Percival Lowell's Last Year

by William Sheehan

Percival Lowell was always a controversial figure in the astronomical world. Despite his fame and large following with the general public, his ideas and methods were largely rejected by many prominent professional astronomers of the day. The *Astrophysical Journal*, founded by George Ellery Hale and James Keeler, leading American astrophysicists, had long since refused to accept his contributions, while in a review of Lowell's 1909 lectures at MIT (published in book form as *The Evolution of Worlds*), Forest Ray Moulton, a University of Chicago expert on celestial mechanics, referred derisively to the "mysterious 'watcher of the stars' whose scientific theories, like Poe's vision of the raven, 'have taken shape at midnight." Similarly, when in 1910 Edward C. Pickering and other astronomers passed through Flagstaff on their way west to the Union for International Cooperation for Solar Research Conference in Pasadena, Pickering invited Lowell to come along. Lowell refused. "No," he told Pickering, "I am an astronomer!" He meant an astronomer in the old sense, someone who actually looked through a telescope, wielded a filar micrometer for accurate measures, and was versed in the methods of classical celestial mechanics. He felt outside of the main thrust of astronomy in his time, which increasingly embraced the methods of astrophysics. In his later years, he became increasingly isolated and defensive, but his head, though bloodied, remained unbowed.

The greatest effort of Lowell's last decade, rivaling even his interest in Mars, which after 1909 was moving through a series of increasingly unfavorable oppositions, was his search for "Planet X"—itself inspired by the great nineteenth century triumph of Adams and Le Verrier, who used perturbation theory to analyze the wayward motions of Uranus and were rewarded with the sensational discovery of Neptune. As such, it was a mathematical investigation of the kind Lowell savored, depending on mathematical techniques developed a hundred years before and mastered in his student days under Harvard's legendary professor Benjamin Peirce. Lowell prided himself in his mathematical prowess. Mathematics was, he once said, "the thing most worthy of thought in the world." But his attitude about mathematics embodied something of what we might now describe as the Dunning-Kruger effect, for though versed in old-style celestial mechanics, he was largely ignorant of the new mathematical ideas that were entering physics and were about to enter astronomy as well, mathematical ideas that were far more complicated than those with which he was familiar. Instead of assimilating these advances, he preferred to see himself as the representative of a dying breed. "It is a popular delusion," he said in a lecture given in 1916, "that all astronomers must be mathematicians. The fact is they ought to be but are not. The mathematical astronomer is now the exception, due chiefly to the rise of astrophysics."[1] The astrophysicist, as Lowell saw it, was a mere collector, concerned with nothing more than mindless data-gathering, taking pictures of spectra and making photometric measures of stars to be stored in huge collections. Such work might lend itself to cooperative efforts, even—to use a word that for Lowell was anathema—unionization. (He hated labor unions with a passion, and even astronomical unions—such as George Ellery Hale's International Union for Cooperation in Solar Research—were thoroughly despised). None of this collectivist effort would lead to great discoveries, however. For that the highly individualistic "genius" was needed—and there could be little doubt in what category Lowell placed himself:

Now unions are excellent in their way for routine work. But though they push the lower men up they pull the upper down. And except for routine work what an unfortunate confession of individual incapability they make. To be willing to cooperate is to admit that one can do better in conjunction with others than he can do alone. No great man ever co-operated with another in the idea which made him great; the thing is unthinkable. Conceive Newton's Principia as a union outcome; and how many co-operators would it take to make one Clerk-Maxwell! That the banding together should be held advisable is a sad comment on the paucity of the age. Wolves hunt in packs, the lion stalks alone. It reflects too on the character of the work done. Just in proportion as the aim is low so may it wisely be widespread. The method has great advantages if the work is what you want. This is why we teach machines to do as much of it as we may. But as it becomes complicated and difficult fewer and fewer persons can be found capable of undertaking it until at last you have but the one man in the world who can, the genius who originates.[2]

In the same lecture, Lowell asked:

What is proof? Outside of mathematics, which is formulated logic, proof consists in an overwhelming preponderance of probability.

