; it became his home away from home. From the busy streets of Boston he would return to Mars Hill and tend a garden that grew legendary pumpkins and squash. He took an intense interest in everything around him and spent most of his spare time exploring places around Flagstaff. He was an amateur botanist as well, dutifully noting the blooming times of wildflowers on Mars Hill and sending specimens of new plants to Dr. Charles S. Sargent at Harvard University's Arnold Arboretum.

Percival Lowell's style of living reflected his personal wealth. In all his portraits, gazing steady-eyed into the camera, he presents an image of sartorial excellence—dressed in starched white shirt and three-piece tweed suit and jauntily holding a walking cane. Distinguished observatory guests who disembarked from the Santa Fe Railroad in Flagstaff were fortunate recipients of Percival's generous hospitality. These people—paleobotanist Lester Frank Ward, newspaper magnate William Randolph Hearst, and legislator Henry Fountain Ashurst to name a few—always sat down at tables bedecked with fine linens and glistening crystal.

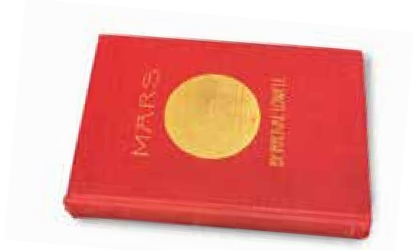
Despite his many diversions, Percival Lowell never strayed from his prime astronomical interest—Mars. The red planet was the reason he had founded Lowell Observatory, and before long he had formulated a comprehensive theory about it. That theory aroused vigorous controversy in the astronomical community and fired a public fever that at times appeared incurable.

Above, the Baronial Mansion on Mars Hill. Below, Percival Lowell, right, in his study with his secretary, Wrexie Louise Leonard, and Edward S. Morse



View of the planet Mars

Lowell and Mars



Percival Lowell's first book about Mars

PERCIVAL LOWELL expressed no doubts about the probability of life on Mars. Entering the field of astronomy when he did, in the late nineteenth century, he inherited earlier views of Earth's near neighbor. Maps of Mars in those days showed ice caps, seas and lakes, and even continents and canals. With attributes so similar to Earth's, it did not require a great leap of faith to assume that life could exist there.

It was this curiosity about Martian existence that spurred Lowell to found an observatory where he could pursue his major interest. Beginning in 1894 when Mars was close to Earth, and for the next twenty-two years, he collected vast quantities of data, sketches, and photographs of the planet, and published volumes of scientific papers, popular articles, and books on his theory.

People have wondered why, at age thirty-nine, this wealthy man suddenly embarked on a career in astronomy with little formal training in the discipline. Lowell himself recalled that his earliest interest in astronomy and Mars dated well before 1894, to 1870 when he said he "used to look at Mars with as keen interest as now." As a young man he read astronomy books, had his own telescope, and gazed at the stars from the roof of his parents' house in Brookline, Massachusetts.

Lowell, whose family name is attached to the Massachusetts textile town, was born in 1855. His upbringing reflected his Bostonian parents' wealth and social stature—Percival attended preparatory schools in France, graduated Phi Beta Kappa from Harvard, learned about investments and business in his grandfather's cotton mill, and then traveled and lived in the Orient. Despite release from the everyday worry of earning a living, he was not one of the idle rich. His father had ingrained in his children the fundamental necessity that "every self-respecting man must work at something . . . of real significance."

In 1893, his fascination with the Orient sated, Percival

Percival Lowell's early sketches of Mars, made in June 1894

Lowell returned to Boston. Lawrence, his younger brother and biographer, said that Percival "left no statement of why he gave up Japan for astronomy." Perhaps he had learned all he could there, or astronomy may have substituted as an intellectual interest. Interestingly, Percival had taken a telescope to Japan with him, the same six-inch one that A.E. Douglass would use on his reconnaissance trip to Arizona.

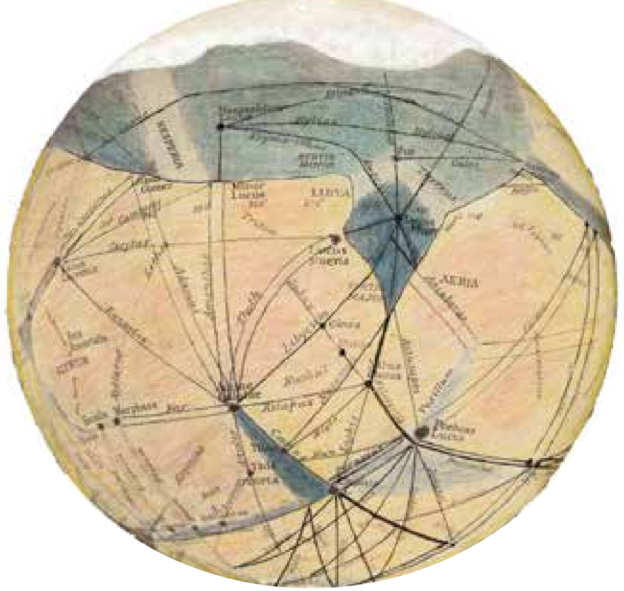
Percival Lowell's three books on the planet Mars

When Lowell arrived at his new observatory in 1894, he was already fully inspired by the work of Italian astronomer Giovanni Schiaparelli. In 1877 Schiaparelli had seen lines on Mars that he called *canali*, or "channels," which Lowell modified to "canals." Of the network of canals, Lowell said, "A mind of no mean order would seem to have presided over the system we see—a mind certainly of considerably more comprehensiveness than that which presides over the various departments of our public works." He noted that the lines were exceedingly uniform in size and pattern—they averaged thirty miles wide, were "fine and straight," and radiated from special points. To him they "certainly" represented an irrigation system, much needed on Mars because of its lack of water. The beings that masterminded this artificial network inhabited an arid planet, whose water came mostly in the form of dew or frost and seasonal meltings of the polar ice caps.

Would other physical conditions on Mars allow life to exist? Lowell's observations and calculations led him to conclude that Mars indeed had an atmosphere that could support life. That atmosphere was thin, cloudless, and calm, with a mean temperature of forty-eight degrees Fahrenheit, he said. The thin atmosphere was not a problem because Lowell did not think lungs were a prerequisite to intelligent life: "There is nothing in the world or beyond it," he wrote, "to prevent . . . a being with gills, for example, from being a most superior person."

Martians as little green men was not an image Percival Lowell would have supported—at least not the part about men. Though he never wavered in his belief that life probably existed on Mars, Lowell never speculated what form that life took. To his chagrin, throughout the Mars furor the public and the press usually failed to acknowledge that important qualification.

Even as early as 1894 and 1895, after only a few months of observation, Percival Lowell began to publish his theory of Mars. The first full explanation appeared in a series in *Popular Astronomy* magazine, followed by another series of articles in the *Atlantic Monthly*. He also wrote three major



Colorized version of 1905 drawing of Mars by Percival Lowell, compiled from observations through the Clark Telescope books on the subject: *Mars* in 1895, *Mars and Its Canals* in 1906, and *Mars as the Abode of Life* in 1908. Lowell was a superlative stylist and punster, and his adeptness at writing for a popular audience made his ideas all the more palatable to an eager public.

Reaction to his theory ran the gamut—the astronomical community ranged from vehement criticism through mild objection to some support. Many astronomers simply did not see the same markings on Mars that Lowell did; often, however, they were as critical of his popularization as they were of the theory itself. But Lowell insisted that scientists were obliged to present their work to the public in clear, understandable terms. The press often responded with wry humor and occasional embellishments, while the public could not seem to get enough.

Percival Lowell's breakneck pace of observing and traveling and writing finally took a toll. In 1897 he suffered a breakdown from nervous exhaustion, forcing him into a lengthy period of convalescence. Not until 1901 was he well enough to return to his observatory and resume his work.

During Lowell's absence, some things had changed at the observatory. The eccentric Dr. Thomas Jefferson Jackson See for a time was there, and his personality quirks drove away most of the assistants. In 1901, Lowell and A.E. Douglass came to an unfortunate and cloudy parting of the ways. Douglass's star was rising, however, and he went on to found and direct Steward Observatory in Tucson and to found the science of dendrochronology, or tree-ring dating.

Upon his recovery, Lowell returned to Flagstaff and reentered the fray with characteristic vigor. In 1903 another opposition of Mars occurred. Lowell made productive observations and some new information resulted. In 1905 he revealed that Carl Otto Lampland, who had joined the observatory staff three years earlier, had taken the first photographs of Mars that seemed to show the controversial canals. Lowell was ready for another opposition of the planet in 1907, and in that year he sponsored an expedition to South America and spent eight months in Flagstaff observing Mars.

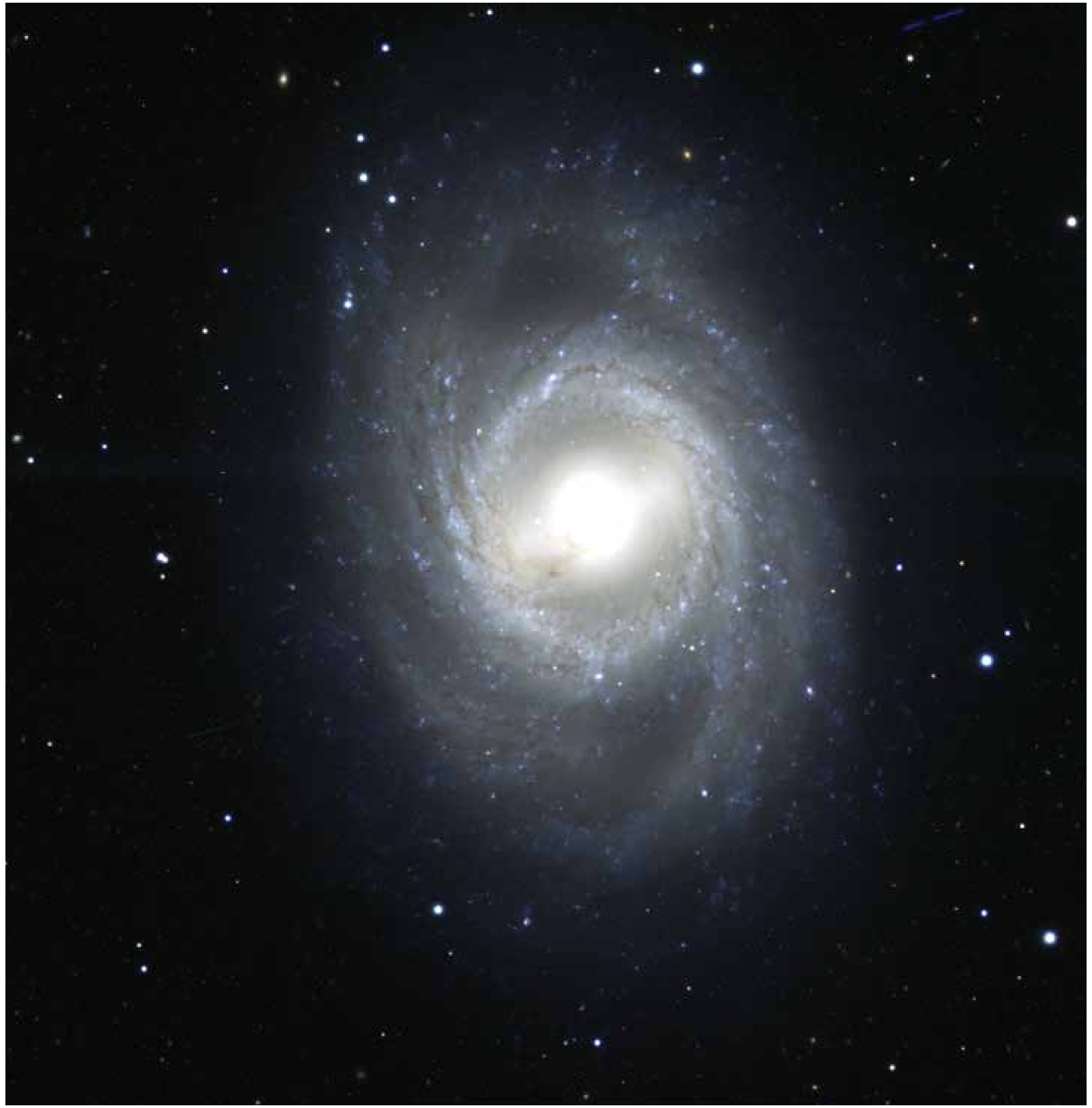
Three wooden globes based on Lowell's sketches of Mars

Curiosity rover on Mars

The year 1907 marked a turning point, however. As author William Hoyt observed, it was a turning point not only in the furor over Mars but also in Lowell's career. "Where before he had aggressively proclaimed his theories and confidently brushed aside the skepticism they stirred, he was now everywhere on the defensive," Hoyt wrote. The public had begun to lose interest in Mars, and Lowell found some difficulty getting his ideas published. As revelations became scarcer, Lowell assumed a more philosophical stance, attributing attacks on his theory to people's inability to accept new ideas.

