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VESTO MELVIN SLIPHER

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A Biographical Memoir by
WILLIAM GRAVES HOYT

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V. M. Slipher

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VESTO MELVIN SLIPHER, a pioneer in the field of astronomical spectroscopy during his long career at the Lowell Observatory at Flagstaff, Arizona, probably made more fundamental discoveries than any other observational astronomer of the twentieth century.[1]

He is best known for his discovery in 1913 of the extraordinary radial velocities of the spiral nebulae, as revealed by the enormous "red shifts" of the absorption lines in their spectra.[2] This discovery provided the first evidence for the now widely held theory of an expanding universe,[3] and it was a prerequisite to Edwin P. Hubble's discovery sixteen years later of the relationship between the radial velocities of nebulae and their distances, which has enabled astronomers to gauge the approximate age and dimensions of the known universe.[4]

In the course of this work, Slipher also discovered that the spiral nebulae are rotating,[5] carried out fruitful investigations of the relative motion and distribution of nebulae and globular star clusters,[6] demonstrated the existence of gas and dust in interstellar space, and found that certain nebulae shine only by the reflected light of nearby stars.[7]

He also made innovative spectrographic studies of the rotation periods of the planets,[8] planetary atmospheres,[9] comets,[10] the solar corona,[11] "peculiar" deep space objects,[12] lightning,[13] the eclipsed moon,[14] the light of the night sky, aurorae, and the zodiacal light.[15] His contributions include his careful planning and effective supervision of the Lowell Observatory's search for Percival Lowell's postulated trans-Neptunian "planet X," which led in 1930 to the discovery of the ninth planet, Pluto, by Clyde W. Tombaugh.[16]

Slipher's productive career spanned nearly forty years, with his most important discoveries coming in the second decade of the century when astronomers were hotly debating the great question of the nature and extent of the universe.[17] It is one of the larger ironies in the history of astronomy that while Slipher's work on nebulae, star clusters, and the interstellar medium bore directly on this problem, his results were not immediately applied to its solution by contemporary theoretical astronomers and astrophysicists.

The reasons for this are many and involve, among other things, a preference by astronomers of the day for other observations, in conflict with Slipher's, that were later found to be erroneous.[18] This, in turn, may reflect the aura of skepticism that then surrounded the work of the Lowell Observatory as a result of the much-publicized ideas of its controversial founder-director, Percival Lowell.[19] Perhaps Slipher's personality was a factor, too. In sharp contrast to his ebullient, impulsive employer, Slipher was a reserved, reticent, cautious man who shunned the public eye and rarely even attended astronomical meetings, often sending his papers for others to read.[20] He consistently postponed publication of his discoveries until he had confirmed them to his own satisfaction, and some of his results were published by others to whom he communicated them in his correspondence. Such distinguished astronomers and astrophysicists as Sir Arthur Stanley Eddington, Knut Lundmark, Gustaf Strömberg, Harlow Shapley, and Hubble were among the beneficiaries of this largesse.[21]

Slipher's published papers number just over one hundred, many of them appearing only as abstracts. They are typically terse, factual accounts of his observations and their results, usually unencumbered by any interpretive discussion.[22] Such speculation as Slipher permitted himself he confined largely to his letters to close and trusted friends in astronomy.[23]

DETAILS OF LIFE AND CAREER

Vesto Melvin Slipher, who was almost always referred to as "V. M.," was born on a farm in Mulberry, Indiana on November 11, 1875 to Daniel Clark and Hannah App Slipher. A younger brother, Earl C. Slipher (1883–1964), also became an astronomer and for a time was one of the leading authorities on the subjects of the planet Mars and planetary photography. Both brothers spent their entire careers at the Lowell Observatory.[24]

Little is known of Slipher's childhood and youth. Certainly life on the family farm helped him develop the strong, vigorous constitution that later stood him in good stead for the more strenuous aspects of observational astronomy. Henry L. Giclas, who worked with Slipher for twenty-three years, remembers that Slipher in his sixties could climb effortlessly on the 12,661-foot San Francisco Peaks north of Flagstaff where the observatory maintained a mountain station in the late 1920's and early 1930's. "V. M. Slipher, thirty-five years my senior, was always ahead of us 'boys' climbing the mountain—we puffing and panting and he, disgusted, waiting for us to catch up," he has recalled.[25] Arthur Adel, also a Lowell astronomer in the 1930's, has noted that "V. M. at age sixty-five could chop wood with the best of them."[26] Slipher sometimes emphasized the necessity for robust health to younger men who sought his advice on a career in astronomy.[27] His bucolic background, incidentally, came in handy during his early years at Lowell Observatory.

For while Lowell lived, Slipher was in charge of the Observatory's cow, Venus, and her progeny and was responsible for Lowell's vegetable garden whenever Lowell himself was not in residence at Flagstaff.[28]

Slipher graduated from high school in Frankfort, Indiana and then taught briefly at a country school north of that city. On September 20, 1897, at age twenty-one, he entered Indiana University at Bloomington. On June 19, 1901 he received an A.B. degree in mechanics and astronomy. He was granted an A.M. degree on June 24, 1903 and the Ph.D. degree on June 23, 1909, also by Indiana. His dissertation was a short paper on "The Spectrum of Mars," which had been published the previous year in the *Astrophysical Journal.*[29]

Slipher's professors at Indiana included John A. Miller, who in 1906 became director of Sproul Observatory at Swarthmore College, Pennsylvania, and Wilbur A. Cogshall, an assistant at Lowell Observatory in 1896 and 1897, thereafter associated with Indiana and its Kirkwood Observatory for more than forty years. Slipher later credited Miller with turning his interest to astronomy,[30] and both Miller and Cogshall remained among Slipher's closest confidants through their long lives.[31]

It was Cogshall who persuaded a reluctant Percival Lowell to bring Slipher to the Lowell Observatory in 1901 for what Lowell clearly intended to be a limited stay.[32] "As regards Mr. Slipher," Lowell wrote to Cogshall in July 1901, "I shall be happy to have him come when he is ready. I have decided, however, that I shall not want another permanent assistant and take him only because I promised to do so and for the term suggested. What it was escapes my memory."[33]

Slipher's "term" turned out to be fifty-three years. He was an assistant at the Observatory until 1915 when he was made assistant director under Lowell. At Lowell's death on November 12, 1916, he became acting director, and he was named director in 1926, serving in that capacity until his retirement in 1954 at the age of seventy-nine. In his later years, he lived quietly in Flagstaff, occasionally taking an interest in astronomical and observatory affairs, but carrying on no further formal research. He died on November 8, 1969, three days before his ninety-fourth birthday.[34] In his will, he provided a fund with which the National Academy of Sciences and the Northern Arizona University Foundation in Flagstaff annually distribute grants and scholarships to science students and for science programs.[35]

On January 1, 1904 Slipher married Emma Rosalie Munger at Frankfort, and brought her to Flagstaff. The couple set up a home at the Observatory atop Mars Hill, on the western edge of the city. They had two children, Marcia Frances (Mrs. K. J. Nicholson) and David Clark Slipher.[36] Slipher was active in community and business affairs, particularly in the years after Lowell's death. He became a member and then chairman of the school board and was instrumental in establishing Flagstaff's first high school. He also participated in the founding of the Northern Arizona Society for Science and Art and its Museum of Northern Arizona, one of the major interdisciplinary research centers of the Southwest, and was a long-time member of its board of directors.[37] As a businessman, Slipher acquired extensive ranch property around Flagstaff, operated a retail furniture store for a time, managed many rental properties, and was a founder of a community hotel (the Hotel Monte Vista) for which he served as board chairman for many years.[38]

EARLY PLANETARY STUDIES

Slipher arrived in Flagstaff on August 10, 1901. Shortly thereafter a fine three-prism spectrograph, made by John A. Brashear of the Allegheny Observatory at Pittsburgh, Pennsylvania, was delivered to the Observatory. Lowell had ordered this instrument the previous year for use "in the matter of Venus' rotation,"[39] and Slipher's first task was to mount it on the Lowell 24-inch refracting telescope, adjust it properly, and then learn its use.[40]

