The Cosmologist *Left Behind*

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Edwin Hubble usually gets the credit, but Vesto Slipher was the first to see the signs that the universe is expanding.

AT THE END of the 19th century, the wealthy Bostonian Percival Lowell — the black sheep of one of New England's leading families — built a private observatory atop a pine-forested mesa in Flagstaff, Arizona, to study Mars, its supposed canals, and its presumed inhabitants. There, some 1.4 miles above sea level, Lowell installed a 24-inch Alvan Clark refractor — not a very large telescope even for the time, but one perched higher than the 36-inch refractor at the venerable Lick Observatory in California.

This pleased Lowell immensely, for he sought to outdo his California competitor at every turn. In 1900 he ordered a custom-built spectrograph that was an improved version of the one at Lick. To operate it, Lowell hired a recent graduate of the Indiana University astronomy program: an Indiana farm boy named Vesto Melvin Slipher.

Lowell chose well. Slipher took a spectrograph intended for planetary work and with great skill eventually extended the observatory's work far beyond the solar system. Instead of discerning new features on the Red Planet, the observatory's raison d'être, Slipher found himself confronting a surprising aspect of the

INSTRUMENT MAKER Vesto Slipher rebuilt and mastered the delicate Lowell Observatory spectrograph. Here he's looking at its plateholder. Light from the 24-inch refractor (top right) enters the prism box (lower left) and is dispersed into a spectrum that is refocused (with more lenses) onto the plate. During long exposures, Slipher fine-guided the spectrograph by leaning on it.

SEEING FAR V. M. Slipher (1875–1969) came to Lowell Observatory in 1901 and served as its director from 1916 until his retirement in 1954. Here he is seen in 1905 at age 29.

wider cosmos, previously unknown. He detected the very first hint — the earliest glimmers of data — that the universe is expanding. But it took more than a decade for astronomers to fully recognize what he had done.

The White Nebulae

A century ago, when one third of Americans lived on rural farms lit by only candle or kerosene, the nighttime sky was breathtaking. The Milky Way arched across the celestial sphere like an army of ghosts. This sublime stellar landscape must have been a powerful inspiration, for many of America's greatest astronomers a century ago were born on Midwest farms, like Slipher.

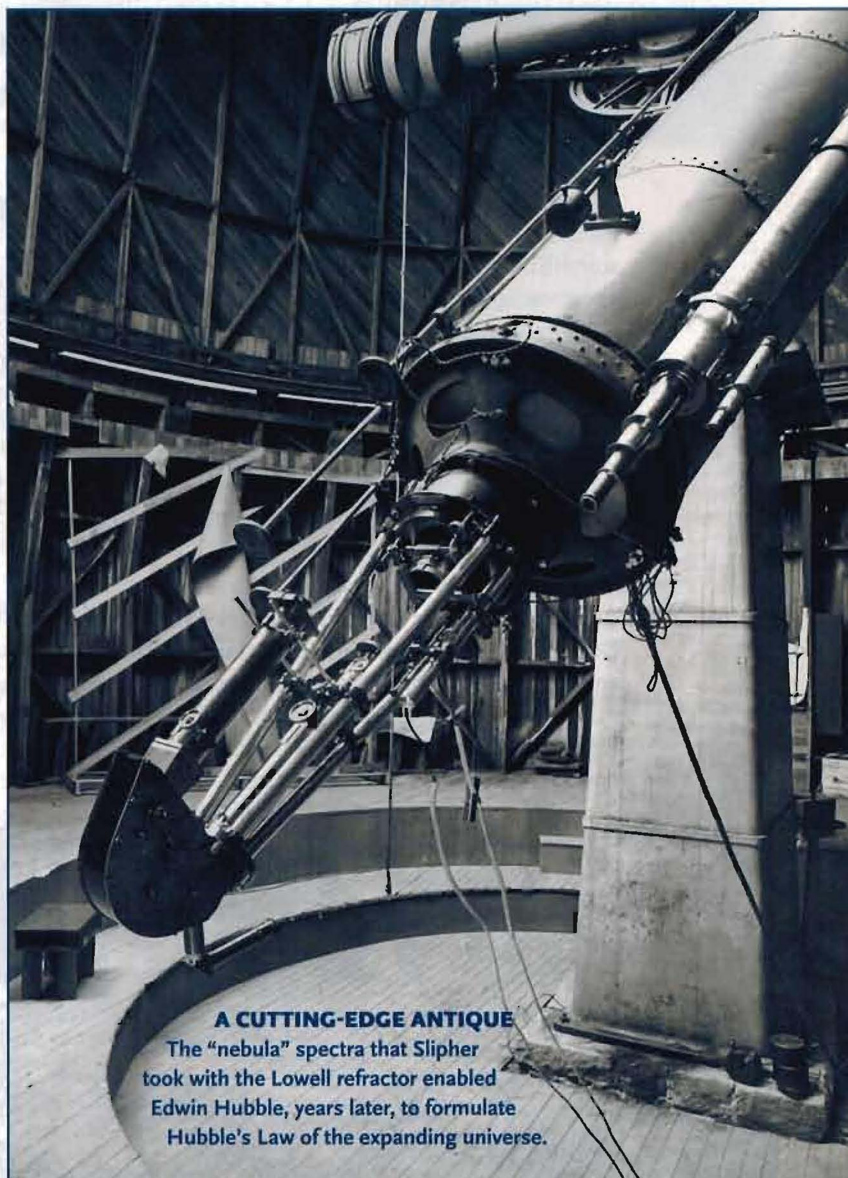
"V. M.," as he was known to friends, must have had qualms upon arriving at Flagstaff in the summer of 1901. The biggest telescope he had ever operated was a 4½-inch reflector. The young man struggled for a year to handle the spectrograph with ease. He even initially confused the red and blue ends of the spectrum on its black-and-white photographic plates, a scientific faux pas of the first magnitude. In distress, Slipher asked Lowell if he could go to Lick for instruction, but his boss firmly said no. Given the rivalry between the two observatories, Lowell didn't want Lick knowing that one of his staff needed help.