> Take, for instance, the law of gravitation, as being inversely as the square of the distance of the bodies apart. We call it proved and rightly, because almost everything stands explained by it and the few things that do not, like the motion of the apsides of Mercury, we are confident will eventually fall into line.[3]

Ironically, as he wrote these words, Einstein, in Berlin, had already made the motion of the apsides of Mercury fall into line, though not on the basis of the Newtonian law of the inverse square but on the basis of his General Theory of Relativity. It is certain that Lowell had never heard of Einstein or of the General Theory of Relativity. Had he lived to a reasonable old age, he would undoubtedly have had to come to terms with them; however, it is more than likely that he would have railed against them continuously—and futilely—in the pages of *Popular Astronomy*, as William H. Pickering, who had assisted him in founding his observatory, would do.

His "greatest disappointment"

Though Lowell's astronomical work involved cooperation, he always made it clear that he was the manager and superintending intelligence; others, including his staff astronomers and computers, were his employees. As such, they took their orders from the "lion," just as household servants would be expected to do. (Eventually the sheer achievement of V.M. Slipher with the spectrograph led Lowell to grant him a somewhat freer hand, and he was no longer charged with taking care of the Observatory Cow or ordering Shredded Wheat for his breakfast table, as he once wired Slipher to do from Chicago.)

From 1910, Lowell employed several human computers, headed by MIT graduate Miss Elizabeth Williams, in a massive effort to calculate the position of a trans-Neptunian planet, Planet X. Most of the work was done in his Boston office. By the end of 1912 and the beginning of 1913, it was undermining his health. Not only did he have to postpone a planned visit to Flagstaff, for a time he was not even able to visit the Boston office. His secretary Wrexie Louise Leonard reported that he could manage "only a word now and then on the phone," and added, "he is weak and run down and must needs be careful and quiet." She confided to her Flagstaff colleagues, "He worries about the work—he wants to be *in it*!" And: "It is nervous exhaustion, and he is *up* and *down*! Some days he cannot even telephone. He gets nervous about the work and impatient for things to come from Flagstaff."

On this occasion, he was "down" for only six weeks, and not the almost four years in which he had been afflicted after he returned from Mexico City in April 1897. But his mood continued to fluctuate between episodes of optimism and despondency. Thus in January 1914, he wrote to his sister Amy, the poet, who seemed to share something of both his temperament and sensitivity to criticism, “So very sorry, dear, to learn that you are down….. I have been down and up and down. Am now hoping for another up.”

No doubt he would have vouchsafed that he was “up” again if “X” had been sighted. He was now planning for yet another try, as he seems to have been caught up in the kind of frenzy that afflicts gamblers unwilling to accept defeat: just one more throw of the dice might rescue the situation. In April 1914 he and his assistants were busy initiating what has been called the “second search” for X, receiving on loan a 9-in. Brashear photographic doublet from the Sproul Observatory, which would be used to photograph the sky in positions where his latest calculations—continually shifting--indicated it was most likely to be found. Lowell had also upped the ante in Boston, overseeing the computations of four human computers. As soon as he had the latest positions, he wired them to direct C.O. Lampland in his search.

Lowell was always high strung, and the tension on Mars’ Hill during the period of this frantic search must at times have been unbearable. He began planning his usual biennial trip to Europe for that spring, but it was delayed a month, until May 1914, because of his wife Constance's needing surgery for an ulcer. The outbreak of the European war in August prompted his early return. (He would never cross the Atlantic again.) As soon as he was back in Boston, he began chasing up news of progress in the search for X, but there was nothing to report. Lampland had made little progress because of a long siege of Flagstaff's July monsoonal rains, and now it was Mrs. Lampland's turn for surgery for an ulcer. "I feel sadly, of course, that nothing has been reported about X," he confided to V.M. Slipher.[4] Sometime shortly thereafter, a discouraged Lowell, quietly and without fanfare, seems to have given up.