Not until the 1960s would Lowell's theory of Mars begin to be really tested. The Mariner space missions, particularly Mariner 9 in 1971, showed the planet marked by vast craters and enormous volcanoes and valleys that looked like they were carved by water. More data and detail came when the Viking Lander actually set down on the surface of the red planet in 1976. It took soil samples that yielded no evidence of organic molecules but did show polar ice caps consisting of water, not carbon dioxide, as previously thought. Then in 2004, Mars Exploration Rovers again landed on the planet. The twin robotic spacecraft, carrying instruments and panorama cameras, wheeled around the surface and returned invaluable geologic information. Following in those tracks, in 2012 the Curiosity rover set down—a mobile laboratory designed to assess whether Mars could support microbial lifeforms. During its years exploring what is now the dry, cold planet, Curiosity found signs of liquid water in ancient streambeds, along with layered rocks, hydrated minerals, and other key elements for life. And in continuing efforts, scientists have presented evidence of water *still* flowing on Mars.

So, in some ways Percival Lowell's theories of Mars have been partially vindicated. But along with Mars, he was working productively on many fronts at his new observatory in the first decades of the twentieth century. He studied Mercury, Venus, and Saturn, and quietly launched a search for a planet beyond Neptune that would lead to the discovery of Pluto. Also during those years, one of astronomy's most significant discoveries was made by a man Lowell hired.



The barred spiral galaxy, M95, in the constellation Leo

An Expanding Universe

The bright, nearby Sombrero Galaxy

VESTO MELVIN SLIPHER was hired by Percival Lowell in 1901 as a "temporary" assistant. Fifty-three years later he retired as the observatory's second director.

Slipher, an Indiana farm boy and country school teacher, had impressed his professor Wilbur Cogshall. Cogshall, who had served on the Lowell Observatory staff, persuaded Percival Lowell to take the young Slipher aboard, but Lowell did so without great enthusiasm. "I shall not want another permanent assistant and take him only because I promised to do so," Lowell wrote Cogshall.

But V.M. Slipher soon distinguished himself as a great asset to Mr. Lowell's observatory. He was intelligent, patient, resourceful—and as cautious as his boss was impetuous. Slipher's first assignment was to learn how to use the observatory's new spectrograph—an instrument attached to a telescope that disperses incoming light into wavelengths to produce a spectrum, much as water droplets do to make rainbows.

Slipher succeeded in producing spectrograms—pictures of the spectra. Those pictures usually exhibit features called spectral lines that are produced by emission or absorption of light by certain atoms or molecules. These "fingerprints" are what make spectrograms useful to astronomers and physicists. With his shiny new spectrograph, Slipher launched studies of several of the planets. In one instance he found that Venus rotated much slower than previously thought—rather than a period of twenty-four hours, it has turned out to be nearly 225 days.

Although Percival Lowell's top priority was planetary work, in 1909 he asked Slipher to begin a study of the celestial phenomenon known as spiral nebulae (then called only "white" nebulae). A great debate had been swirling among astronomers for more than a century about the true nature of these faint but numerous patches of light. Were they clouds of gas? New solar

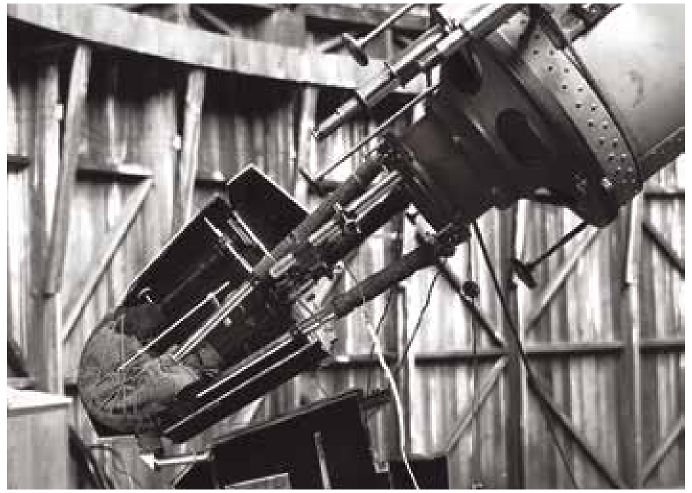
This page, the Clark twenty-four-inch telescope in its dome on Mars Hill

Facing page, above, the spectrograph V.M. Slipher used to make his fundamental discoveries; below, image of the spiral galaxy NGC 7331 from Lowell Observatory's Discovery Channel Telescope

systems being born in our Milky Way? Or "island universes," galaxies entirely separate from our own?

Slipher began the observations but feared that the twenty-four-inch Clark was not strong enough to detect the extremely dim nebulae. A faster lens on the spectrograph camera attached to the scope proved a great boon. Though total exposure times over several nights were still commonly twenty hours or more, he was getting far more detail in his photographic plates. Through the cold nights of the fall and winter of 1912 Slipher shivered in the dome at 7,200 feet elevation, but the rewards were worth the discomfort. With the telescope trained on the Andromeda Nebula, Slipher discovered that the nebula was moving at an incredible speed, three times faster than anything then known.

These results led him on to a spiral nebula in Virgo. When he examined the Virgo plates, Slipher noticed a displacement of lines toward the red end of the spectrum. He knew that if a light source is moving toward an observer, the spectral lines are shifted to the blue. On the other hand, if a light source is moving away, the lines shift to the red. This so-called "red shift" indicated to him that the nebula was receding from Earth. And it was doing so at an almost unbelievable rate of 620 miles a second, or two million miles an hour, much faster than the velocity Slipher had calculated for the Andromeda Nebula.



In 1914 V.M. Slipher presented his velocities for fifteen spiral nebulae at the American Astronomical Society meeting. He reported that "In the great majority of cases the nebula is receding; the largest velocities are all positive…. The striking preponderance of the positive sign indicates a general fleeing from us or the Milky Way." His listeners were so impressed with the speech that they erupted in a standing ovation.

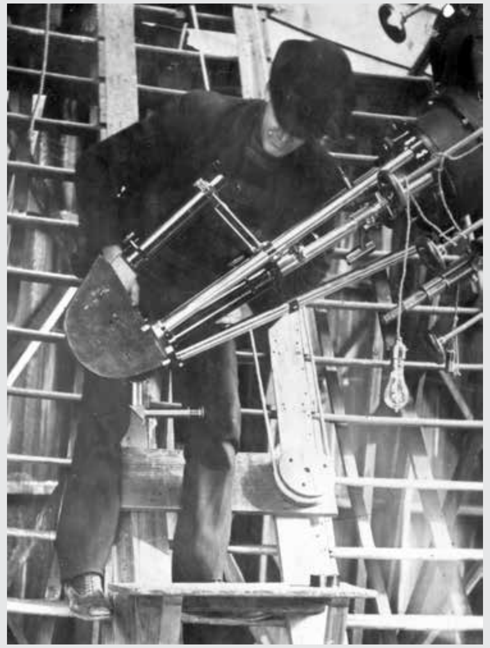
In that "general fleeing" or receding of the spiral nebulae rested the universe-shaking significance of Slipher's discovery. Several years later his velocities were incorporated into equations that showed that the universe was indeed expanding. This assertion, now basic to modern astronomy, holds that when viewed on the scale of the entire universe, galaxies on average are moving away from each other. This idea was nearly as radical as the proposal made centuries earlier by Copernicus that the planets were moving around the sun rather than Earth.

Not until 1917 would Slipher commit himself to the conclusion that the great speeds of the spiral nebulae indicated that they were indeed "island universes" far beyond our own galaxy. (The island universe debate was finally resolved in the early 1930s when the great distances of spiral nebulae from Earth were directly measured.)

Although his spiral nebulae velocities were contribution enough to science, Slipher also could claim a number of other "firsts." He discovered that the spiral nebulae were rotating, observed the existence of interstellar gas and dust, and planned and oversaw the successful search for Pluto.

Following Percival Lowell's death in 1916, V.M. Slipher became acting director of Lowell Observatory and ten years later its director. He continued his explorations into the heavens while tending to the myriad administrative

V.M. Slipher's Spectrograph



THE HISTORIC SPECTROGRAPH THAT V.M. SLIPHER used to make his monumental discoveries of the speeds of galaxies was brought out of mothballs and renovated at Lowell Observatory. The brass was polished and parts refitted, and the beautiful result is on display at Lowell. Made by John A. Brashear of Pittsburgh's Allegheny Observatory, the spectrograph was purchased by Percival Lowell in 1900. It used prisms to separate light into a spectrum. With a camera attached, the spectrograph produced photographs of the spectra. At the time, spectrographs represented a major advancement in astronomy.

When he arrived at Lowell Observatory in 1901, V.M. Slipher mounted the spectrograph on the Clark twenty-four-inch refractor on Mars Hill and began making measurements. Early results were unsatisfactory, and it took nearly a year before he had solved most of the problems. Slipher then produced spectrograms of the planets and, by attaching a faster camera lens and switching from three prisms to one, he obtained good spectrograms of faint spiral nebulae. The shift of the absorption lines toward the red end of the spectrum led V.M. Slipher to deduce that those galaxies were moving away from Earth at unheard-of velocities.

The large Whirlpool Galaxy with smaller M51 above it

VM Slipher (left) and Carl Lampland discuss spectra in 1947

details involved with running the observatory. Not the least of his tasks, and one taken seriously by this Indiana farmer's son, was the care of the observatory's cow "Venus" and her calf "Satellite." And in 1926, with a road completed up to the San Francisco Peaks, the robust Slipher established an observing station at 11,500 feet, which operated for about a decade.

Slipher's spiral nebulae discoveries earned him great distinction. In 1933 he was awarded the Royal Astronomical Society's Gold Medal and the National Academy of Sciences Henry Draper Medal. In receiving the Draper award, he thanked several people and also mentioned the blessings of good equipment, favorable skies, and the freedom to pursue his own research. With typical humility, Slipher concluded by saying that "Under such conditions, some one else might have accomplished more, but surely no one could find more pleasure in doing it than I."

V.M. Slipher retired from Lowell Observatory in 1954. He spent the rest of his life in Flagstaff, and died in 1969 at the age of ninety-three.

Image of Pluto, taken by New Horizons spacecraft in 2015

Pluto

Clyde Tombaugh

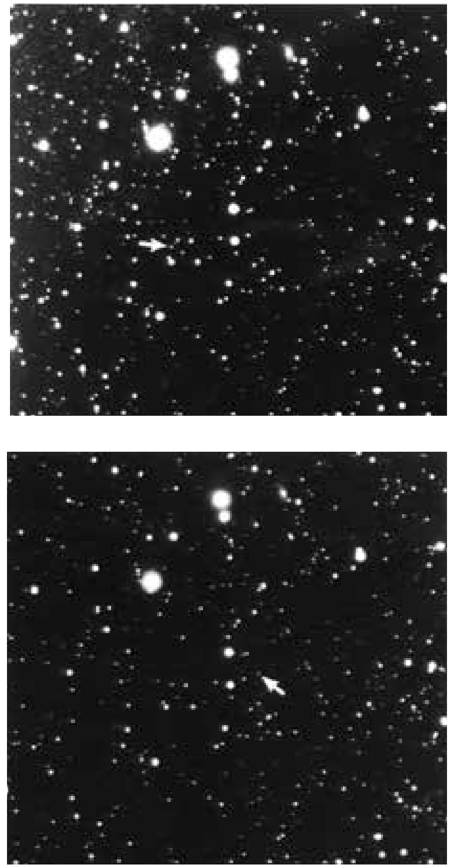
CLYDE TOMBAUGH was advised that he was wasting his time looking for another planet in the solar system. If one were there, it would have been discovered a long time ago, an elder visiting astronomer told him.