Slipher and Lowell were an intriguing mesh of personalities, like a harmony created from two different notes. Flamboyant and aggressive, Lowell hated to share the spotlight. Slipher was fortunately Lowell's opposite in character. A modest and reserved man, he knew it wasn't wise to steal Lowell's thunder. More than that, he didn't want to.

Slipher eventually made progress on the spectrograph, becoming a virtuoso at its operation. By 1909 he was able to confirm that thin gas existed in the seemingly empty space between the stars; it left spectral lines in starlight that were narrower and at slightly different Doppler shifts than the spectral lines arising in the stars' atmospheres. This triumph won him praise from astronomers around the world. In 1912 he determined that the faint Merope Nebula in the Pleiades had the same spectrum as the Pleiades stars themselves, the first proof of a reflection nebula made of interstellar dust ("pulverulent matter," he called it). In due course these pursuits led Slipher to his greatest discovery of all.

It began innocently enough. On February 8, 1909, Lowell in Boston sent a typed letter to Slipher with concise instructions: "Dear Mr. Slipher, I would like to have you take with your red sensitive plates the spectrum of a white nebula — preferably one that has marked centres of condensation." By "white nebula" Lowell meant what we now call a spiral galaxy. At the time, however, many astronomers assumed that these were nearby planetary systems under construction. Lowell stressed that he wanted "its outer parts." He longed to see if the chemical elements at a spiral nebula's edge, as revealed by their spectral lines, matched the composition of the giant planets in our outer solar system. A connection would mean the spirals could indeed be the precursors of planetary systems.

Slipher balked at first. "I do not see much hope of our getting the spectrum," he told Lowell. Photographic emulsions in 1909 had extremely slow speeds. Slipher knew that it would take at least a 30-hour exposure to take just



A CUTTING-EDGE ANTIQUE The "nebula" spectra that Slipher took with the Lowell refractor enabled Edwin Hubble, years later, to formulate Hubble's Law of the expanding universe.

SCIENCE LAB The tailpiece of the Lowell refractor today, with the spectrograph's antique spark coil on display at right. The spark coil created the high voltages (stored in the Leyden-jar capacitors beneath) needed to vaporize iron and vanadium for comparison spectra.

an ordinary photograph of the nebula with the long-focus refractor. To acquire a spectrum — what with light being lost in the spectrograph and the remaining light being spread out into a strip — seemed impossible.