Initially, Slipher encountered many difficulties with the spectrograph. Lowell, from his Boston office, patiently forwarded advice on adjustments and observing techniques.[41] By mid-1902 Slipher had resolved his problems and produced spectrograms of Mars, Jupiter, and Saturn which Lowell thought were good enough to send to several eminent scientists as evidence of the excellence of both his new instrument and his new assistant. Slipher had, in fact, spectrographically confirmed the visually known periods of the planets, as Lowell proclaimed to the Washington, D.C. meeting of the American Association for the Advancement of Science in December.[42]

Slipher's own research interests, however, concerned the determination of radial velocities of stars and the discovery of spectroscopic binary stars by measuring Doppler shifts of the Fraunhofer lines in their spectra resulting from the differential motion of their components in the line of sight. Lowell encouraged this interest, although he set a firm policy that the planetary work of the Observatory must have first priority. Slipher faithfully adhered to this policy, and he pursued his own work only when time and circumstances permitted. It is notable, however, that his first formal publication was a 1902 paper in the *Astronomical Journal* on the variable velocity of the star ζ [zeta] Herculis.[43]

In the fall of 1902, Lowell assigned Slipher two projects; the first involved what came to be known as the "velocity-shift" method for determining constituents of planetary atmospheres.[44] Lowell was anxious for Slipher to apply his new method to determine whether water vapor and oxygen were present in the atmosphere of Mars, and Slipher did, in

1904 and 1905, undertake such observations. They were not successful, however, because the absorption lines he sought are in the near infrared region of the spectrum, i.e., above 6900 Ångstroms, and photographic plates sensitive in this range were simply not available at this time.[45] The method, although theoretically sound, did not in fact prove viable until 1963 when astronomers at the Mount Wilson Observatory, with the 100-inch Hooker reflector, used it to detect slight traces of water vapor and oxygen on Mars.[46] Slipher, in 1908, claimed the spectrographic detection of Martian water vapor and oxygen on other grounds,[47] but his finding was disputed.[48] Although his conclusion was seemingly confirmed by several later observers,[49] it has not been accepted by modern astronomers. This work, nevertheless, turned Slipher's attention to the near infrared of the spectrum where he would soon make some significant discoveries.

Slipher's second assignment concerned the rotation period of Venus, which had long been assumed to be about 23+ hours on the basis of vague shadings on the planet's cloud-shrouded disk, reported as early as 1666 by Giovanni Domenico Cassini. In 1890, however, astronomer Giovanni Virginio Schiaparelli, discoverer of the so-called "canals" of Mars which so intrigued Lowell, concluded that Venus had a much longer rotation period and rotated only once in 225 days, the period of its revolution around the sun.[50] This conclusion was widely disputed, but in 1896 Lowell announced that he had confirmed it from observations of streak-like markings on the planet's "surface."[51] In 1900 Aristarch A. Belopolsky, of Russia's Pulkowa Observatory, reported spectrographic observations that again favored Cassini's short period.[52] It was to counter Belopolsky's finding that Lowell had ordered the Brashear spectrograph. In giving Slipher the assignment, he warned that "the sentence of Belopolsky is indeed a hard nut to crack."[53]

Slipher began work on the problem in November 1902, and by March 1903 he had obtained a series of spectrograms that Lowell claimed confirmed Schiaparelli's and his own conclusions.[54] But the cautious Slipher reported only that they showed "no evidence that Venus has a short period of rotation," and that "so fast a spin as 24 hours could not have escaped detection."[55] Slipher, among others, made similar observations in subsequent years with essentially the same result.[56] His conclusion remained the best available estimate of the situation until the early 1960's, when radar observations revealed that the planet's spin is very slow indeed—243 days and in a retrograde direction.[57]

In 1903 Slipher began a spectrographic investigation of the giant outer planets—first Uranus and Neptune and then Jupiter and Saturn—in the then unexplored infrared region of the spectrum. In this work he experimented with chemical dyes and plate baths to make his plates sensitive farther into the red, and these efforts were quite successful. By 1907 he had obtained a series of spectrograms of the outer planets that revealed strong spectral bands neither he nor anyone else could immediately identify.[58] Not until 1931, with the work of Rupert Wildt, was it found that a few of these bands were due to methane and ammonia in the atmospheres of the planets.[59] Slipher subsequently worked with Lowell astronomer Arthur Adel to confirm this finding and extend it to the rest of the unidentified bands in Slipher's early spectra.[60]

At Lowell's direction, Slipher undertook several other spectrographic studies of the planets. Between 1905 and 1907, and again in 1924, he sought to detect chlorophyll on Mars with a negative result that has stood the test of subsequent observations, both by terrestrial observers and the 1976 Viking spacecraft's examination of the surface of Mars itself.[61]

In 1911 Slipher became the first to spectrographically determine a rotation period for Uranus of 10.75 hours,[62] a result ultimately confirmed both photometrically and spectrographically and not questioned until 1975, when observers using more sophisticated equipment tentatively suggested a period of 25±4 hours.[63] The rotation period of Neptune, too, was a concern. In 1912 and 1913 he sought to determine the length of the Neptunian "day" spectrographically at Flagstaff,[64] and in 1921 he made another attempt, using the 100-inch Hooker reflector on Mount Wilson. His results, he determined, were inconclusive.[65]

INTERSTELLAR GAS AND DUST

Throughout these years, Slipher continued his work on spectroscopic binary stars. "With regard to yourself, by all means make your star measures for velocity—whenever there is no pressing planetary work—and good luck to you in the result," Lowell had written him in 1904.[66] Slipher had, from time to time, published observations of stars with variable radial velocities, and by 1909 this work had led him to a major discovery.

In 1904 astronomer J. F. Hartmann had noted that the conspicuous H and K calcium lines in the spectrum of the binary star δ [delta] Orionis remained sharp and stationary, while other spectral lines were blurred or broadened by the differential velocity of the components in the line of sight. He thought that this might indicate light absorption by a calcium vapor cloud between the earth and the star, but both his observation and his suggestion remained obscure, and Hartmann did not pursue the work.[67] In 1908 the Dutch theoretical astronomer J. C. Kapteyn independently suggested that interstellar space contained vast quantities of gas and predicted that this gas should produce what he called "space lines" that "would not share in that part of the radial motion which is due to the motion of the stars themselves. . . ."[68] That same year Slipher discovered sharp, stationary calcium lines in the otherwise blurred spectrum of the star β [beta] Scorpii, and over the ensuing year he found the same phenomenon in the spectra of a number of both double and single stars, not only in Scorpio, but in Perseus and Orion as well. From this he concluded that interstellar gas exists in widely separated regions of space, notably "in and near branches of the Milky Way," and produces "selective absorption of light in space." He also suggested that the stationary H and K calcium lines were "the 'space lines' which Kapteyn's researches had led him to predict."[69]

These conclusions brought Slipher congratulatory letters from many eminent astronomers, including Hartmann and Kapteyn.[70] Yet his findings were largely ignored in astronomy for nearly two decades, despite the pertinence of interstellar absorption of light to the so-called "great debate" ten years later over the size of a universe then measured by the intensity of light alone.[71] Further observations by John S. Plaskett in the early 1920's and the theoretical work by Eddington in 1926 eventually showed the validity of Slipher's earlier work.[72] Plaskett considered Slipher's 1909 discovery "the most suggestive and penetrating early contribution to the problem...."[73]

In December 1912, Slipher also demonstrated the existence of dust, or "pulverulent matter," in interstellar space with his discovery that the nebula in the Pleiades near the star Merope was shining solely by reflected starlight.[74] In 1916 he made similar observations of the nebula near the star ρ[rho] Ophiuchi, obtaining a similar result,[75] and in later years he and others added nebulosities in other regions of space to the new class of reflection nebulae.[76]

OBSERVATIONS OF SPIRAL NEBULAE

For a brief time, Slipher considered his Pleiades discovery his most significant work, for he believed that it provided the solution to the long-standing problem of the spiral nebulae.[77] For three centuries astronomers had observed and speculated about these numerous, but faint, diffuse objects, yet almost nothing about them was then known. Some believed that they were vast aggregations of stars beyond the Milky Way, "island universes" as suggested by philosopher Immanuel Kant in 1755. Others felt they might be embryonic planetary systems in early stages of evolution and thus analogs of the primordial solar system. The problem was not resolved until the third decade of this century, and Slipher's discoveries played a part in its resolution.