But Tombaugh persisted in the quest for the ninth planet in our solar system and he found it, in 1930, after only about six months of searching.

V.M. Slipher had hired Clyde Tombaugh, an amateur astronomer from Kansas, as an assistant to help search for the so-called Planet X. At home on the farm in Kansas, when chores allowed, Clyde spent his time grinding mirrors for his own telescopes. Slipher was impressed by Tombaugh and described him as "a young man of the self-made variety." For Tombaugh, a job at the observatory founded by his boyhood hero, Percival Lowell, was the opportunity of a lifetime.

With money he made in the harvest, Tombaugh bought a one-way train ticket and arrived in Flagstaff on January 15, 1929. After dinner (which he thought must have been bear meat) and a night's rest, he started his new job. His duties included stoking the big coal and log furnace in the basement, leading visitors on afternoon tours, and readying the new thirteen-inch telescope for the planet search. Lawrence Lowell, then president of Harvard University, had given the $10,000 to build the telescope. His gift covered the cost of having the thirteen-inch lens ground and figured by C.A. Robert Lundin, of Alvan Clark and Sons, who had built the observatory's twenty-four-inch and forty-inch telescopes.

Though it took longer and cost more than was expected, the thirteen-inch lens finally arrived on February 11 and proved a real gem. Tombaugh soon started making one-hour exposures on fourteen-by-seventeen-inch glass photographic plates. After ironing out a few technical difficulties, he began to make two good plates of an area of sky, comparing them on a device called a blink comparator.



The Pluto discovery plates, top plate from January 23, 1930 and the bottom plate from January 29, 1930

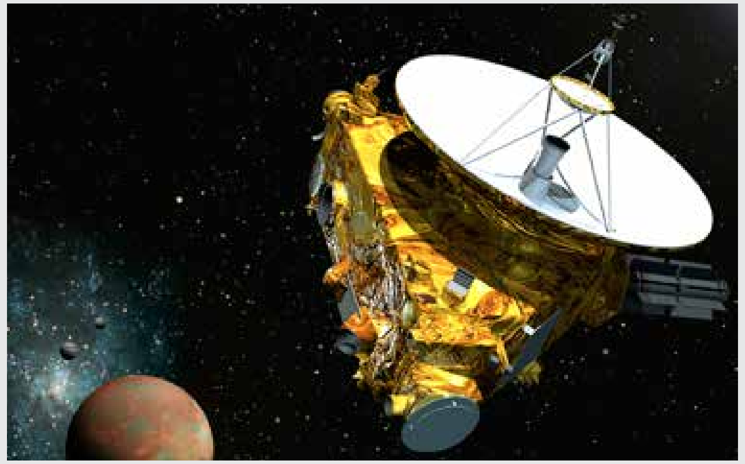
Clyde Tombaugh at the blink comparator

This useful instrument was a microscope on which a pair of plates was mounted, and corresponding areas on each plate were then alternately viewed. As the comparator projected first one plate and then the other into the eyepiece, a moving object—a planet for instance—would appear to jump back and forth.

The process may sound deceptively simple, but it was neither simple nor quick. Other objects, such as asteroids, also moved or changed in brightness as the plates were "blinked." And the photographic plates were literally filled with thousands, sometimes millions, of dots of starlight. "It was as if out of many thousand pins thrown upon the floor one were slightly moved and someone were asked to find which it was," wrote V.M. Slipher and Lowell trustee Roger Lowell Putnam in a 1932 *Scientific Monthly* article.

On the nights of January 23 and 29, 1930, Clyde Tombaugh shot plate numbers 165 and 171 in the constellation Gemini. On February 18 he started to examine them on the blink comparator. At four o'clock in the afternoon his eyes detected an object "popping in and out of the background." "That's it!" Tombaugh exclaimed to himself. A check of a third, backup plate confirmed what he had seen. For the next forty-five minutes, Tombaugh said he "was in the most excited state of mind in my life." He let C.O. Lampland know of his discovery and then announced to Dr. Slipher, "I have found your Planet X." That night was cloudy and telescope viewing was poor, so to pass the time Tombaugh went

New Horizons



NINE YEARS AND THREE BILLION MILES—that's how long and how far it took the New Horizons spacecraft to reach Pluto. Finally, on July 14, 2015, New Horizons approached within 8,000 miles of Pluto. It was a warm, rainy evening in Flagstaff, and the Steele Visitor Center auditorium at Lowell Observatory was standing-room only. The first image of Pluto from New Horizons—showing a perfect golden orb—was up on the screen.

The audience erupted in applause when mission control back in Laurel, Maryland, announced, "We have a healthy spacecraft . . . and we're outbound from Pluto." It was an historic moment and "a celebration for Lowell Observatory, "declared director Jeff Hall. Ever since Clyde Tombaugh made his discovery in 1930, the observatory has remained steadfastly engaged in studies of Pluto.

NASA's New Horizons took four years to build, at a cost of more than $700 million. The thousand-pound, plutonium-fueled spacecraft is fairly small—imagine a baby grand piano. It's equipped with seven instruments, including imagers, spectrometers, and dust counters, with names like LORRI and RALPH.

The spacecraft was launched with an Atlas rocket in 2006; slingshotting past Jupiter, it picked up speed, flying at 51,000 miles an hour and covering a million miles a day. As it approached Pluto, New Horizons stayed perfectly on course, and to everyone's relief did not strike any ejecta or space debris. The Pluto flyby, which lasted just over four hours, went off without a hitch. Clyde Tombaugh's ashes were on board, and his son and daughter, Alden and Annette, witnessed the event that would have amazed their father.

The data from all the instruments on board would take more than a year to download to astronomers around the world, including Will Grundy and colleagues at Lowell. That data, says New Horizons principal researcher Alan Stern, will "help us understand the origin and the evolution of the Pluto system for the first time."

As New Horizons continues out into the farther reaches of our solar system, the discoveries it makes will undoubtedly keep us on the edge of our seats for a long time.

New Horizons sent back these images as it flew past Pluto (right) and its moon, Charon (left)

downtown and watched Gary Cooper in *The Virginian*.

Hoping to say confidently that this "very exceptional object" was indeed a planet, Slipher delayed announcement of the discovery to the public. After locating the tiny object in the telescope and tracking and photographing it for three more weeks, the observatory finally released the news on March 13, the anniversary of Percival Lowell's seventy-fifth birthday. Slipher proudly informed the world that the ninth planet in our solar system had been found at Lowell Observatory, the only traditional planet in our solar system yet found at an observatory in the United States.

Now that the new planet was verified, what should it be named? Apollo, Atlas, Cronus, Minerva, Perseus, Vulcan, and Zymal were among almost a hundred suggestions submitted. With the public clamoring to be part of the competition, trustee Roger Lowell Putnam urged Slipher and the astronomers in Flagstaff to bestow a name posthaste. Such opportunities at immortality can be delicate matters—Mrs. Lowell asked whether the planet might be called either Percival or Constance (her own name). Slipher realized it was time to act. On May 1 he officially proposed Pluto—the name sent in by an eleven-year-old English schoolgirl and one of Putnam's top choices. Pluto was fitting, Putnam pointed out, because it perpetuated the theme of Roman gods and goddesses for planet names. And the first two letters of the name were conveniently Percival Lowell's initials, a fine memorial. The name was highly appropriate too, for Pluto is the god of the underworld, the domain of the new planet at the outermost reaches of the solar system.

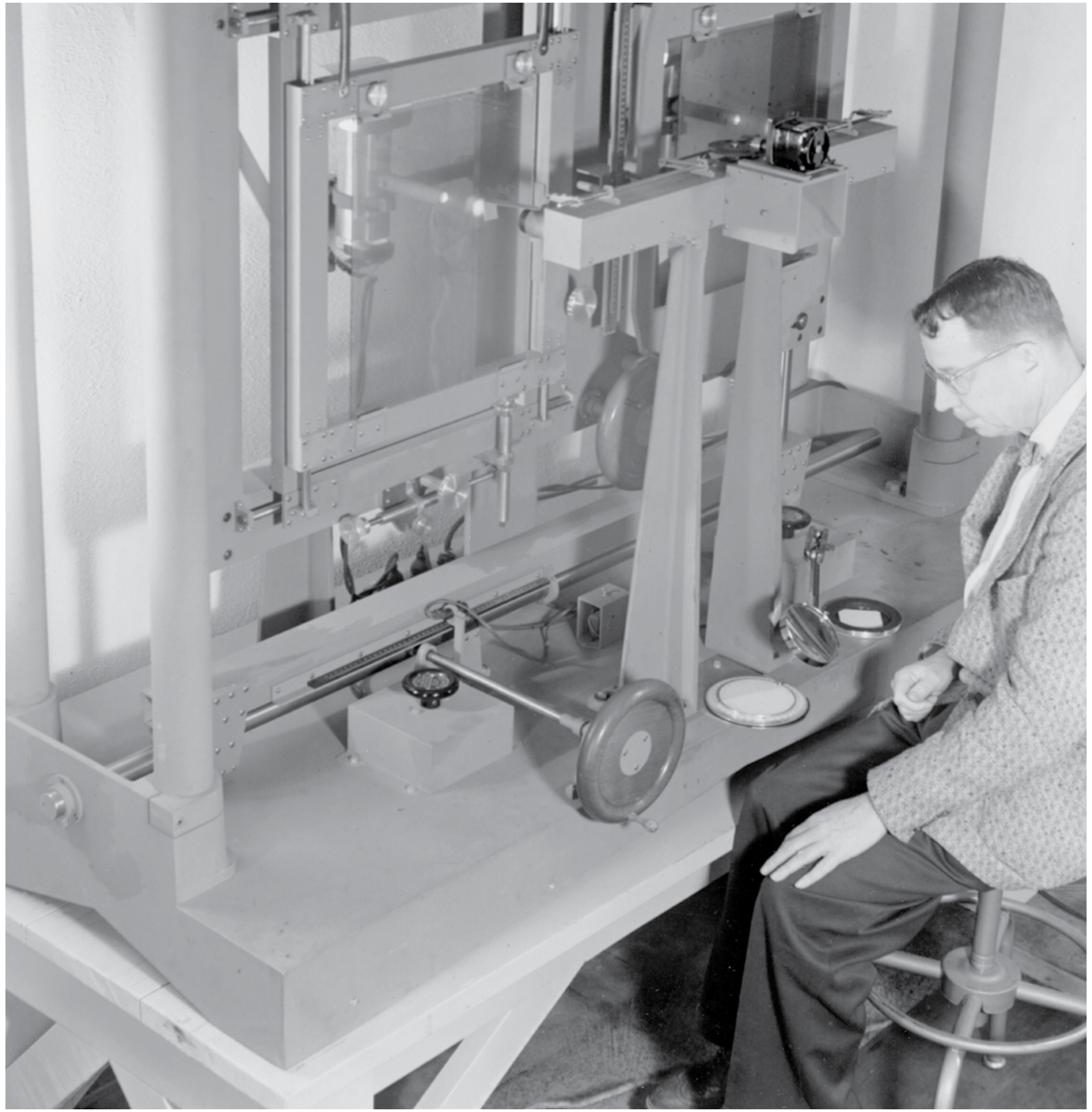
With the thrill of discovery waning, Slipher knew a monumental task still loomed—computing the orbit of the new planet. This challenge bore especially heavily, because of the desire to demonstrate that Pluto was in fact the Planet X that Percival Lowell had predicted twenty-five years earlier. When the orbit was finally computed and then fine-tuned, Slipher announced with a fair amount of confidence that the planet Tombaugh had found "fits substantially Lowell's predicted longitude, inclination and distance for his Planet X."