Although Slipher considered the task hopeless, he persevered and by December 1910 was able to wrench some feeble data from the Great Nebula in Andromeda (M31). "This plate of mine," he informed Lowell by letter, "seems to me to show faintly peculiarities not commented upon...." He was convinced that he had captured something on the spectrum previously unseen by other spectroscopists.

By trial and error, Slipher made improvements to the spectrograph. Instead of using a set of three prisms, which separated spectral lines widely, he decided to use just one, which reduced the light loss and also spread out the light less on the plate. He also understood that increasing the speed (f/ratio) of the system was vital; he bought a very fast, commercially available photographic lens to go ahead of the plate.

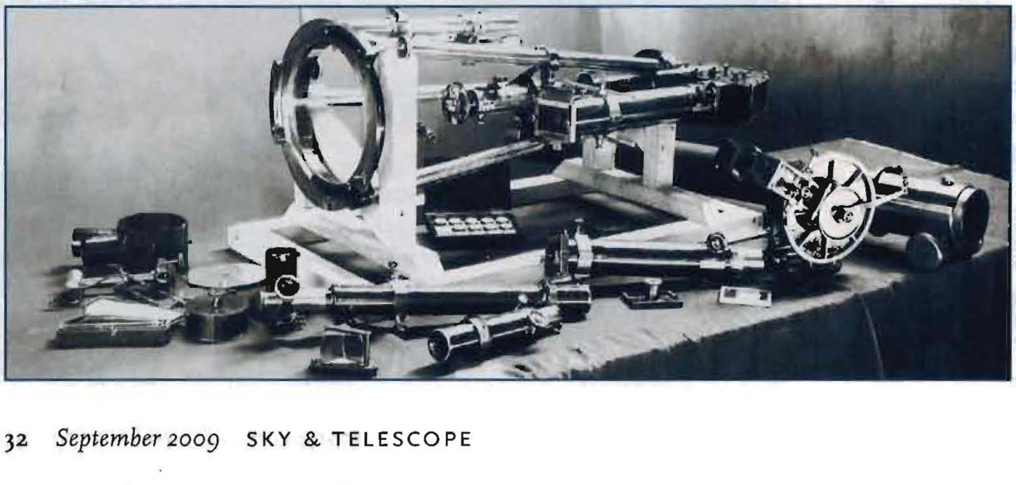
Planet studies and reports on the return of Halley's Comet kept Slipher from getting back to the Andromeda Nebula until the fall of 1912. But by then his refashioned spectrograph was operating 200 times faster than its original specifications, allowing him to slash his long exposure times. He could at last try for the spectrum he had so long sought.

Big Blueshift

Slipher made his first exposure with the new system on September 17th. It took a total of 6 hours 50 minutes for Andromeda's faint light to fully register. The plate is shown at right. "It is not really very good and I am of the opinion that we can do much better," he relayed to Lowell. He soon acquired two more spectra. When carrying out these observations, the interior of the wooden dome at times could resemble the movie version of a mad scientist's laboratory, with a high-voltage induction coil sparking and sputtering by the side of the telescope. A row of old-fashioned Leyden jars served as capacitors to juice up the sparks. This contraption (see above) served to vaporize traces of iron and vanadium inside the spectrograph; the light of the sparks passed through the spectrograph and onto the photographic plate. The known emission spectra of the vaporized elements provided the calibration lines needed to measure the exact wavelengths of the absorption lines in the nebula's spectrum.

Each spectrum that Slipher produced was tiny: just a centimeter long and a millimeter wide. He needed a microscope to measure how much the spectral lines might have been Doppler-shifted from their rest wavelengths (see the box above). The microscope was with Lowell in Boston temporarily, and Slipher didn't get it back until mid-December. But once it arrived, he couldn't resist taking a quick peek at the Andromeda plates he had so far. There were "encouraging results or (I should say) indications," Slipher reported to Lowell, "as there appears to be an appreciable displacement of the nebular lines toward the violet." A shift of the lines toward the blue-violet end of the spectrum meant that Andromeda was moving toward Earth.