Slipher turned his attention to the spiral nebulae in 1909 at the behest of Percival Lowell, who thought that if such objects were indeed incipient solar systems, they might show spectrographic similarities to the solar system itself. Early in 1909 he asked Slipher to observe what were then only classified as "green" and "white" nebulae, the latter group containing the enigmatic spirals, and to compare the spectra of their "outer parts" with his spectra of the giant outer planets.[78]

Slipher approached this assignment pessimistically. Because of their faintness, the spirals were difficult to observe spectrographically; the few such observations that had been attempted up to this time had been generally unproductive, even with telescopes larger and considered more suitable for the work than Lowell's 24-inch refractor. "I do not see much hope in getting the spectrum of a white nebula," he pointed out to Lowell, "because the high ratio of focal-length to aperture of the 24-inch gives a very faint image of a nebula.... It would seem the undertaking would have to await the [40-inch] reflector."[79] (The Lowell 40-inch reflector would not be fully operational for another year, and even then Slipher had to carry on his nebular work with the smaller refractor. Lowell assigned the new instrument to what he considered to be more promising work—observations of Mars and his trans-Neptunian planet search.[80])

Despite his pessimism, Slipher went to work on the problem, seeking advice from spectroscopists Edward A. Fath of the Lick Observatory and Edwin B. Frost of Yerkes Observatory, and experimenting with various instrumental and photographic techniques.[81] He soon realized that focal lengths and apertures, or the degree of dispersion his prisms provided, were not particularly germane to the problem—the key factor was the speed of the spectrograph's camera lens. By November 1910, he had devised a single-prism spectrograph "from equipment on hand,"[82] which, he advised Lowell, "requires only about a hundredth part of the exposure required by the three-prism arrangement."[83] Early in December he obtained a spectrogram of the Great Nebula in Andromeda which, he wrote, "seems to me to show faintly peculiarities not commented upon" by earlier workers in the field. "These earlier observations were made with large reflecting telescopes and the idea seems to go undisputed that a long focus telescope and of course a refractor is unsuitable for such work. But I convinced myself that I knew of no reason why the focus-to-aperture ratio had the slightest part to play in spectrum work on extended objects, and this plate proves the proposition completely to my mind."[84]

Through 1911 and 1912 Slipher continued to experiment with faster lenses and with observation techniques whenever the regular work of the Observatory gave him the opportunity and access to the 24-inch telescope. In September 1912, his spectrograph now equipped with a commercial Voigtlander f 2.5 lens, which "gave something like 200 times the speed of the usual three-prism spectrograph,"[85] he again turned his attention to Andromeda.

On September 17, in an exposure of more than six hours, Slipher obtained a plate of the Andromeda nebula that recorded enough detail to encourage him to try specifically to measure the radial velocity of the nebula, an observational feat that astronomers of the day generally considered beyond practical achievement.[86] At this time the radial velocities of some 1200 bright stars and a few bright planetary nebulae had been measured and all found to be moving at speeds on the order of tens of kilometers per second (km/sec). No radial velocities were known for nebulae, but no one expected that they would be appreciably different.[87]

Although encouraged, Slipher was still not confident. "If I succeed in getting any spectra worth while," he wrote Lowell in October, "I might try to measure them for velocity.... But of course there is no rush as I do not know if it is possible to get such spectrograms."[88]

Slipher now made two spectrograms of Andromeda with exposures extending over two nights, on November 15–16 and on December 3–4. These were even more encouraging, for the plates contained "a somewhat larger number" of spectral lines than had been recorded by the few other astronomers who had observed spirals spectrographically, notably Sir William Huggins in England, Max Wolf and Julius Scheiner in Germany, and Fath in the United States. "Of course the spectrum is very faint," Slipher conceded to Lowell, "and getting the velocity from the spectrograms would doubtless impress these observers as quite a hopeless undertaking, and maybe it is but I want to make the attempt."[89]

On December 28 Slipher advised Lowell that he planned to get "one good carefully made spectrogram" of the Andromeda nebula for velocity,[90] and the following night he began this spectrogram, exposing the plate over three nights and into the pre-dawn hours of January 1, 1913.[91] After a preliminary inspection of the plate, he reported, "I feel it safe to say here that the velocity bids fair to come out unusually high."[92]

Over the next two weeks, Slipher carefully measured all four of his Andromeda plates, finding that the nebula was moving at a radial velocity some three times that of any other known object in the universe. The result seems to have caused him some concern, and even to have raised doubts in his mind that the Doppler shift was a valid indicator of radial velocity. To reinforce his conclusion, he sent a print of his Andromeda spectrum to Fath. "You will I think," he wrote, "be able to see the displacement of the nebular lines toward the violet with reference to such lines as 4325, 4308, and 4272 [Ångstroms] of the Fe [iron] and V [vanadium] comparison spectrum. Other plates show the same thing, which corresponds to a velocity of 275 km.... I cannot find any other explanation...."[93]

To further resolve his doubts, Slipher spent another two weeks painstakingly remeasuring his Andromeda plates and found the mean velocity to be slightly higher. On February 3, 1913 he wrote Lowell that the Great Nebula in Andromeda was approaching the earth at the then unheard-of speed of 300 km/sec, the value, incidentally, that is accepted today.[94] "It looks as if you had made a great discovery," Lowell replied. "Try some other spiral nebulae for confirmation."[95]

Slipher now turned his attention to a spindle-shaped, edge-on spiral in Virgo, designated NGC 4594, and by April his spectrograms showed that its spectral lines were shifted far toward the red, indicating that it was receding from the earth at about 1000 km/sec, an astounding velocity at that time.[96] "This nebula is leaving the solar system," he pointed out to Lowell, "hence it seems safe to conclude that motion in the line of sight is the real cause of these great displacements in their nebular spectra, for if there were some unknown agency akin to the pressure shifts but enormously magnified residing in the nebulae, we would not expect it to one time act one way, another time the opposite way."[97]

Slipher continued these observations through the next year. In August 1914, at the American Astronomical Society's seventeenth meeting at Evanston, Illinois, he could announce radial velocities for fifteen spirals.[98] "In the great majority of cases," he reported, "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. . . ."[99] Three years later, when Holland's Willem de Sitter first theorized that the universe might be expanding, Slipher's list contained twenty-five spiral nebulae and globular clusters, their velocities continuing to be "preponderantly positive."[100]

DISCOVERY OF NEBULAR ROTATION

Slipher's investigations of the spiral nebulae had one other important result. His 1913 spectrograms of the Virgo spiral had not only shown that its spectral lines were shifted toward the red, but that they were slightly inclined, indicating differential radial motion in the nebula itself, and thus rotation. With typical caution, Slipher waited a full year, until he could obtain a satisfactory confirmatory spectrogram, before telegraphing Lowell: "Spectrograms show Virgo nebula rotating."[101] Over the next few years he found that a number of other spirals, including Andromeda's, were rotating, and by late 1917 he concluded that they were all spinning in the same relative direction, "turning into the spiral arms like a winding spring."[102]

This discovery, however, conflicted with an earlier finding by Mount Wilson Observatory's Adriaan van Maanen, based on the comparative photography of nebulae, that the spirals' arms were, in effect, unwinding. Van Maanen's results were of great interest, because if angular motion within a nebula could be detected in photographs taken at relatively short intervals, then the nebula could be at no very great distance from the earth. Quite a few astronomers, then and in subsequent years, cited van Maanen's work to argue against the "island universe" theory and the proposition that spiral nebulae were distant galaxies of stars like the Milky Way itself.[103]