Percival Lowell first predicted the existence of an unknown Planet X in a lecture in 1902, based on deviations from the expected orbital motion of Uranus. A body of some mass had to be causing those irregularities. Sporadically through the years he pursued the search, comparing photographs and making complex mathematical calculations to determine a location for Planet X. He died without ever seeing the planet, but Lowell was close in his predicted location: Pluto was within six degrees of where he said it would be in the sky.

But is Pluto really Planet X, is there another planet out there, or is Pluto a planet at all? With discovery of Pluto's moon Charon in 1978 (also in Flagstaff at the U.S. Naval Observatory), the mass of Pluto could be calculated. It was so small it could not account for the irregular motions in orbits of neighboring planets. In 2006, the International Astronomical Union reclassified Pluto as a dwarf planet, a unique category. That action was based partly on Pluto's diminutive size and the discovery of similar objects in Pluto's "neighborhood" of the Kuiper belt. The decision raised a flurry of controversy among both astronomers and members of the public. The debate has continued to rage, even as the New Horizons spacecraft successfully completed its historic flyby of Pluto in the summer of 2015, returning stunning, high-resolution photographs and reams of data that have revolutionized how astronomers look at Pluto.

After 1930, Tombaugh scanned the skies from Lowell Observatory for more than a dozen years. In the 7,000 hours he spent looking at nearly three-fourths of the sky, he never found another planet. Yet Clyde Tombaugh would have been the last person to discourage would-be planet hunters; he often offered this commandment, based on long experience: "Thou shalt not engage in any dissipation, that thy years may be many, for thou shalt need them to finish the job."

New Horizons image, showing Pluto's layered atmosphere



Henry Giclas at the blink comparator used in his proper motion survey of stars

A New Era Begins

Henry Giclas

AFTER THE HEADY discovery of Pluto, Lowell astronomers had to roll up their sleeves and devote themselves to perfecting calculations of the planet's orbit. Engaged in that effort was Henry Giclas, whose father Eli had helped build the observatory's forty-inch telescope. Henry grew up around Lowell Observatory, and as a college student during the Great Depression he landed a job as an observing assistant helping the senior astronomers with Pluto's orbit. The most sophisticated tool they had was a hand-cranked "measuring engine" for taking raw measures of the photographic plates.

Meanwhile, Arthur Adel joined the staff of Lowell, arriving from Michigan in 1933. Adel pioneered infrared spectroscopy, was the first to demonstrate that almost all features in the spectra of the giant planets are due to methane and ammonia, and discovered nitrous oxide and deuterium oxide (heavy-water) vapor in Earth's atmosphere. He also found the "twenty-micron window," a region of increased transparency in the terrestrial atmosphere that lets infrared radiation reach the ground. Through that window, important observations can be made.

After Adel's departure in 1942, exciting discoveries at Lowell Observatory seemed to be growing fainter. But big changes were occurring beyond Mars Hill, and the observatory would soon be swept up in those changes. In the years following World War II, the federal government began funding space and astronomical research in an unprecedented way.

One man—John Scoville Hall—boldly led Lowell Observatory into this new era. A New Englander by birth and education, John Hall seemed to be following in Percival Lowell's footsteps. Hall came to northern Arizona in search of a new home for a forty-inch telescope that belonged to his employer, the U.S. Naval Observatory. When he first arrived in 1952, the road up to Lowell Observatory was still dirt and its small staff of astronomers was working with

John Scoville Hall

only three telescopes. Three years later, the Naval Observatory's telescope was relocated to a hill five miles from Lowell, and Hall came out often to use it.

In 1957, the Soviets successfully launched Sputnik. In quick response, the United States government created the National Aeronautics and Space Administration (NASA) in 1958, and the international space race was in full swing. Trustee Roger Lowell Putnam recognized John Hall's talents, and in the fall of 1958 Hall was named the fourth director of Lowell Observatory.

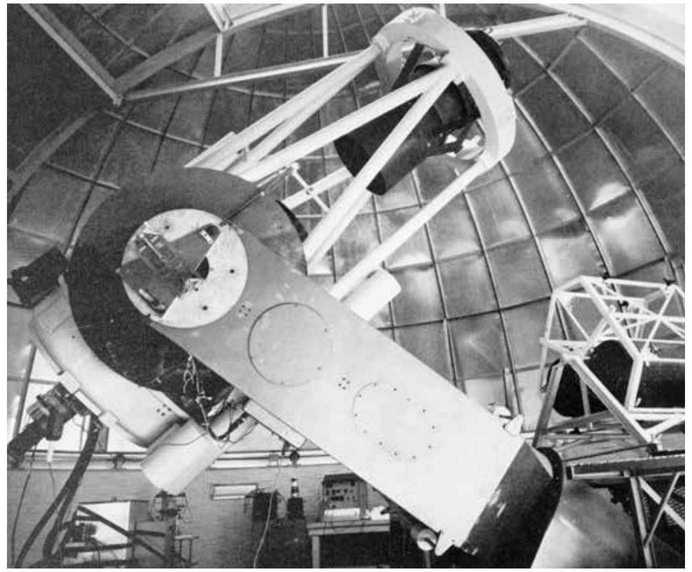
He came in quickly, had a vision, and garnered the resources that breathed new life into Lowell's research program. During his nineteen-year tenure, Hall also oversaw significant expansion of the observatory's physical facilities. "More than any single individual," declared former Lowell trustee William Putnam, "he molded the Lowell Observatory" as it approached its second century.

Among his many accomplishments, Hall brought the seventy-two-inch Perkins Telescope to Flagstaff and oversaw construction of a new forty-two-inch telescope. Through his supervision, an instrument shop was built, and in 1960 Lowell Observatory became home for a project to map our Moon under the auspices of the U.S. Air Force. Hall also hired a number of new professional astronomers and introduced an international influence by bringing in a stream of outside, visiting astronomers.

In 1964, a major event took place with establishment of the Planetary Research Center on Mars Hill, again through funding secured by Hall. At its head was William Baum, formerly of Mount Wilson Observatory. In the ensuing years the center's primary work was the International Planetary Patrol, an ambitious NASA project that involved continuous photographic surveillance of Mars and Jupiter at Lowell and six other locations around the globe. More than a million usable images were produced and stored at the center. Those ground-based patrol photos yielded a great deal of information about fantastic dust storms on Mars during 1971, Jupiter's rotational velocity, and Saturn's rings, among others.

As the mountain town of Flagstaff continued to grow, Lowell astronomers faced a vexing problem—light pollution. Thus came the next significant development, the dark-sky site on Anderson Mesa. Staff astronomer Harold Johnson had explored several locations outside town, including Padre Butte, A-1 Mountain, and Woody Mountain. After evaluating the ever-important quality of "seeing," along with fire danger, obscuring dust, and the potential for encroaching lights, Johnson recommended Anderson Mesa, about twelve miles southeast of Flagstaff, as the best choice. Hall accepted the recommendation, and by the mid 1960s white domes began to sprout on the mesa top, like mushrooms after a summer rain. Several large telescopes on Anderson Mesa now permit astronomers to see even deeper into the night sky.

Meanwhile, Henry Giclas pursued a productive long-term study, a "proper motion" survey of the stars. Assisted by Norman Thomas and Robert Burnham, he set out to duplicate most of Clyde Tombaugh's 1,650 photographic plates and analyze them on a blink comparator, to discern any movement of foreground stars relative to background stars. With the long time lapse of thirty years between Tombaugh's and Giclas's plates, the proper, or actual, motion of stars could be detected. As a result, thousands upon thousands of stars close to our solar system were characterized.



The forty-two-inch John S. Hall Telescope

The Anderson Mesa site, with the Perkins, Hall, Schmidt, and thirty-one-inch telescopes, and the Navy Precision Optical Interferometer

By the time John Hall retired in 1977, Percival Lowell's small observatory in the pines ranked as a full-fledged scientific institution with an international reputation. Astronomers, with ever-more sophisticated tools and technology, found themselves well poised to usher Lowell Observatory into the twenty-first century.

Lowell Observatory's Discovery Channel Telescope

Those Miraculous Optical Tubes

IN 1610 Galileo Galilei took the senators of Venice to the top of a watchtower to demonstrate a new-fangled invention called a telescope. Grasping the utilitarian value of the rudimentary instrument, Galileo wanted to show how easy it was to spy flags flying on ships entering the Venetian harbor.

An outspoken, rabble-rousing, medical school dropout, Galileo built one of his first telescopes by placing two lenses in either end of an organ pipe. When he turned the miraculous optical tube heavenward, he saw some amazing sights—the Moon had mountains and chasms, the giant planet Jupiter was orbited by four satellites, and nearby Venus actually moved around the sun rather than Earth. He also marveled at "stars, which escape the unaided sight, so numerous as to be beyond belief."

Astronomers are notorious for their insatiable appetites for light. Any instrument that would satisfy that appetite and that would distinguish far greater detail than could the human eye, was naturally in great demand. From Galileo's time until the present, optical telescopes have remained the major tools of the trade for most astronomers.

The first telescopes were refractors, which use lenses to bring light beams to a focal point. As their size increases, however, refractors become increasingly unfeasible. Sir Isaac Newton subsequently invented an alternative telescope design, the reflector, which does not suffer from these limitations and has other advantages as well. As the name implies, reflectors use mirrors to gather and focus light. By the 1930s a substance known as Pyrex was invented and used in telescope mirrors because it was relatively insensitive to temperature changes inside a cold telescope dome. That is a valuable quality because temperature changes can alter the mirror shape and thus distort the image. (The size of telescopes, incidentally, is expressed as the diameter of the lens or the mirror.)

Although the basic idea behind telescopes has changed little in four centuries, the instruments called detectors that are attached to them have. In the old days, the only detector was the human eye. Then photographic plates were added to gather and record light. After World War II, photoelectric devices were perfected that produced electrical signals in exact proportion to the brightness of the light source being observed. In the 1970s CCDs—charge-coupled devices—combined attributes of both photographs and photoelectric detectors. Charge-coupled devices are semiconductors that record images as an array of typically millions of small picture elements, or pixels. CCDs are linked to computers that recreate a visible picture on a monitor. Ever more sophisticated software, robotics, smartphones and other digital devices are adding to the power of detection and precision.

All this was undreamt of in Percival Lowell's time. But from the beginning, he did seek to obtain the best telescopes for his observatory that money could buy. His first major investment was a Clark twenty-four-inch (0.6-meter) refractor. In 1896, Alvan Graham Clark of the famous Alvan Clark and Sons lens makers, came to Flagstaff to personally install the new lens in the "Clark." Lowell paid $20,000 for the thirty-ton telescope, one of the last large refractors made by the firm.

For more than a century, the Clark has been used to view Mars, map the Moon, and reveal the glories of the heavens to more than two million visitors. After 117 years of admirable performance, the telescope was in bad need of a facelift. In 2014, it underwent a complete overhaul, with Lowell's Ralph Nye and crew taking on the task. Everything—telescope tube, main bearing, mount, clock drive, every gear, bolt, and screw—was taken apart. Accumulated rust, grease, grime, and lead paint were stripped away and sandblasted, and some pieces were repainted or replaced. The precious glass lens was even removed and carefully cleaned. In fall 2015, with everything tucked neatly back into place, gleaming and good as new, this historic telescope was reopened for public viewing.

The Clark is joined by another telescope, the McAllister sixteen-inch (0.4-meter). This Cassegrain reflector was installed specifically for public use and fills in when the Clark is in heavy demand. Acquired from Northwestern University, the telescope is named for John McAllister, an amateur astronomer. His wife Frances, a Flagstaff philanthropist, donated funds for the dome in memory of her husband.