But Slipher felt he needed a better spectrum to measure the speed accurately. He started the final exposure on December 29th and stayed with it until clouds rolled in near midnight. On a seeing-quality scale from 1 to 10 — 1 being the worst, 10 the best — Lowell astronomers often joked that at 10 you can see the Moon, at 5 you can still see the telescope, and at 1 you can only feel the telescope. Fortunately, the sky was clear the



SOME ASSEMBLY REQUIRED The spectrograph had many swappable parts for different purposes.

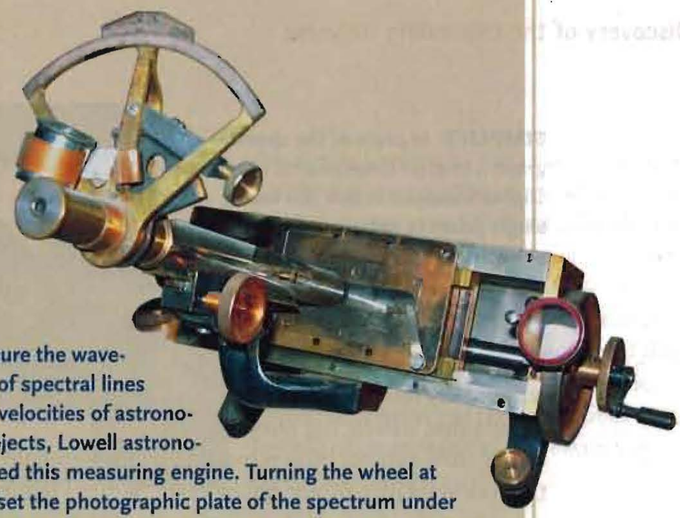
The Cosmos Under the Microscope

When an astronomer takes a spectrum today, he or she can watch it build up on a computer screen in real time while munching pizza thousands of miles away. Measuring the wavelengths of spectral features is easily done with a mouse. But a century ago when the whole world was analog, measuring cosmic velocities in a spectrum was an extremely delicate and skilled art.

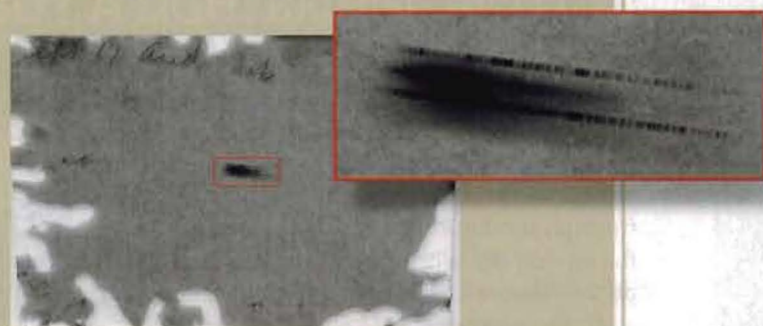
Vesto Slipher did it by putting his photographic plates in the spectrocomparator (or "measuring engine") above. It allowed him to examine the tiny spectrum on the plate with a microscope. About a millimeter above and below the astronomical object's spectrum were twin spectra of an electric spark, which provided emission lines with known wavelengths. By turning a screw, he moved the plate sideways by tiny, precisely measurable amounts to center one line after another — in both the nebula's spectrum and that of the spark — under a crosshair in the microscope's eyepiece.

He then converted the measured positions into wavelengths based on the spark lines (applying a formula for the spectrum's nonlinear dispersion), compared them with the laboratory wavelengths of known lines in the nebula's spectrum, converted the differences into a single Doppler shift applying to the whole spectrum — and from that calculated the object's velocity. The process involved pencils, a lot of paper, and intimate familiarity with the relevant math.

— *Alan MacRobert*



To measure the wavelengths of spectral lines and the velocities of astronomical objects, Lowell astronomers used this measuring engine. Turning the wheel at right offset the photographic plate of the spectrum under a microscope by tiny amounts. These offsets were precisely measurable on a fine scale under the magnifying lens at right.