In the long debate over this issue, Slipher's work on nebular rotation was largely neglected in favor of van Maanen's. Slipher himself did nothing to bring it to the fore, preferring always to avoid controversy. This he managed to do even in his private correspondence, writing to an inquiring colleague, for example:

> It is unfortunately a fact that the results from the spectrographic observations of nebulae show the central parts of the spirals to be rotating in a direction opposite to that indicated by Van [*sic*] Maanen's observed motions of nebulae. No results have been got here since to modify the conclusions drawn from the earlier spectrographic rotations. . . . I have heard expressions of doubt as to whether Van Maanen's results might not be somehow in error. Then perhaps there are some astronomers who might think some other interpretations might be applied to the spectrographic observations. It is perhaps natural that I should not hear the spectrographic results questioned. . . .[104]

More than ten years would pass before astronomers in general would conclude that van Maanen's results were wrong, and van Maanen himself reject them.[105] The issue of nebular rotation, moreover, was complicated by the problem of which edge of the spiral was nearest the observer—Slipher opting for the edge showing dark, silhouetted lanes of absorbing material.[106] It was more than twenty years before this aspect of the controversy was settled—primarily by Hubble—and Slipher's reasoning shown to be sound.[107]

Slipher's work on nebulae was extremely difficult and laborious, and represented a major technical achievement for observational astronomy at the time. It required precise guidance of the 24-inch refractor for periods ranging from five to more than sixty hours, frequently extending over many nonconsecutive nights.[108] Slipher once remarked that he should have observed some of the bright planetary nebulae as "it would be a real recreation to be able to secure a satisfactory spectrogram of a nebula in one night's exposure." But to this he quickly added: "To do the best work one must limit himself to a few problems."[109] Some of his colleagues marvelled that he did not electrocute himself with the makeshift array of Leiden jars he used to create the spark for his comparison spectra. When Slipher described his equipment and techniques along with his results at the August 1914 AAS meeting at Evanston, he received an unprecedented standing ovation.[110]

Some of Slipher's early speculations on his nebular work were not as valid or as durable as the work itself. He did not at first think, for example, that the spirals were vast exterior galaxies, and his discovery of the reflection nature of the Pleiades nebula briefly reinforced this belief. "If this nebula shines by reflected light," he wondered, "why could not the nebula in Andromeda shine in the same way being lighted by a central sun obscurred [*sic*] by the fragmentary material around it?"[111] Again, he speculated briefly that the spirals might be "very advanced stars in old age undergoing a strange disintegration, brought about possibly by their swift flight through stellar space";[112] that novae, like the one that flared in Andromeda in 1885, might be explained by such a fast-moving nebula encountering a "dark sun."[113] He also suggested that the higher velocities he found for edge-on spirals might indicate that spirals in general moved "as a disk in a resisting medium."[114]

Slipher's own later work, as well as Lowell's quick grasp of the implication of high nebular velocities,[115] soon changed such ideas. By April 1917 Slipher declared that the "island universe" theory "gains favor in the present observations." He also noted that early in his nebular work he had discovered indications of group motion by both the spirals and clusters, and he now used his list of twenty-five velocities to compute the earth's motion relative to these objects. He reported that "our whole stellar system moves and carries us with it" at a velocity of about 700 km/sec in the direction of Capricorn. And he added: "It seems that if our solar system evolved from a nebula as we have long believed, that nebula was probably not one of the class of spirals here dealt with."[116]

By 1917 only four of Slipher's velocity measures had been confirmed,[117] but by the end of World War I, others began to take up the work and fully established the validity of his discoveries. Slipher, however, still dominated the field. In 1921—the year he was elected to the National Academy of Sciences—he found that the spiral NGC 584 in Cetus was receding at about 1800 km/sec, the fastest-moving object yet discovered, and added thirteen more objects to his list of velocities.[118] In 1922 he sent forty-one velocities to Eddington for use in a book on relativity. In requesting these, the English astrophysicist declared, "I do not trouble myself about measures which merely duplicate yours as I know the agreement is in general quite satisfactory."[119]

In 1929 Hubble derived his important velocity-distance relationship for nebulae using, as he later wrote Slipher, "your velocities and my distances."[120] Hubble acknowledged Slipher's seminal contribution to his own work by declaring that "the first steps in a new field are the most difficult and the most significant. Once the barrier is forced, further development is relatively simple."[121]

AURORAE AND NIGHT SKY LIGHT

After 1921 Slipher's work on nebulae dropped off sharply. He had by this time largely exhausted the brighter nebulae and clusters within reach of the 24-inch and his spectrograph. Also, after Lowell's death he necessarily devoted more time to the administrative affairs of the Lowell Observatory. After 1927 his supervision of the new search for Lowell's trans-Neptunian planet drew much of his attention. Finally, he was deep into another investigation, involving the aurorae and the light of the night sky, which had emerged serendipitously from his nebular studies.

On February 7, 1913, in reporting the Andromeda velocity to his friend, astronomer John C. Duncan, Slipher discussed the differences between the spectra of the Andromeda nebula and of globular clusters and added: "I want to get the spectrum of the integrated light of the night sky to see how well the composite features come out in it as a suggestion of what we might expect from a galaxy observed from a great distance."[122]

He did not get around to doing this until June 1915, and then he found that a bright, greenish-yellow line at about 5571 Å dominated his long-exposure plate. This line had been observed before as the most prominent line in the spectrum of an auroral display. Slipher made some more night sky plates, and in March 1916 Lowell announced his assistant's discovery of a "permanent aurora."[123] In November Slipher published the results of more than fifty such observations, reporting the "chief auroral line" in all of his plates, even though no auroral displays were evident during the exposures.[124]

The following year, using a three-prism spectrograph with the 24-inch refractor, he measured a series of night sky plates, one exposed 115 hours, and showed that this line was at 5578 Å, seven Ångstroms above the previously accepted value. From these observations he concluded that the line was not due to nitrogen, as others had hypothesized. In 1924 it was found to be the result of atomic oxygen.[125]

Through the 1920's Slipher continued his observations of the night sky and of the rare auroral displays visible at Flagstaff's latitude. He discovered many new features in their spectra that were soon shown to be due to nitrogen, sodium, and other components of the earth's upper atmosphere in various ionized states.[126] In the early 1930's he extended this work to the zodiacal light, finding faint auroral features in its spectrum and concluding that upper atmospheric radiations contributed to what was otherwise predominantly a reflection phenomenon.[127] In 1933 Slipher's night sky and auroral work was carried on from Antarctica, with one of his spectrographs, by Thomas C. Poulter, chief scientist of the Byrd Antarctic Expedition II. Slipher was one of ten members of the honorary scientific staff of the expedition.[128]

Marathon exposures—in one case 147 hours—were needed to record a readable spectrum of the night sky light.[129] Despite this, the work was far less time-consuming than his nebular work; there was no telescope to guide, and it was only necessary to point the spectrograph toward the desired region of the sky, and check it periodically.[130] Slipher continually sought better optics for his instruments in this work. In 1924 he was offered a $300 grant by the National Academy of Sciences' Henry Draper Committee for special lenses. He never used the money, however, explaining later that "it turned out that I was able personally to pay for the optical parts. . . . Thus, as it worked out, I felt I should leave the grant to cases that could not—or would not—go on without it."[131]

Slipher also found time to lead two Lowell Observatory eclipse expeditions—to Syracuse, Kansas in 1918, and Ensenada, Mexico in 1923[132]—and for spectrographic studies of "peculiar" objects. In 1913 and 1915 he observed the Crab Nebula (NGC 1952), later found to be the remnant of a brilliant supernova reported by Chinese astronomers in A.D. 1054, and found its spectrum "the most extraordinary one known."[133] Its spectral lines, he discovered, were split and displaced at equal distances on each side of their normal place, a phenomenon he erroneously attributed to the Stark effect involving radiation in a strong electric field.[134] In 1917 he found that Hubble's variable nebula (NGC 2261) and the variable nebula NGC 6729 both had nova-like spectra.[135]