A noteworthy member of the Mars Hill collection is the Pluto Discovery Telescope. This thirteen-inch (0.3-meter) refractor is the telescope with which Pluto was discovered in 1930, and was funded specifically for that search by Percival Lowell's brother, Lawrence. In 1970 the telescope was moved to Anderson Mesa, but enjoyed a homecoming when it was returned to Mars Hill and rededicated in 1995.

The Clark Telescope restoration

SOFIA

EVER WONDERED WHAT TO DO with a mothballed Boeing 747? Put a telescope in it and fly it high above Earth, that's what. That's exactly what was done to create SOFIA, the Stratospheric Observatory for Infrared Astronomy. A cooperative project between NASA and the German space agency DLR, it is the largest airborne observatory in the world.

Extensive modifications were made to the commercial jetliner, with an opening cut out behind one wing to accommodate a 100-inch (2.5-meter) telescope, which is also fitted with vibration isolators, gyrostabilizer, and optical tracker. The plane flies at altitudes of 39,000 to 45,000 feet, putting the telescope above nearly 99 percent of the water vapor in Earth's atmosphere and permitting views of regions of the infrared spectrum that can't be seen by ground-based telescopes.

While SOFIA has been used mostly for infrared spectroscopy, Lowell's Ted Dunham had optical uses in mind. With colleague James Elliot, he designed and built HIPO, a high-speed imaging photometer, for the telescope. Using this instrument, Dunham observes occultations of stars by bodies in our solar system, and transits of planets orbiting other stars as well. For these, says Dunham, it's critical to get above the clouds and be in the right place at the right time.

SOFIA has also carried teams of educators, known as "Airborne Ambassadors," to work on projects aimed at engaging students and the public in science.

Visitors can stroll to the end of the Pluto Walk and see the basalt-based dome that houses this historic telescope.


TiMo

A workhorse on Mars Hill has been the twenty-one-inch (0.53-meter) reflector devoted to studies of the luminosity of stars like our sun. This telescope, which dates to 1953, is housed in a nontraditional "dome" that looks more like a small house with a pitched roof. The roof slides off horizontally, permitting a wide view of the sky. The telescope tube, a recycled old gas line pipe, evidences a resourceful time.

Among the newest telescopes on Mars Hill is the twenty-inch (0.5-meter) TiMo, built in-house and used to monitor the weather on Titan, Saturn's largest moon. The fully robotic TiMo is part of the Titan Monitoring Project, a global network of ground-based telescopes. Lowell astronomers also still occasionally call into duty an eighteen-inch (0.45-meter) refractor.

Larger telescopes are located at Lowell's dark-sky site on Anderson Mesa. The seventy-two-inch (1.8-meter) Perkins Telescope used to probe the depths of space is the granddaddy of them all. Hiram Mills Perkins, a graduate of Ohio Wesleyan University, joined the staff of his alma mater just as the Civil War broke out. Decreased college enrollments cost him his job, so Hiram returned to the family hog farm. That enterprise, plus Perkins' frugality, led to the accumulation of a tidy fortune. After the war, he rejoined the faculty at Ohio Wesleyan, and by the time of his death in 1924 he had founded Perkins Observatory and contributed close to $200,000, nearly two-thirds of the cost of a new telescope.

Originally the Perkins was built as a sixty-inch (1.5-meter) telescope but lacked one important part—a mirror. Clifford Crump, the first director of Perkins Observatory, persuaded the United States Bureau of Standards to undertake an experimental optical program to cast a mirror for it. "Experimental" was the right word. Four mirrors were made and all broke. The fifth, cast in 1928, was a success, but it turned out to be a 3,300-pound, *sixty-nine-inch* disk. Two years later, after the telescope tube was enlarged, it was finally completed and put to work.

The Perkins Telescope served well for the next twenty-nine years, but in a 1961 agreement between Lowell Observatory and Ohio Wesleyan and Ohio State universities it was relocated to Anderson Mesa. In 1965 the sixty-nine-inch mirror was replaced with a seventy-two-inch mirror; in 1998 Lowell became full owner of the telescope and now operates it in partnership with Boston University.

The Perkins has no eyepiece. Instead, astronomers sit before a bank of computers in a warm control room, guiding the telescope's movements and monitoring incoming data gathered on a television-camera system. Hiram Perkins might get a chuckle out of one of the spectrographs attached to his telescope. On the grey metal box, a sticker boasts "Don't Laugh, It's Paid For."

Beside the Perkins Telescope stands another classic white dome which houses the John Scoville Hall Telescope. This forty-two-inch (1.06-meter) reflector, named in honor of the observatory's fourth director who acquired it, is used for stellar research and many other projects.

Anderson Mesa is a hub of activity for the Navy Precision Optical Interferometer (NPOI), a pioneering project begun in the 1990s. This "telescope" actually consists of six mirrors, called siderostats, arrayed in a three-armed Y-shape spread over about fifteen acres of land. This extended reach lets NPOI mimic a monstrous telescope 1,475 feet (450 meters) in diameter.

NPOI's siderostats gather light from stars, beam it down vacuum pipes to a collection room where optical carts equalize the paths of light, then recombine the light waves to produce "interference patterns." The recombination is the critical aspect of optical interferometry, because it must be correct to millionths of an inch. NPOI is exciting because it can measure star positions with unprecedented accuracy, and can produce high resolution images that reveal extremely fine detail—star size, shape, position, changes on the surface of very bright ones, and separation of binary pairs. As a partner with the U.S. Naval Observatory and the Naval Research Laboratory, Lowell did the site development and operations for NPOI. Under Lowell emeritus astronomer Nat White's management, construction began in 1992, and "first light" was obtained in 1994.

The refurbished twenty-four-inch (0.6-meter) Schmidt telescope on Anderson Mesa was dedicated to the LONEOS project—Lowell Observatory Near-Earth Object Search. The Schmidt, a 1940s-era telescope, was brought from Ohio and refitted with a CCD camera inside the tube. Though not a remarkably large telescope, the Schmidt's wide field of view is well suited to sweeping generous portions of the sky looking for asteroids or comets headed on a collision course with Earth. After LONEOS was completed, the Schmidt was not used much. But with a robotic refit, it can be enlisted again in the continuing search for near-Earth objects.

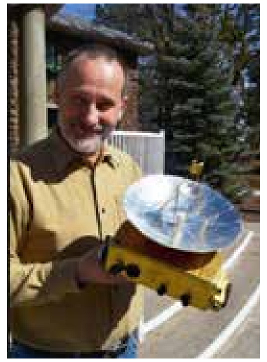

Perkins Telescope

Standing apart from the other telescopes on Anderson Mesa is a thirty-one-inch (0.8-meter) reflector, originally owned by NASA and operated by the U.S. Geological Survey for Moon mapping. Lowell took over the telescope in 1972 and used it intermittently until the main gear cracked. In the late 1980s, engineers completely overhauled the thirty-one-inch—bearings, axles, and the main drive gear were replaced, the mirror was realuminized, and the telescope was cleaned and repainted. With new computerized detectors attached, including a CCD, it can perform the work of a much bigger telescope. It is still used by Lowell researchers and the National Undergraduate Research Observatory, a consortium of Lowell, Northern Arizona University, and several other universities. This program allows undergraduate students to gain on-the-job training with a small, research-quality telescope.

Pursuing a keen interest in obtaining a "next-generation" ground-based telescope, Lowell Observatory secured a major gift from the Discovery Channel in 2003 to build the Discovery Channel Telescope. The DCT, as it's called, is located in the forest about forty miles southeast of Flagstaff. Dedicated in 2012, it is being used by Lowell astronomers and partner institutions for cutting edge investigations of celestial objects near and far.

New Horizons spacecraft

Worlds Without End



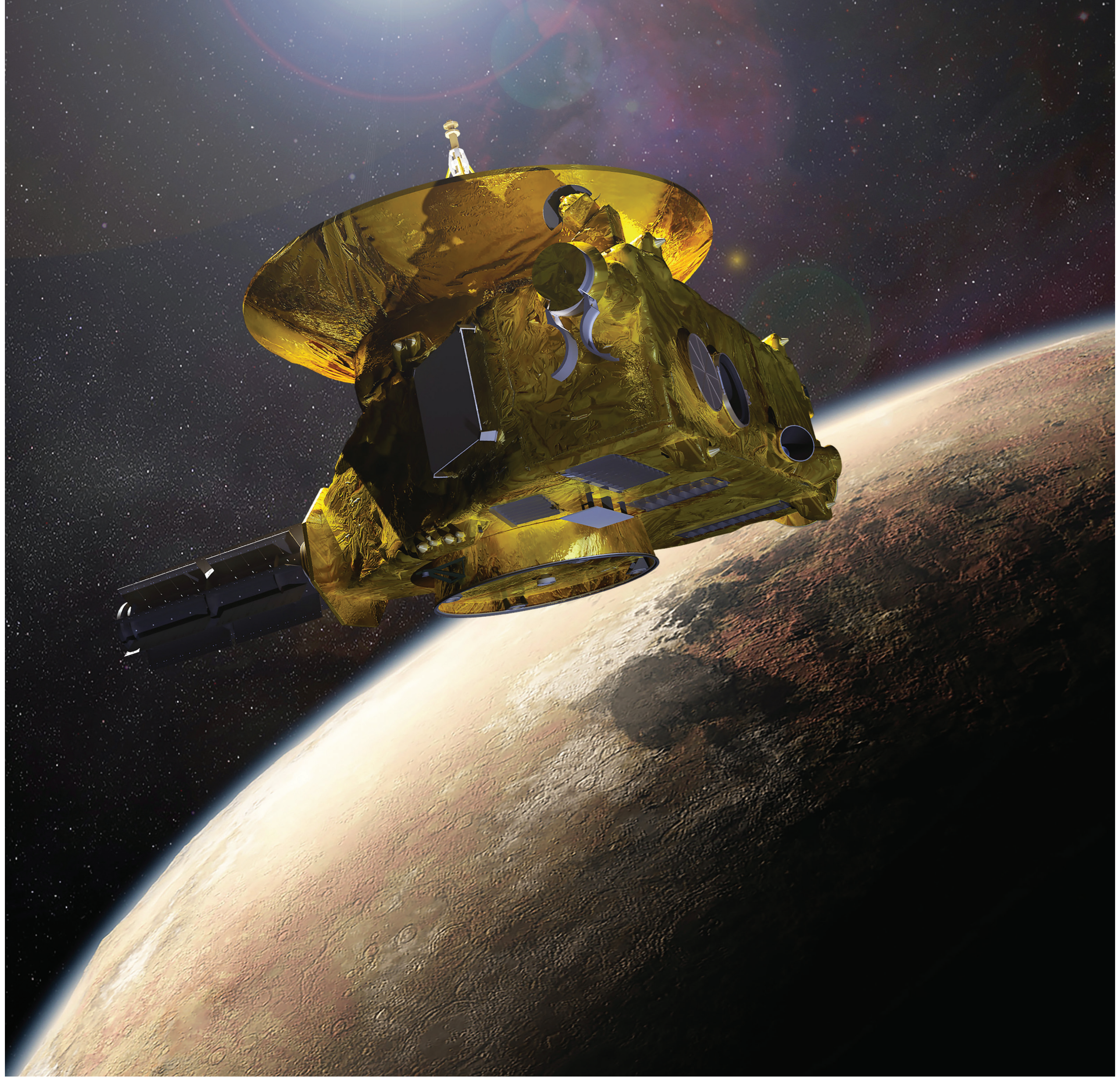
Will Grundy with homemade model of New Horizons

PERCIVAL LOWELL was first and foremost a planet man. That tradition of planetary work remains strong at his observatory. Continuing to use the latest advances in technology, and adding a few innovations of their own, Lowell astronomers cast their eyes not only at the planets of our solar system, but also those in other solar systems—and to stars and galaxies and other objects in the universe.

Ever since Clyde Tombaugh's discovery in 1930, Pluto has been an ongoing focus of research at the observatory. Former Lowell astronomer Marc Buie created the first map of Pluto's surface. With images from the Hubble Space Telescope, other maps were produced, but Pluto remained a tiny pinpoint of light with little detail beyond bright and dark spots.