On September 17, 1912, in an exposure nearly seven hours long, Slipher obtained the world's first spectrum of a galaxy (the "Andromeda Nebula") good enough to show a Doppler shift. The galaxy's tiny spectrum is flanked above and below by the comparison spark spectrum. The plate is a negative; the barely visible absorption lines in the galaxy's spectrum appear light, and the spark's emission lines appear dark. The old emulsion is flaking near the edges.

following night, and he was able to collect additional light for nearly 7 more hours. Perhaps pressing his luck, he went into a third night, New Year's Eve.

Throughout January 1913 Slipher focused on measuring his plates with utmost precision. The result astonished him. The Andromeda Nebula was rushing toward the solar system at the ridiculous speed of 300 kilometers per second (670,000 miles per hour). This was about 10 times faster than the average motion of stars in the Milky Way. If the nebula was really a nearby star and planetary system in formation, it was wildly abnormal.

Instead of announcing this result in a major astronomical journal, Slipher chose to publish a brief account in the *Lowell Observatory Bulletin*. True to form, Slipher held off any grander statement until he had some confirmation. Yet even one spiral-nebula velocity was an exceptional accomplishment. Lowell was enormously pleased. "It looks as if you had made a great discovery," he wrote Slipher. "Try some more spiral nebulae for confirmation."

Island Universes

Working on Andromeda, though, was a holiday compared to gathering enough light from other white nebulae. Andromeda is the biggest spiral in the sky; the others only get smaller and dimmer, which made it even harder for Slipher to obtain their velocities. "Spectrograms of spiral nebulae are becoming more laborious now because the additional objects observed are increasingly more faint and require extremely long exposures that are often difficult to arrange and carry through owing to Moon, clouds and pressing demands on the instrument for other work," he noted.

Slipher's first target after Andromeda was M81. He then worked on a peculiar nebula in southern Virgo, NGC 4594, which he described as a "telescopic object of great beauty." It's now known as the Sombrero Galaxy. Slipher eventually found that it was moving at a speed "no less than three times that of the great Andromeda Nebula." This time, however, the nebula was not traveling toward

SIMPLIFY In place of the spectrograph's original three prisms in series, Slipher swapped in this box with a single prism to reduce exposure times — at the cost of low dispersion.

us, but away — at some 1,000 kilometers per second. Slipher was greatly relieved. Finding a nebula that was racing outward rather than approaching removed any lingering doubts that the velocities might not be real. "When I got the velocity of the Andr. N. I went slow for fear it might be some unheard-of-physical phenomenon," he wrote his former Indiana professor John Miller.

In the succeeding months Slipher kept expanding his list. His accomplishment was all the more amazing, considering the relative crudeness of his instrument. The 24-inch telescope had only manual controls, and they weren't yet sophisticated enough for fine guiding. Yet Slipher had to hold the tiny image of each nebula on the slit of the spectrograph steadily for hours on end as the telescope tracked the turning sky. When asked years later how he was able to do this, Slipher replied dryly, "I leaned against it."

By the summer of 1914 Slipher had the velocities of 14 spiral nebulae in hand. And with this collection of data, an undeniable trend at last emerged: While a few nebulae, such as Andromeda, were approaching us, the majority were rapidly moving away.

Suddenly the older idea that the white nebulae were not protoplanetary systems but whole other galaxies — other "island universes" of stars at fantastically great distances (an idea dating from Immanuel Kant in 1755) — looked newly plausible. "It seems to me, that with this discovery the great question, if the spirals belong to the system of the milky way or not, is answered with great certainty to the end, that they do not," Danish astronomer Ejnar Hertzsprung wrote Slipher. The speeds were too great for them even to stay within our home galaxy. But Slipher at this stage was still on the fence: "...it is a question in my mind to what extent the spirals are distant galaxies," he responded. So were other astronomers; the Shapley–Curtis "Great Debate" over the question, held in April 1920, was still six years away.

For most of his career Slipher published few detailed papers of his work outside of Lowell's in-house bulletin. He published very little at all from 1933 until his retirement in 1954, having turned much of his attention to local business pursuits and community affairs. The great standout in his otherwise sparse research record was his work on spiral-nebula velocities. He was absolutely confident of what he was seeing — so confident that he for once overcame his homebound nature and traveled to Atlanta, Georgia, and then, in August 1914, to Northwestern University in Evanston, Illinois, to present his results in person.