Throughout his career, Slipher continued to carry out observations of the planets and to otherwise work on projects to which Lowell had given priority. These included such transient phenomena as comets and novae, and on one occasion a transit of Mercury. Of this latter event, he noted that while such transits were not particulary rare, "the individual's opportunity to observe one is rare enough that he should not let it go unimproved."[136]

INFLUENCE OF PERCIVAL LOWELL

Perhaps the most interesting aspect of Slipher's career was the extent to which his flamboyant employer, Percival Lowell, and Lowell's often sensational ideas influenced his work and thought. There can be no doubt that Slipher was a cautious but convinced Lowellian. Not even in private did he question Lowell's controversial theories of the habitability of Mars or of the probable existence of intelligent Martians. Rather, he considered them possibilities that had been neither proven nor disproven, and used them as working hypotheses around which he programmed much of the work of the Observatory. When this work and work elsewhere seemed to support Lowell's ideas, as it sometimes did in the 1920's, Slipher carefully pointed this out to correspondents. In 1926 for example, when a student asked him for a disclaimer of life on Mars to use in a class debate, Slipher replied: "Unfortunately for your side, recent investigations tend more and more to confirm Lowell's conclusions... by adding further evidence of atmosphere and water and temperature such as would sustain organic life. While the *canali* markings [the so-called "canals"] are best interpreted by assuming Mars possessed of intelligent beings, yet the great distance between us and Mars renders the telescope incapable of showing directly objective presence of living beings."[137]

Slipher did, in fact, believe that millions of other planets exist in the universe and that many of them could, and probably did, support some form of life. "A thousand million rose bushes and one rose!" he once exclaimed to a botanist who had inquired about extra-mundane life. "It is neither according to religious or scientific teaching, but reminds us of the time when the earth was regarded as the center of the universe."[138]

Slipher's discovery of the extraordinary velocities of spiral nebulae, however, remains the most important of his many contributions to knowledge, as President F. J. M. Stratton of the Royal Astronomical Society pointed out in presenting him with the Society's Gold Medal in 1933:

> In a series of studies of the radial velocities of these island galaxies he laid the foundations of the great structure of the expanding universe.... If cosmogonists today have to deal with a universe that is expanding in fact as well as in fancy, at a rate which offers them special difficulties, a great part of the blame must be borne by our medalist.[139]

Slipher's own assessment of his work was more modest. This same year, in accepting the Henry Draper Medal from the National Academy of Sciences, he acknowledged a debt to Lowell, to "my good teacher Doctor John A. Miller," and to "scientific friends," and added:

> Other helpful factors for me have been good instrumental equipment and favorable skies for observation.... Added to these was that of a rather free hand to choose my own program, which fit happily a spirit of exploration. Under such conditions, some one else might have accomplished much more, but surely no one could find more pleasure in doing it than I.[140]

THE PRIMARY reference materials used for this memoir are contained in the Lowell Observatory Archives and consist of letters, texts, and other documents relating to Slipher's tenure at the Observatory, 1901–1954. Letters dated prior to 1917 can also be found in W. G. Hoyt and A. Babbitt, eds., *The Early Correspondence of the Lowell Observatory 1894–1916* (microfilm ed.; Flagstaff: Lowell Observatory, 1973). I have also used Slipher's will, his Indiana University transcript, and several biographical notes in the Archives prepared at the time of his death by colleagues and members of his family.

Printed materials used were preeminently Slipher's own publications (listed in the Bibliography), as well as publications by others in the astronomical literature relating to his work. A number of general works on astronomy have also been used to provide background and set Slipher's work in the context of that of his contemporaries. These include, notably, A. M. Clerke, *A Popular History of Astronomy During the Nineteenth Century* (4th ed.; London: Adam and Charles Black, 1902); O. Struve and V. Zebergs, *Astronomy of the Twentieth Century* (New York: Macmillan, 1962); E. P. Hubble, *The Realm of the Nebulae* (New Haven: Yale University Press, 1936); and R. Berendzen, R. Hart, and D. Seeley, *Man Discovers the Galaxies* (New York: Science History Publications, 1976).

In addition I have also drawn on two of my own works which are the only fully documented volumes extant relating to Percival Lowell, his observatory, and his early assistants. These are: *Lowell and Mars* (Tucson: University of Arizona Press, 1976); and *Planets 'X' and Pluto* (Tucson: University of Arizona Press, 1980).

FOOTNOTES

[1] J. S. Hall, "V.M. Slipher's Trail-blazing Career," *Sky and Telescope,* 39(1970):84; "Vesto Melvin Slipher (1875–1916)," *American Philosophical Society Yearbook,* 1970, pp. 161–66.

[2] V. M. Slipher, "The Radial Velocity of the Andromeda Nebula," *Lowell Observatory Bulletin,* no. 58, 2(1913):56; "Spectrographic Observations of Nebulae," *Publications of the American Astronomical Society,* 3(1913):18(A); *Popular Astronomy,* 22 (1914):146.

[3] W. Bonner, *The Mystery of the Expanding Universe* (New York: Macmillan, 1964), p. 1; R. Berendzen, R. Hart, and D. Seeley, *Man Discovers the Galaxies* (New York: Science History Publications, 1976), pp. 104–7.

[4] E. P. Hubble, *The Realm of the Nebulae* (New Haven: Yale University Press, 1936),

pp. 102–5. See also E. P. Hubble to V. M. Slipher, April 11, 1930, and March 6, 1953, Lowell Observatory Archives, (LOA).

[5] V. M. Slipher, "The Detection of Nebular Rotation," *Lowell Observatory Bulletin*, no. 62, 2(1914):65.

[6] V. M. Slipher, "Spectrographic Observations of Nebulae," *Publications of the American Astronomical Society*, 3(1914):98(A); *Popular Astronomy*, 23(1915):21–24; "Nebulae," *Proceedings of the American Philosophical Society*, 56(1917):403–10; and "Spectrographic Observations of Star Clusters," *Publications of the American Astronomical Society*, 3(1918):331(A); *Popular Astronomy*, 26(1918):8.

[7] V. M. Slipher, "Peculiar Star Spectra Suggestive of Selective Absorption of Light in Space," *Lowell Observatory Bulletin*, no. 51, 2(1909):1; and "On the Spectrum of the Nebula in the Pleiades," *ibid.*, no. 55, 2(1913):26–27.

[8] V. M. Slipher, "A Spectrographic Investigation of the Rotation Velocity of Venus," *ibid.*, no. 3, 1(1903):9; and "Detection of the Rotation of Uranus," *ibid.*, no. 53, 2(1912):17–20.

[9] V. M. Slipher, "The Spectrum of the Major Planets," *ibid.*, no. 42, 1(1908):231; "The Spectrum of Mars," *Astrophysical Journal*, 28(1908):397; "Spectrographic Studies of the Planets," (George Darwin Lecture), *Monthly Notices of the Royal Astronomical Society*, 93(1933):657–68. See also Bibliography for papers with A. Adel, 1934–1936.

[10] V. M. Slipher and C. O. Lampland, "Preliminary Notes on Photographic and Spectrographic Observations of Halley's Comet," *Lowell Observatory Bulletin*, no. 47, 1(1910):252–54; Slipher, "The Spectrum of Halley's Comet as Observed at the Lowell Observatory," *ibid.*, no. 52, 2(1911):3–16. See also Bibliography for publications on comets in 1914, 1916, 1919, 1927, and 1938.