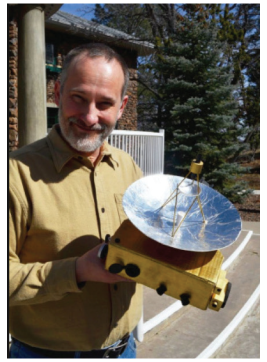
Finally, in 2015, astronomers obtained historic close-up views of Pluto. In July of that year, the New Horizons spacecraft flew within 8,000 miles of Pluto and started returning data, at least a year's worth, for astronomers to interpret. Lowell's Will Grundy, head of the New Horizons surface composition team, was intimately involved from the beginning. He had already been observing Pluto with the infrared spectrometer on the Perkins Telescope, but with New Horizons he got the chance to work with the spacecraft's designers to get desired instrumentation on board.

In 2007, after New Horizons received a gravity assist from Jupiter, the teams "started rehearsing" in earnest for the Pluto flyby, Grundy recalls. The actual encounter was a wildly busy time for him and everyone involved in the mission. The fine-resolution images and spectroscopy that immediately started streaming back were phenomenal. They revealed unprecedented detail, and several surprises, about Pluto's surface—high mountains; flat plains; impact craters; and icy flows likely consisting of frozen nitrogen, methane, and carbon monoxide.



New Horizons spacecraft

Worlds Without End



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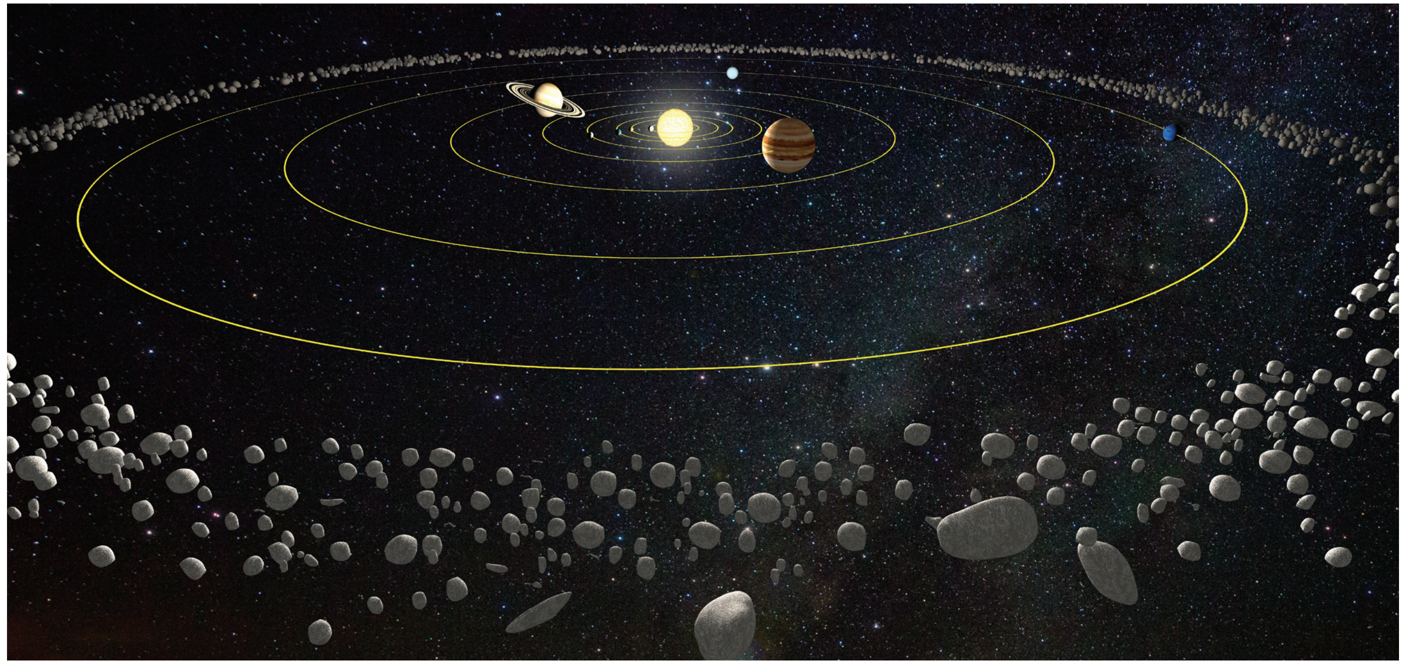
Finally, in 2015, astronomers obtained historic close-up views of Pluto. In July of that year, the New Horizons spacecraft flew within 8,000 miles of Pluto and started returning data, at least a year's worth, for astronomers to interpret. Lowell's Will Grundy, head of the New Horizons surface composition team, was intimately involved from the beginning. He had already been observing Pluto with the infrared spectrometer on the Perkins Telescope, but with New Horizons he got the chance to work with the spacecraft's designers to get desired instrumentation on board.

In 2007, after New Horizons received a gravity assist from Jupiter, the teams "started rehearsing" in earnest for the Pluto flyby, Grundy recalls. The actual encounter was a wildly busy time for him and everyone involved in the mission. The fine-resolution images and spectroscopy that immediately started streaming back were phenomenal. They revealed unprecedented detail, and several surprises, about Pluto's surface—high mountains; flat plains; impact craters; and icy flows likely consisting of frozen nitrogen, methane, and carbon monoxide.



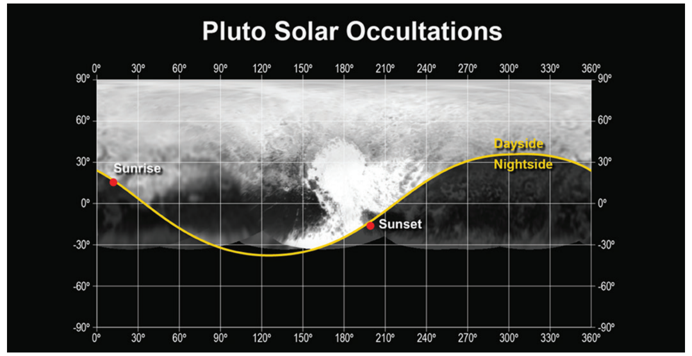
Artist's rendering of the Kuiper belt

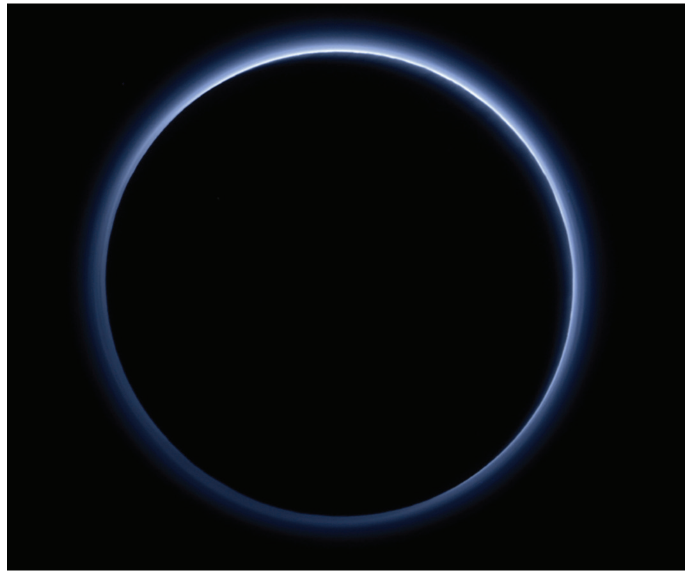
The goal of the surface composition team is to see "what that geology is made of," says Grundy. "Puzzling it out . . . that for me is the fun part," he professes. For example, volatile ices were something he had worked on in the laboratory, but seeing them ”writ large" as flowing glaciers on Pluto's surface was a different story. Other features, like curious polygon shapes on a flat area called Sputnik Planum, suggest underground convection cells. A large number of pits, decidedly not craters, haven't been explained to anyone's satisfaction yet. Pluto's complex seasonal changes are also a major interest to Grundy. In addition, images of Pluto's largest moon, Charon, show intriguing red-tinged polar areas that may indicate the presence of hydrocarbons. Ultimately, the surface composition team, working closely with the New Horizons geology team, will deliver global maps of the "ingredients" of Pluto's surface.

Pluto is one of many faint, icy objects beyond Neptune in what's called the Kuiper belt. The region attracts special interest because it consists of the leftovers from the earliest days of our solar system's formation. In Will Grundy's words, these planetesimals are the "original bricks" from which the "house" of Pluto was built. With ground-based telescopes, Lowell astronomers had already added dozens of Kuiper belt objects, but there could be more than 100,000 of them sixty miles or more in diameter. As Lowell's former director Bob Millis puts it, "We thought we'd completed a reconnaissance of the solar system, but we're not done at all."

KBO's, as they're known, are of great interest to Grundy, Larry Wasserman, and others at Lowell who follow them with the Discovery Channel Telescope and the Hubble Space Telescope. There is also a proposal in for New Horizons to stage a future flyby of a specific Kuiper belt object. As with Pluto, astronomers don't really know what to expect of such an encounter, but they feel fairly certain it will prove enlightening.

Henry Roe is also interested in the outer icy regions of our solar system. With a low resolution spectrometer on the DCT, he's planning an extensive survey of Kuiper belt objects. Roe has also had long involvement with Saturn's largest moon, Titan. Before coming to Lowell, he was co-discoverer of methane clouds in Titan's atmosphere.





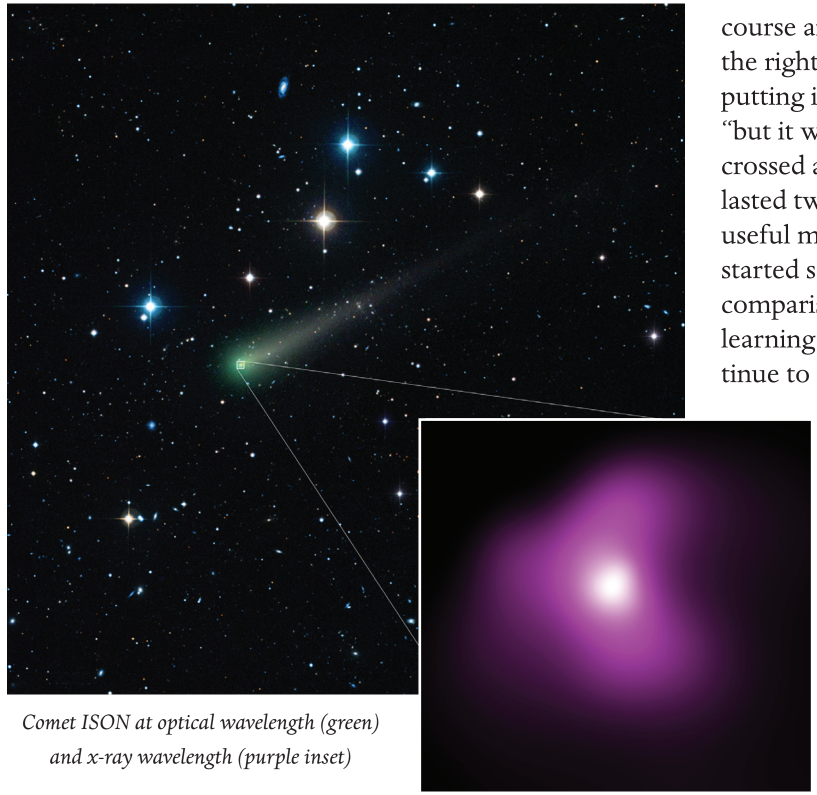
Above, Lowell staff and team members involved in Pluto research. Center, graph of a solar occultation of Pluto captured soon after New Horizons flyby. Below, Pluto's atmosphere backlit by the sun.

After arriving, Roe set up the twenty-inch (0.5-meter) telescope on Mars Hill called TiMo, part of a global network of telescopes monitoring Titan. Photos show an orange, hazelike "smog" in Titan's thick atmosphere. Occasionally, the atmospheric methane (and ethane) condense and rain down as liquid that gathers in lakes and seas on Titan's surface; it then evaporates to continue a fascinating "hydrologic" cycle. Roe also studies Pluto's atmosphere, revealed as a blue encircling haze that also contains methane, among other chemicals. In all his research, Roe finds it "dramatic" how complicated these atmospheres are.