At Northwestern, 66 astronomers from around the United States gathered by Lake Michigan for their annual meeting. Slipher reported in his talk that the average speed of the spirals was now "about 25 times the average stellar velocity." Of the 15 spiral nebulae he had measured so far, three were approaching Earth and the rest were moving away. The velocities ranged from "small," as it was recorded on his list, to an astounding 1,100 kilometers per second, the greatest speed of a celestial object ever measured up to then. When Slipher finished delivering this remarkable news, his fellow astronomers rose to their feet and gave him a resounding ovation. No one had ever seen such a spectacle at an astronomical meeting. And with good reason: Slipher alone had climbed to the top of the Mount Everest of spectroscopy.

THE CODIFIER Building on Slipher's work, Edwin Hubble (1889–1953) formulated Hubble's Law describing the expanding universe of galaxies. Unlike the modest, retiring Slipher, Hubble — a former champion college basketball star and amateur boxer — was not shy about self-promotion.

Enter Edwin Hubble

In the audience was a young, ambitious astronomer named Edwin P. Hubble, just starting his career, who would later seize on Slipher's work and extend it.

After a few more years, the cautious Slipher at last came around to Hertzsprung's view and began to envision the Milky Way as moving among other galaxies just like itself. He even speculated at one point that the spirals might be "scattering" in some way — a precocious intimation of cosmic expansion that took many more years to fully recognize. But acceptance of spiral nebulae as distant galaxies could not be fully achieved until astronomers figured out a method for determining how far away Andromeda and its sisters truly were.

That, of course, famously occurred in 1923–24 when Hubble, using the 100-inch telescope on California's Mount Wilson, identified Cepheid variable stars within Andromeda and used their pulsation periods as cosmic yardsticks to establish that the nebula was indeed a separate island universe. Five years later, working with Milton Humason, Hubble identified a mathematical trend in the flight of the galaxies. The velocity at which the galaxies were moving away from us steadily increased as he peered ever deeper into space. The numerical value describing this trend became known as the Hubble constant.

Hubble was quite possessive of this finding and kept close watch on it. When Dutch astronomer Willem de Sitter, in a 1930 review article, casually referred to several astronomers linking a galaxy's velocity to its distance, Hubble picked up his pen and reminded de Sitter who should receive the lion's share of the credit. "I consider the velocity-distance relation, its formulation, testing and confirmation, as a Mount Wilson contribution and I am deeply concerned in its recognition as such," he wrote.

Hubble conveniently forgot to tell de Sitter that the galaxy velocities he first drew upon in his 1929 paper were actually Slipher's old data, which Hubble used without acknowledgment, a serious breach of scientific protocol. Hubble partially made up for this nefarious deed much later, in 1953. As Hubble was preparing a talk he wrote Slipher asking for some slides of his first 1912 spectrum of the Andromeda Nebula, and in this letter he at last gave the Lowell Observatory astronomer due credit for his initial breakthrough. "I regard such first steps as by far the most important of all," wrote Hubble. "Once the field is opened, others can follow." In the lecture itself, Hubble professed that his discovery "emerged from a combination of radial velocities measured by Slipher at Flagstaff with distances derived at Mount Wilson."

Privately, Slipher was bitter that he didn't receive more immediate public credit but was too humble to demand his share of the glory.

In some ways, Slipher's accomplishment resembled that of Arno Penzias and Robert Wilson several decades later. In 1964 the two Bell Laboratories researchers were calibrating a horn-shaped antenna in New Jersey in preparation for some radio observations and found unexpected static wherever they pointed. Just as Slipher made a remarkable cosmological find that took others time to fully interpret, Penzias and Wilson needed fellow astronomers to tell them what they had found: the afterglow of the Big Bang. But whereas Penzias and Wilson received the Nobel Prize for their serendipitous discovery, Slipher, as the years passed, was nearly forgotten in the momentous saga of the fleeing galaxies. A namesake like the Slipher Space Telescope was never to be. ✦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Marcia Bartusiak is a professor of science-writing at MIT. This article is adapted from her latest book, The Day We Found the Universe, *a history of the period from 1900 to 1930 when our view of the cosmos was completely transformed.*