[11] V. M. Slipher, "Some Spectrographic Results of the Lowell Observatory Eclipse Expedition," *Publications of the American Astronomical Society*, 4(1918):49–50(A); *Popular Astronomy*, 27(1918):148; "The Spectrum of the Corona as Observed by the Expedition from Lowell Observatory of the Total Eclipse of June 8, 1918," *Astrophysical Journal*, 55(1922):73–84.

[12] V. M. Slipher, "A New Type of Nebular Spectrum. I. The Spectrum of Hubble's Variable Nebula NGC 2261. II. The Variable Nebula NGC 6729," *Lowell Observatory Bulletin*, no. 81, 3(1918):63.

[13] V. M. Slipher, "The Spectrum of Lightning," *ibid.*, no. 79, 3(1917):55.

[14] V. M. Slipher, "On the Spectrum of the Eclipsed Moon," *Astronomische Nachrichten*, 199(1914):103.

[15] V. M. Slipher, "Spectral Evidence of a Persistent Aurora," *Lowell Observatory Bulletin*, no. 76, 3(1916):1; "On the General Illumination of the Night Sky and the Wave-length of the Chief Auroral Line," *Astrophysical Journal*, 49(1919):266–75; "Emissions of the Spectrum of the Night Sky," *Publications of the American Astronomical Society*, 6(1931):241–42(A); "Preliminary Note on the Spectrum of the Zodiacal Light," *Lowell Observatory Circular*, Feb. 20, 1931. See also Bibliography for publications on night sky spectra in 1918, 1929, 1930, 1933, 1934, and 1938.

[16] W. G. Hoyt, *Planets 'X' and Pluto* (Tucson: University of Arizona Press, 1980), chaps. 7–12. See also C. W. Tombaugh, "The Discovery of Pluto," *Astronomical Society of the Pacific Leaflet*, no. 209, 1946; and "The Trans-Neptunian Planet Search," in *The Solar System: Planets and Satellites*, ed. G. P. Kuiper and B. Middlehurst (Chicago: University of Chicago Press, 1961), pp. 12–30.

[17] H. Shapley and H. D. Curtis, "The Scale of the Universe," *Bulletin of the National*

Research Council, 2(1921):217. See also O. Struve and V. Zebergs, *Astronomy of the Twentieth Century* (New York: Macmillan, 1962), pp. 416ff. and 441ff., and Berendzen, Hart, and Seeley, *Man Discovers the Galaxies,* pp. 35–47.

[18] Berendzen, Hart, and Seeley, *Man Discovers the Galaxies,* pp. 146–51.

[19] W. G. Hoyt, *Lowell and Mars* (Tucson: University of Arizona Press, 1976), *passim.* For a specific instance, see V. M. Slipher to P. Lowell, May 7, 1913, LOA.

[20] For example, Slipher's announcement of his initial nebular velocities was read to the Atlanta meeting of the American Astronomical Society in 1913 by Philip Fox of Dearborn Observatory in Illinois and "was greeted with some expression of incredulity, especially on the part of Professor [Henry Norris] Russell. . . ." See P. Fox to V. M. Slipher, April 10, 1920, LOA.

[21] See correspondence between V. M. Slipher and H. Shapley, Oct. 31 and Nov. 13, 1917; between Slipher and A. S. Eddington, Nov. 11, 1921, Feb. 5, and March 8, 1922; Slipher to K. Lundmark, March 11, 1924; between Slipher and G. Strömberg, Sept. 30, Oct. 7 and 11, Nov. 29, and Dec. 8, 1924; between Slipher and L. Silberstein, Sept. 8 and 18, 1924; between Slipher and W. S. Adams, May 29 and 31, 1930; and between Slipher and E. P. Hubble, April 11, 1930, and July 22 and Aug. 4, 1932, LOA.

[22] See Slipher, Bibliography, *supra.*

[23] Slipher was not, however, a particularly prolific correspondent. Lick Observatory's Robert G. Aitken once complained: "I have as you know a very high regard for you as a man and as an astronomer, but you have one little failing that makes me want to curse you loud and deep; *you do not answer letters!*" See R. G. Aitken to V. M. Slipher, Sept. 16, 1931, LOA.

[24] J. S. Hall, "Slipher's Trail-blazing Career," "Vesto Slipher"; *Arizona Daily Sun* (Flagstaff), Nov. 9, 1969, p. 1; *ibid.,* Aug. 8, 1964, p. 1; and V. M. Slipher to F. R. Elliott, May 29, 1930, LOA.

[25] W. G. Hoyt, "Historical Note: Astronomy on the San Francisco Peaks," *Plateau,* 47(1975):116.

[26] A. Adel Feb. 1, 1978: personal communication.

[27] See, for example, V. M. Slipher to H. E. Knight, May 9, 1924, LOA; and C. W. Tombaugh, "Reminiscences of the Discovery of Pluto," *Sky and Telescope,* 19(1960):264–70.

[28] P. Lowell to V. M. Slipher, June 4, 1904, LOA: "I trust you have seen to the cow's calving regularly since I went away?" Lowell writes here. "If not, see to her at once please."

[29] Transcript of course work of V. M. Slipher, issued by the Alumni Office, Indiana University, Nov. 18, 1969. See also J. S. Hall, "Slipher's Trail-blazing Career," "Vesto Slipher."

[30] V. M. Slipher to F. R. Elliott, May 29, 1930, LOA.

[31] Miller and Cogshall, along with John C. Duncan of Wellesley College, who was on the Lowell staff in 1905–1906, were the only persons outside the Observatory circle to whom Slipher gave advance notice of Pluto's discovery. See Slipher to J. A. Miller and to W. A. Cogshall, March 8, 1930, and to J. C. Duncan, March 9, 1930, LOA.

[32] W. A. Cogshall to P. Lowell, June 24, 1901, LOA.

[33] P. Lowell to W. A. Cogshall, July 7, 1901, LOA.

[34] J. S. Hall, "Slipher's Trail-blazing Career," "Vesto Slipher"; *Arizona Daily Sun*, Nov. 9, 1969, p. 1.

[35] V. M. Slipher, last will and testament, dated Dec. 17, 1967, and filed for probate Nov. 12, 1969 in Coconino County (Arizona) Superior Court.

[36] Biographical note on V. M. Slipher, prepared Nov. 12, 1966, by K. J. Nicholson (Slipher's son-in-law), LOA.

[37] *Ibid.*

[38] *Ibid.*

[39] P. Lowell to H. S. Pritchett, Sept. 30, 1902, LOA.

[40] P. Lowell to V. M. Slipher, Sept. 17, 1901, LOA.

[41] P. Lowell to V. M. Slipher, Oct. 21 and 28, Nov. 14, and Dec. 18, 1901; and Jan. 4, March 10 and 26, 1902, LOA.

[42] P. Lowell, "Spectrographic Proof of the Rotations of Jupiter, Saturn and Mars," text (dated Dec., 1902) of paper for Washington, D.C. Meeting of the American Association for the Advancement of Science, LOA.

[43] See Bibliography for years 1902–1907.

[44] P. Lowell to V. M. Slipher, Oct. 4, 1902, LOA.

[45] V. M. Slipher, "An Attempt to Apply Velocity-Shift to Detecting Atmospheric Lines in the Spectrum of Mars," *Lowell Observatory Bulletin*, no. 17, 1(1905):118.

[46] H. Spinrad, G. Münch, and L. Kaplan, "Spectrographic Determination of Water Vapor on Mars," *Astrophysics Journal*, 137(1963):1319.

[47] V. M. Slipher, "The Spectrum of Mars," *Astrophysics Journal*, 28(1908):397. See also V. M. Slipher to P. Lowell, Feb. 4 and 20, 1908, and P. Lowell to V. M. Slipher, Feb. 26, 1908, LOA; and F. W. Very, "Measurements of the Intensification of Aqueous Bands in the Spectrum of Mars," *Lowell Observatory Bulletin*, no. 36, 1(1909):207–12.