It was an indirect method called occultation that led to discovery of Pluto's atmosphere in the first place. An occultation occurs when a body such as a planet or asteroid comes between Earth and a star. During the event the star's light dims and brightens as the body passes in front of it, and a shadow, whose cross-section is the size and shape of the occulting object, is produced. When the opportunity arises to observe a good occultation, Lowell astronomers hurry to the location, to high mountains and remote islands, even to aircraft, to chase these shadows. Location and timing are critical, and an occultation may yield only a few seconds or minutes of data. But big discoveries can result. In 1977, for example, Lowell's Bob Millis and Ted Dunham were among those who found that Uranus has a ring system, which was completely unexpected.

For Amanda Bosh, the occultation technique continues to shed more light on Pluto. She and Lowell's Stephen Levine combine data from the Discovery Channel Telescope with other ground-based facilities, and often with Ted Dunham and his instrument team aboard the SOFIA airborne observatory, to predict and observe occultations of Pluto with various stars. From a number of such observations, Bosh has learned a great deal about the pressure and temperature of Pluto's atmosphere.

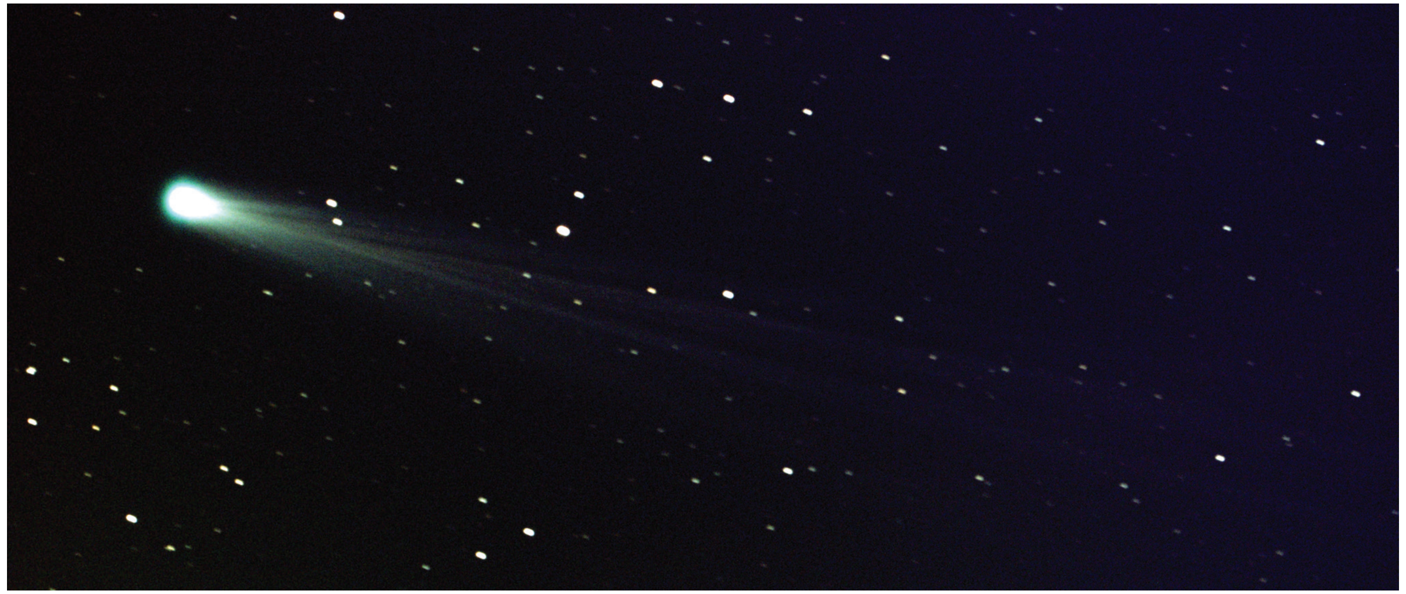
An especially notable occultation by Pluto took place in late June 2015, only two weeks before New Horizons made its closest flyby of Pluto. At Lowell, Amanda Bosh was in direct communication with SOFIA, which had taken off from Christchurch, New Zealand, in anticipation of intersecting with the occultation. Five hours before the event, Bosh informed them they were about 125 miles off



Comet ISON at optical wavelength (green) and x-ray wavelength (purple inset)

course and would have to head north in a hurry to be in the right place at the right time. She and colleagues were putting in a hundred hours a week leading up to the event, “but it worked,” Bosh declares. SOFIA changed course and crossed at the very center of the shadow. The occultation lasted two minutes. Those turned out to be incredibly useful minutes, because in a short time New Horizons started sending back data from its flyby, allowing direct comparisons with the occultation. Bosh believes they’re learning and getting better with each one. She will continue to chase the shadows of Pluto, Kuiper belt objects, small bodies between Jupiter and Neptune called “centaurs,” and Neptune’s satellite Triton.

Asteroids are another flourishing field of research. One big reason is because some of them may be on a collision course with Earth. Consider this: in seconds a rock six miles in diameter hurtles to Earth at a thousand times the speed of an automobile driving down the highway. It strikes with the explosive force of 100 million megatons of TNT and blasts out a monstrous crater, shattering and cooking the surrounding bedrock. Dust rises high into the atmosphere and blocks the sun, first darkening, heating, and acidifying the environment, then rendering Earth a cold, uninhabitable place. Half of all lifeforms on the planet die. A special-effects scene from the latest sci-fi movie? Not really. Scientists can envision such an impact because it’s similar to the one that likely led to the extinction of dinosaurs sixty-five million years ago. In fact, such events happen with some regularity.



Comet ISON showing bright tail

“It is certain that another one will occur,” says Lowell emeritus astronomer Edward Bowell, “we just don’t know when.” Bowell should know. He headed the Lowell Observatory Near-Earth Object Search, and finding potential Earth-bound asteroids was one of the survey’s major goals. Besides being a preeminent asteroid discoverer, Bowell scanned the heavens for objects coming within a few million miles of Earth, then computed their orbits to see if and when they would intersect Earth’s orbit. For a decade the entire dark sky was observed every month with Lowell’s twenty-four-inch Schmidt telescope. LONEOS found 300 near-Earth asteroids and more than forty comets, and produced more than four million positions of asteroids and comets.

Lowell astronomer Nick Moskovitz has followed in Ted Bowell’s pioneering path by studying near-Earth asteroids. Using a wide range of telescopes, from Lowell’s DCT to some of the biggest in the world, he targets objects that are small (less than a kilometer in size), ones that can and do impact Earth more frequently than their larger counterparts. Thanks to new technology, the searches “have gotten really good,” says Moskovitz. Nearly 700,000 asteroids have been found in our solar system, at least 14,000 of them in the near-Earth category.

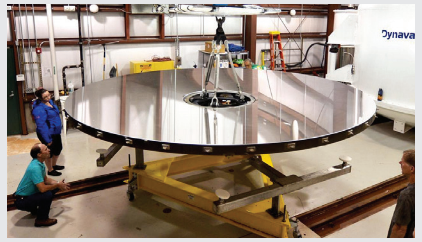
He helps manage the MANOS project—Mission Accessible Near-Earth Object Survey—designed to study near-Earth asteroids suitable for exploratory missions by robots, landers, and flybys. To undertake such missions, scientists first want to know something about the physical properties of asteroids--size, shape, composition, and rotation rate for example. (Moskovitz and colleagues have found some really small near-Earth objects that are spinning very fast. They’ve detected the two fastest so far, one rotating completely in only 15 seconds, the other in 17 seconds. As new data comes in, he hopes to determine if this is typical, or not.) Knowledge of physical properties might also help predict the amount of damage such an impact could cause.

Nick Moskovitz standing in Lowell’ Steele Visitor Center, next to a chunk of the asteroid that created Meteor Crater

The relationship between near-Earth asteroids and meteorites is another promising area. Meteorites, space debris that has actually struck Earth, are usually composed of asteroid fragments. Being able to examine them firsthand can yield clues about the diverse constituents of asteroids. Moskovitz built a fairly low-tech arrangement to monitor Earth-bound meteorites. Lowell’s all-sky meteor surveillance system consists of arrays of small, security-grade cameras mounted on rooftops at the observatory, which will detect meteorites as they flash through the night sky. Astronomers then can locate and retrieve fresh samples that have hit the ground.

As to the structure of asteroids, scientists still debate whether they are rockbound rubble piles; monolithic, mountainlike blocks; or something in between. Nick Moskovitz thinks we are in a “golden age” of small body exploration, and up-close and personal looks at the objects

Discovery Channel Telescope



WHEN IT COMES TO TELESCOPES, bigger is almost always better. When Lowell Observatory decided to build the Discovery Channel Telescope (DCT), it went very big. The fifth largest telescope in the continental United States, the DCT has a fourteen-foot-diameter (4.3-meter) primary mirror that alone weighs more than three tons. With accompanying instrumentation, the DCT is indeed large, but at the same time is designed to be swift and nimble.

The project got underway in 2003, through a partnership between Lowell and Discovery Communications. Discovery's founder, John Hendricks, also on Lowell's board of advisors, underwrote a sizable portion of the $53-million signature project. This unique collaboration can make the results of science much more widely available to the public via Discovery Communications.

The DCT is located on top of a cinder cone, at 7,760 feet elevation near the small community of Happy Jack, forty miles southeast of Flagstaff. Of a half dozen or so sites investigated, this one was selected for best "seeing" and dark skies. Ground was broken in 2005, and construction of the seventy-foot-tall telescope enclosure began that fall. The gleaming octagonal dome has shuttered openings that allow the telescope to be kept at ambient temperature.

After Corning Glass completed the primary mirror blank, it took almost five more years to grind and polish the four-inch-thick mirror at the University of Arizona in Tucson. The mirror was installed in 2010, and its initial micro-thin coating of aluminum was done onsite in a special chamber. Having that facility adjacent to the telescope means future recoatings can be done right there. The mirror is cradled in 120 computer-controlled supports—the active optics system that controls the mirror's "floppiness" as the telescope moves. The telescope mount can rotate 360 degrees in two minutes, giving great responsiveness.

The DCT can accommodate up to five instruments at once, including a large-field visible imager and spectrophotometers in both visible and infrared. The instruments are mounted to the sides of a cube attached to the back of the telescope. The cube, developed and machined at Lowell, allows researchers to switch instruments in about a minute, making for maximum flexibility.

So-called "zeroth light," the first image made from the primary mirror, was achieved in September 2011. "First light," the milestone of full functionality, was celebrated in July 2012 with a gorgeous image of a barred spiral galaxy. The DCT was dedicated that year by Neil Armstrong, who did astronaut training at Lowell Observatory for the historic 1969 Moon landing; the telescope was officially declared commissioned in 2014.

Lowell's Discovery Channel Telescope has been in constant demand. Astronomers are casting eyes at Pluto and primordial objects in the Kuiper belt, asteroids and comets, exoplanets, and stars and galaxies. In short, with this bold step, Lowell Observatory has entered a brave big world, allowing astronomers to see ever deeper into the universe and further back in time.

A flashy meteor streaking through the sky above Sunset Crater in Arizona, during the Perseid showers

will help clarify the debate. Beyond that, what excites him most is the opportunity to discover what these objects reveal about the evolution of our solar system.

Despite their dramatic potential, asteroids are sometimes considered the wallflowers of celestial society. These "vermin of the sky," as they've been called, are outshone by their flashier cousins, the comets. Comets spend most of their time as frozen rock and ice on the outskirts of the solar system. They catch our attention when they fly into the inner solar system, their bodies streaming gas and dust in their heads (comae) and tails as they approach the sun, reflecting light and appearing as glowing wonders. People have vested comets with all sorts of powers, often omens of evil.