[48] W. W. Campbell, "Note on the Spectrum of Mars," *The Observatory*, 51(1928): 322; V. M. Slipher, "On the Spectral Proof of Water and Oxygen on Mars," *ibid.*, 53(1930):79–81; and W. W. Campbell to V. M. Slipher, Oct. 5, 1932, LOA.

[49] W. S. Adams and C. St. John, "An Attempt to Detect Water Vapor and Oxygen Lines in the Spectrum of Mars with the Registering Microphotometer," *Publications of the Astronomical Society of the Pacific*, 37(1925):158–59.

[50] A. M. Clarke, *A Popular History of Astronomy During the Nineteenth Century*, 4th ed. (London: Adam and Charles Black, 1902), pp. 250–51.

[51] P. Lowell, "Detection of Venus' Rotation Period and of the Fundamental Physical Features of the Planet," *Popular Astronomy*, 4(1896):281; and "Determination of the Rotation and Surface Character of the Planet Venus," *Monthly Notices of the Royal Astronomical Society*, 57(1897):148.

[52] A. A. Belopolsky, "Ein versuch die Rotationgeschwindigkeit des Venusequators auf spectrographischen Wege zu bestimmen," *Astronomische Nachrichten*, 152(1900): 263–75.

[53] P. Lowell to V. M. Slipher, Nov. 5, 1902, LOA.

[54] P. Lowell to H. S. Pritchett, March 23, 1903, LOA.

[55] V. M. Slipher, "Spectrographic Investigation of the Rotation Velocity of Venus," *Lowell Observatory Bulletin*, no. 3, 1(1903):9; and *Astronomische Nachrichten*, 163(1903):35.

[56] V. M. Slipher, "The Spectrum of Venus," *Lowell Observatory Bulletin*, no. 84,

3(1922):85–89. See also V. M. Slipher to S. B. Nicholson, July 15 and Aug. 10, 1922, LOA.

[57]R. M. Goldstein, "Radar Observations of Venus," *Astrophysical Journal*, 69(1964):12; R. B. Dyce, G. H. Pettingill, and I. I. Shapiro, "Radar Determination of the Rotations of Venus and Mercury," *ibid.*, 72(1967):351; and R. L. Carpenter, "A Radar Determination of the Rotation of Venus," *ibid.*, 75(1970):61.

[58]V. M. Slipher, "The Spectra of the Major Planets," *Lowell Observatory Bulletin*, no. 42, 1(1908):231.

[59]R. Wildt, "Methan in den Atmosphäre der grossen Planeten," *Die Naturwissenschaften*, 20(1932):851; and "Ammoniakgas in der Atmosphäre des Planeten Jupiter," *Forschungen und Fortschritte*, 8(1932):223.

[60]See Bibliography for years 1934–1935 for papers with A. Adel.

[61]V. M. Slipher to W. A. Cogshall, Feb. 25, 1908, and to Guy Lowell, Oct. 4, 1924, LOA. See also G. P. Kuiper, "Planetary Atmospheres and Their Origin," in *The Atmospheres of the Earth and the Planets*, ed. G. Kuiper (Chicago: University of Chicago Press, 1952), p. 399.

[62]V. M. Slipher, "Detection of the Rotation of Uranus," *Lowell Observatory Bulletin*, no. 53, 2(1912):19. See also P. Lowell "Spectroscopic Discovery of the Rotation Period of Uranus," *ibid.*, 2(1912):17–18.

[63]S. H. Hayes and M. J. S. Belton, "The Rotational Period of Uranus and Neptune," paper (no. 133-5) read to the Eighth Meeting of the Division for Planetary Sciences of the American Astronomical Society, Honolulu, Hawaii, Jan. 22, 1977. Hayes' and Belton's result, however, has not yet been confirmed.

[64]V. M. Slipher to P. Lowell, Jan. 3, Feb. 3 and 5, 1913, LOA.

[65]V. M. Slipher to G. Lowell, March 22, and May 5, 1921; and G. Lowell to V. M. Slipher, April 4, 1921, LOA.

[66]P. Lowell to V. M. Slipher, May 23, 1904, LOA.

[67]J. F. Hartmann, "Investigations on the Spectrum and Orbit of δ [delta] Orionis," *Astrophysical Journal*, 19(1904):268–86.

[68]J. C. Kapteyn, "On the Absorption of Light in Space," *Astrophysical Journal*, 29(1909):46–54.

[69]V. M. Slipher, "Peculiar Star Spectra Suggestive of Selective Absorption of Light in Space." See also P. Lowell to J. C. Kapteyn, Oct. 1, 1909, LOA.

[70]J. Hartmann to V. M. Slipher, March 6, 1910; J. C. Kapteyn to V. M. Slipher, Oct. 20, 1909; E. Hertzsprung to V. M. Slipher, April 16, 1911; and correspondence between E. B. Frost and V. M. Slipher between Oct. 18, 1908 and Jan. 25, 1910, LOA.

[71]H. Shapley, *The View From a Distant Star* (New York: Basic Books, 1963), pp. 5–6, 21. See also Berendzen, Hart, and Seeley, *Man Discovers the Galaxies*, p. 76.

[72]J. S. Plaskett and J. A. Pearce, "The Problems of Diffuse Matter in the Galaxy," *Publications of the Dominion Astrophysical Observatory*, 5(1933):169; and A. S. Eddington, "Diffuse Matter in Interstellar Space," *Proceedings of the Royal Society of London*, Series A, 3(1926):424.

[73]Quoted in F. J. M. Stratton, "President's Speech on Presenting Gold Medal," *Monthly Notices of the Royal Astronomical Society*, 93(1933):476–77.

[74]V. M. Slipher, "On the Spectrum of the Nebula in the Pleiades."

[75]V. M. Slipher, "On the Spectrum of the Nebula About Rho Ophiuchi," *Lowell Observatory Bulletin*, no. 75, 2(1916):155–56.

[76] V. M. Slipher, "Spectra of the Pleiades, Scorpio and Cygnus Nebulosities," *Publications of the American Astronomical Society,* 9(1938):168–69.

[77] V. M. Slipher to P. Lowell, Dec. 16 and 17, 1912; and to J. C. Duncan, Dec. 29, 1912, LOA.

[78] P. Lowell to V. M. Slipher, Jan. 29, and Feb. 8, 1909, LOA.

[79] V. M. Slipher to P. Lowell, Feb. 26, 1909, LOA.

[80] Hoyt, *Planets 'X' and Pluto,* chap. 5.

[81] See, for examples, V. M. Slipher correspondence with E. A. Fath between Nov. 11, 1910 and Jan. 18, 1913; with E. B. Frost between Aug. 12, 1909 and Oct. 23, 1913; and with J. M. Schaeberle, Aug. 3 and 23, 1911, LOA.

[82] V. M. Slipher to E. A. Fath, Dec. 5, 1910, LOA.

[83] V. M. Slipher to P. Lowell, Nov. 9, 1910, LOA.

[84] V. M. Slipher to P. Lowell, Dec. 3, 1910, LOA.

[85] V. M. Slipher to W. W. Campbell, undated, LOA.

[86] V. M. Slipher, "The Radial Velocity of the Andromeda Nebula." See also V. M. Slipher to F. W. Very, Sept. 20, 1912, LOA.

[87] W. W. Campbell to V. M. Slipher, June 6, 1911, LOA.

[88] V. M. Slipher to P. Lowell, Oct. 2, 1912, LOA.

[89] V. M. Slipher to P. Lowell, Dec. 19, 1912, LOA.

[90] V. M. Slipher to P. Lowell, Dec. 28, 1912, LOA.

[91] V. M. Slipher, "The Radial Velocity of the Andromeda Nebula."

[92] V. M. Slipher to P. Lowell, Jan. 2, 1913, LOA.

[93] V. M. Slipher to E. A. Fath, Jan. 18, 1913, LOA.

[94] V. M. Slipher to P. Lowell, Feb. 3, 1913, LOA.

[95] P. Lowell to V. M. Slipher, Feb. 8, 1913, LOA.

[96] V. M. Slipher, "Spectrographic Observations of Nebulae."