We still eagerly anticipate rare close encounters with comets, ones like Hale-Bopp in 1997, Hyakutake in 1996, and Halley in 1986. When Hyakutake came closest to Earth, astronomers trained four telescopes on it simultaneously for three days. When Halley reappeared, Lowell scientists were the first to determine that the widely accepted rotation period of two days for the comet was incorrect. They announced that Halley's rotational period was instead seven and a half days, and ultimately determined that its rotation is highly complex.

The analysis of Comet Halley proved "good training" for Hale-Bopp, says Lowell's Dave Schleicher. Hale-Bopp's rotation produces spiral features and is also more complex than first thought. But its composition, notes Schleicher, is "perfectly normal."

Beyond observing such celebrities of the comet world, Schleicher and colleagues have conducted a long-term study of the properties of comets as a group, a less glamorous but no less important endeavor. That effort—forty years and counting—includes several hundred comets with results published in major journals.

As Schleicher explains, the composition of comets depends on their heritage. Those from the outer zone, or Oort cloud, appear to be fairly homogeneous. But ones from the second source area, coming from the Kuiper belt in past Jupiter, are less homogeneous. About half of those have the same composition as the Oort cloud group, but half don't. If you're a comet, says Schleicher, it matters "where you come from."

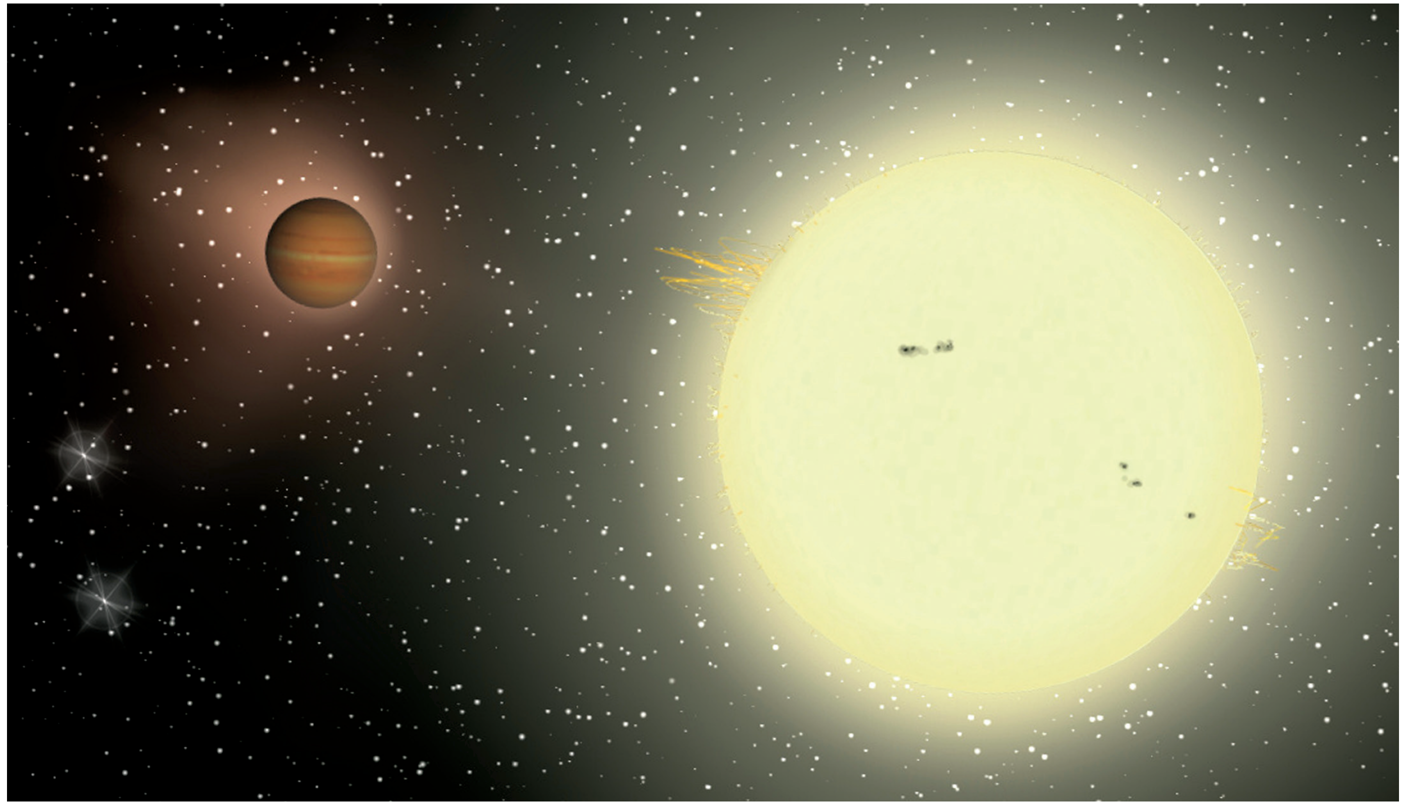
While composition speaks to source, Schleicher is also interested in the very hearts of comets, their nuclei. Looking at the jets spraying from the nucleus into the coma, and studying brightness variations as a comet rotates, he can learn a good deal about the physical characteristics of a nucleus—how much ice remains on its surface, for example.

Comet Hale-Bopp over the Slipher Building at Lowell Observatory, 1997

The sun, the omnipotent engine that powers every aspect of our solar system, has also been the focus of long-term research at Lowell Observatory. Using the Solar Stellar Spectrograph, Lowell director Jeffrey Hall, astronomer Wes Lockwood, and observers Brian Skiff and Len Bright have been studying the sun and the nearest sunlike stars. The big question driving the research is whether our sun's variations are like those of other sunlike stars, or are they different?

One key to answering that question is to study the variability of the sun's brightness and compare it to other sunlike stars, ones whose mass is similar to the sun. The project mainly uses a fiber optic-fed spectrograph on the forty-two-inch telescope on Anderson Mesa, producing spectrograms that give a star's "fingerprint," says Hall. Combined with offsite photometry, the data show that our sun appears to roughly fit the pattern of other sunlike stars, in that the amount of brightness change is similar to those of the sun's stellar cousins and is a function of solar activity and age. As a star gets older, brightness variations (related to sunspot activity) decline. That's what's happening to our sun—at 4.6 billion years, it's reached middle age and is starting to slow down, says Lockwood. One practical application of this long-running study is seeing how solar variations affect Earth's climate and environment.

There are many other stars beyond our sun, of course, and they also have planets orbiting them. These "exoplanets" captured the attention of Lowell's Ted Dunham back in the mid 1990s. The discovery of a special class of exoplanets called "hot Jupiters" at that time was a game changer, says Dunham. These are Jupiter-sized gas giants, but instead of being cold they have extremely high surface temperatures because they're extremely close to their host stars—in fact their very existence defied what little was known about solar systems then. Hot Jupiters made the search for exoplanets easier because they transit their stars in much shorter intervals—days rather than years—and because their large size makes them much easier to detect. He expected to observe some of them passing across the



Simulation of exoplanet TrES-4

face of their stars by measuring the dimming of the star's light during those few hours of transit. (A transit is similar to an occultation, but involves a smaller object that partially covers a larger one; in an occultation, the foreground object completely covers up the background object.)

Dunham installed an army surplus camera lens on an old telescope mount and took test data over one winter to see if a ground-based search would work. Needing better optics, he assembled a new system with a four-inch telescope at Anderson Mesa. A collaboration including two other partners resulted in the first of what would become a flood of ground-based exoplanet discoveries.

Georgi Mandushev works with Dunham on the surveys, and his software creations for data analysis made ground-based exoplanet discoveries possible for all the partners in their effort. Mandushev finds it "very exciting" to see whole planetary systems, ones that might actually harbor life. In fact, a prime motivation is to find exoplanets like our Earth, those in the so-called "Goldilocks zone" where conditions are right to support water, and perhaps, life.

Dunham and Mandushev ended their ground-based survey to focus on the Kepler mission and transit observations with SOFIA. Dunham is a co-investigator on the Transiting Exoplanet Survey Satellite (TESS) project that will take on an ambitious survey of the entire sky, looking for Earthlike planets around the brightest stars in the sky and nearest red dwarf stars.

The sun is only one of at least a couple hundred billion stars in our galaxy, the Milky Way. The Milky Way, in turn, is one of some ten billion galaxies that can be seen with the largest ground-based telescopes. Beyond that, the Hubble Space Telescope showed evidence of 200 billion to two trillion galaxies in the universe! It's no wonder that Lowell Observatory astronomers seek to understand the nature

Rho Ophiuchi, a binary star system, visible in the light-colored region on right side of this image. It is one of the closest star-forming regions, only 400 light years away and fundamental processes of the evolution of stars and galaxies—their births, lives, and deaths.

Binary stars may help shed light on these questions. These are double stars that orbit around their common center of mass, gravity-bound to each other. Astronomers now know that upwards of three-fourths of all stars are binaries, so understanding them should lead to a better understanding of star formation in general. Otto Franz has spent his career looking at these companion stars. He first traveled to Lowell Observatory to observe them in 1959, and through the ensuing decades has employed many methods and instruments. Using the fine-guidance sensors on the Hubble Space Telescope, Franz got the first definitive orbit on a binary star. He went on to graph the key relationship of mass to luminosity for ten faint binary stars—ground-breaking work presented before the International Astronomical Union in 2006.

Lowell astronomer Lisa Prato spends a large portion of her time looking at binary stars too. Using infrared spectroscopy and some of the biggest telescopes in the world, she can see and measure the spectra of a pair of stars, from that derive velocity, and then obtain mass—the "holy grail," she says, fundamental to everything that can be known about a star.


The spiral galaxy NGC 7331 is the largest of a group of galaxies known at Deer Lick

Prato also searches for exoplanets, but not with the transit technique. Instead, she uses infrared spectroscopy to determine a star's unique spectrum. Because of the Doppler effect, the wavelengths of lines in a spectrum of a star with a planet around it show how the planet "is tugging the star back and forth." With multiple observations Prato can determine a star's radial velocity and thus some of the planet's properties.

Whether exoplanets or binary stars, it is youthfulness that sparks Prato's scientific imagination, because that quality speaks of origins. By "young" she means very young, mostly stars only a million years old "give or take." These youngest stars forming from dust- and gas-filled molecular clouds are "a mess," she says. They can produce violent flares, harbor giant star spots, and display extremely strong magnetic fields. Because they are still contracting to their final adult dimensions, they are also "fluffy" and more luminous than older stars of the same type at the same distance.

Gerard van Belle spends his nights stargazing too. His research is accomplished with optical interferometers, and he was lured to Lowell by the Navy Precision Optical Interferometer on Anderson Mesa. Van Belle is also interested in fundamental properties of stars—how big, how hot, how fast they rotate. The very high resolution images produced by NPOI, he says, can provide empirical results that can test theoretical models. The direct images can reveal size, structure, and activity, essentially providing "a window into how stars are put together." He studies hundreds of stars, including main sequence stars like our sun; giants and supergiants; binaries; and carbon stars, so named because they leave behind ash as they mature and burn out.

Lowell astronomer Phil Massey studies massive stars, those at least eight times the mass of our sun, sometimes much larger. Though relatively rare, such stars are very luminous because they're producing lots of energy. As massive stars die, their cores collapse and they explode as supernovae, sending out many of the basic elements found on Earth. Massey trains large telescopes on these standouts in nearby galaxies, mostly the Magellanic Clouds and the Andromeda and Triangulum galaxies. He and Lowell research associate Kathryn Neugent look for what are called Wolf-Rayet stars, and have found a new class of them with "peculiar properties," says Massey. He also co-discovered the first known Thorne-Żytkow object, a hybrid in which a neutron star has been absorbed by a red supergiant. These were long theorized to exist, but he and colleagues made the first actual observation of one.


A starburst in dwarf irregular galaxy NGC 1569

Deidre Hunter has spent a good part of her career at Lowell studying galaxies, specifically star formation in dwarf irregular galaxies. Of the three major types of galaxies—irregular, elliptical, and spiral—irregulars are by far the most common. As the name suggests, they are less regular in shape and tend to be smaller (only a few billion stars), bluer in color, and lower in metal content.