[97] V. M. Slipher to P. Lowell, April 12, 1913; and to J. A. Miller, May 16, 1913, LOA.

[98] V. M. Slipher, "Spectrographic Observations of Nebulae." See also text of paper read at the Seventeenth (Evanston) Meeting, American Astronomical Society, Aug. 14, 1914, LOA. It is interesting to note that Edwin P. Hubble, then a young astronomer at Yerkes Observatory, attended this meeting, was elected to membership, and heard Slipher deliver the paper.

[99] *Ibid.*

[100] V. M. Slipher, "Nebulae."

[101] V. M. Slipher to P. Lowell, cablegram, May 25, 1914, LOA. See also, V. M. Slipher, "The Detection of Nebular Rotation."

[102] V. M. Slipher, "The Spectrum and Velocity of the Nebula NGC 1068," *Lowell Observatory Bulletin,* no. 80, 3(1917):59.

[103] Shapley and Curtis, "The Scale of the Universe." See also Hubble, *The Realm of the Nebulae,* p. 85; Struve and Zebergs, *Astronomy of the Twentieth Century,* p. 439; and Berendzen, Hart, and Seeley, *Man Discovers the Galaxies,* pp. 108–131.

[104] V. M. Slipher to A. C. Gifford, Oct. 10, 1924, LOA. Slipher learned of van Maanen's conflicting result even before it was published; see J. C. Duncan to V. M. Slipher, July 14, 1916, LOA.

[105] E. P. Hubble, "Angular Rotations of Spiral Nebulae," *Astrophysical Journal,* 81(1935):334–35; and A. van Maanen, "Internal Motions in Spiral Nebulae," *ibid.,* 81(1935):336–37.

[106] V. M. Slipher, "Nebulae."
[107] E. P. Hubble, "The Direction of Rotation in Spiral Nebulae," *Astrophysical Journal,* 97(1943):112–18; V. M. Slipher, "The Direction of Rotation in Spiral Nebulae," *Science,* 99(1944):144–45. See also Berendzen, Hart, and Seeley, *Man Discovers the Galaxies,* pp. 151–52.
[108] V. M. Slipher, "Spectrographic Observations of Nebulae."
[109] V. M. Slipher to F. W. Very, Jan. 12, 1917, LOA.
[110] J. S. Hall, *op. cit.*
[111] V. M. Slipher to J. C. Duncan, Dec. 29, 1912, LOA.
[112] V. M. Slipher to E. Hertzsprung, May 8, 1914, LOA.
[113] V. M. Slipher to J. C. Duncan, Feb. 7, 1913; and J. C. Duncan to V. M. Slipher, Feb. 11 and 17, 1913, LOA.
[114] V. M. Slipher, "Spectrographic Observations of Nebulae"; and "Nebulae." See also V. M. Slipher to P. Lowell, May 16, 1913; and to E. B. Frost, Nov. 4, 1913, LOA.
[115] P. Lowell, "Nebular Motion," text (dated Nov. 23, 1915) of lecture for Melrose Club, Boston, LOA. See also E. Hertzsprung to V. M. Slipher, March 14, 1914, LOA.
[116] V. M. Slipher, "Nebulae."
[117] *Ibid.* See also W. W. Campbell to V. M. Slipher, March 30, 1914; M. Wolf to V. M. Slipher, June 13, 1914; and F. G. Pease to V. M. Slipher, July 13, 1916, LOA.
[118] V. M. Slipher, "Two Nebulae with Unparalleled Velocities," *Lowell Observatory Circular,* Jan. 17, 1921; *Astronomische Nachrichten,* 213(1921):391–93. Re election to National Academy, see W. S. Adams to V. M. Slipher, June 14, 1921, LOA.
[119] See correspondence between V. M. Slipher and A. S. Eddington, Nov. 5, 1921, Feb. 2, and March 8, 1922, LOA.
[120] E. P. Hubble to V. M. Slipher, March 6, 1953, LOA.
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[122] V. M. Slipher to J. C. Duncan, Feb. 7, 1913, LOA.
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[124] V. M. Slipher, "Spectral Evidence of a Persistent Aurora," *Lowell Observatory Bulletin,* no. 76, 3(1916):1.
[125] V. M. Slipher, "On the General Illumination of the Night Sky and the Wavelength of the Chief Auroral Line." See also correspondence between V. M. Slipher and W. W. Campbell, Aug. 17, 20, 27, 31, and Sept. 21, 1917, LOA.
[126] V. M. Slipher, "Emissions of the Spectrum of the Night Sky." See also V. M. Slipher to W. W. Campbell, Jan. 28, 1929, LOA.
[127] V. M. Slipher, "Preliminary Note on the Spectrum of the Zodiacal Light." See also V. M. Slipher to F. R. Moulton, Feb. 9, and 16, 1931; and E. A. Fath to V. M. Slipher, April 24, 1931, LOA.
[128] See correspondence between V. M. Slipher and T. C. Poulter from June 6, 1932 to Sept. 28, 1933, LOA.
[129] V. M. Slipher to D. Menzel, May 6, 1940, LOA.
[130] V. M. Slipher to J. W. Miles, May 18, 1922, LOA.
[131] W. W. Campbell to V. M. Slipher, Jan. 9, 1929; and V.M. Slipher to W. W. Campbell, Jan. 29, 1929; LOA.
[132] V.M. Slipher, "The Lowell Observatory Eclipse Expedition," *Popular Astronomy,* 30(1918):346–47; and V. M. Slipher to J. A. Miller and C. Lowell, Feb. 14, 1923; D. Roberts to V. M. Slipher, July 17, 1923; V. M. Slipher to D. Roberts, July 25, 1923;

and W. W. Campbell to V. M. Slipher, July 16, 1923, LOA.

[133] V. M. Slipher to C. Lowell, Jan. 18, 1919; and to E. A. Fath, March 19, 1921; LOA. See also N. U. Mayall, "The Story of the Crab Nebula," *Science*, 137(1962):91–102.

[134] V. M. Slipher to P. Lowell, Jan. 23, 25, and 26, 1915; to J. A. Miller, Dec. 10, 1915, Jan. 9, Feb. 3 and 23, and March 2, 1916; to F. R. Moulton, Feb. 9, 1916; and J. H. Moore to V. M. Slipher, March 1, 1915, LOA. See also R. Sanford, "The Spectrum of the Crab Nebula," *Publications of the Astronomical Society of the Pacific*, 31(1919): 108–9.

[135] V. M. Slipher, "A New Type of Nebular Spectrum."

[136] V. M. Slipher to E. W. Scott, April 28, 1924, LOA.

[137] V. M. Slipher to H. Wetherald, March 9, 1926, LOA.

[138] V. M. Slipher to F. O. Grover, Jan. 23, 1923, LOA.

[139] F. J. M. Stratton, "President's Speech."

[140] V. M. Slipher, text, response to citation and award of Henry Draper Medal of National Academy of Sciences, April 25, 1933, LOA.

HONORS AND DISTINCTIONS

MEDALS AND AWARDS

Lalande Prize, Académie des Sciences de Paris, 1919
Henry Draper Medal, National Academy of Sciences, 1933
Gold Medal, Royal Astronomical Society, 1933
Bruce Medal, Astronomical Society of the Pacific, 1935

HONORARY DEGREES

The University of Arizona, 1923, Sc.D.
Indiana University, 1930, LL.D.
The University of Toronto, 1935, Sc.D.
Northern Arizona University, 1957, Sc.D.

AMERICAN MEMBERSHIPS

American Academy of Arts and Sciences (Fellow)
American Association for the Advancement of Science (Fellow)
American Astronomical Society
American Philosophical Society
Astronomical Society of the Pacific
National Academy of Sciences
Phi Beta Kappa
Sigma Xi

FOREIGN MEMBERSHIPS

International Astronomical Union
Royal Astronomical Society (Associate)
Société Astronomique de France

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1907

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1909

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1910

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