It was on October 17, 1914-—during a brief visit to Flagstaff—that he went to the telescope in full sartorial splendor to observe Venus by daylight—an iconic pose captured for all time by then-visiting Northwestern University astronomer Philip Fox. He also embarked upon yet another project. He wanted to establish, under the sponsorship of the American Academy of Arts and Sciences, a new medal, to be awarded to a deserving astronomer working on traditional problems in astronomy. Clarifying his intention to John Trowbridge, the president of the Academy, he wrote, "I beg to call your attention to the fact that [for this purpose] astronomer is used in its technical sense, and not including astrophysics which, of late years, owing to the effect that pictures have on people, has usurped to itself the lime-light to the exclusion of the deeper and more profound parts of astronomy proper."[5]

In January 1915 he presented to the same Academy a summary of his long and painstaking "X" calculations: the "Memoir on a Trans-Neptunian Planet," which became famous after the discovery of Pluto. Not only did it attract little attention at the meeting, but the Academy declined to publish it. An irritated Lowell had to publish it himself, at his own expense, the following September (as Lowell Observatory Memoir no. 1). To add insult to injury, his proposal to establish the medal also was rejected. He fumed to Trowbridge, without, apparently, sensing the irony of his position, about the "stagnation and old-fogyism" of the Academy, and accused its leaders of being "a set of men certainly not broad [of] view or judgment."[6] One can forgive him if he felt that the astronomical community was treating him as a pariah.

At this point, the search for Planet X disappears completely from the archival records. Though Lowell was never one to dwell—publicly at least—on his failures, the defeat must have bit him hard. According to his brother (and first biographer) Abbott Lawrence Lowell, the failure to find "X" was "the greatest disappointment of his life."

On to New—Old--Directions

The X search, in which Lowell had reanalyzed the validity of the calculations that had led to the discovery of Neptune, reprised one of the major themes of the work of his Harvard mentor Benjamin Peirce. After he gave up on X, he turned with a will to another of the themes Peirce had made his own: the structure and evolution of Saturn's system of rings and satellites.

Lowell's interest in Saturn went far back. While a Harvard student, he received as a gift from his mother, Richard A. Proctor's *Saturn and Its Satellites*. According to Proctor, the subject "gathered additional interest for its bearing on the speculations of Laplace," since it was "not altogether impossible that in the variations perceptibly proceeding in the Saturnian ring-system a key may one day be found to the law of development under which the solar system had reached its present condition."[7] Lowell gave his Harvard graduation dissertation on Laplace's nebular hypothesis, and in 1893, on his fourth and last visit to Japan with his 6-inch Clark refractor, he is observed Saturn from Tokyo.

At Flagstaff, Lowell's initial interest was in the inner planets—Mercury, Venus and, of course, especially Mars. Only after 1907 did he begin to devote an appreciable effort to the Giant Planets. Thus, in 1907, he verified delicate markings in the Equatorial Zone of Jupiter, which the English amateur astronomer Stanley Williams had first seen in the 1890s and referred to inauspiciously as "canals." (As an aside, there were also "barges" on Jupiter.) In 1907, another English astronomer, Scriven Bolton, observed them. He renamed them "wisps," and wrote to Lowell to confirm them.

Also in 1907, Lowell observed the edgewise rings of Saturn. Over the next few years, as he became increasingly immersed in the intricacies of celestial mechanics because of the "X" search, he devoted more time to Saturn, especially in 1915, when on March 21 the rings reached almost their maximum possible angle of tilt toward the Earth, $26^{o}56'.8$.

At the end of the 18th century, Laplace had supposed that the rings, in order to remain stable, must consist of a myriad of solid ringlets, each nested inside one another. For the first half of the 19th century, visual observers of the planet would report—in addition to the very conspicuous Cassini division--subdivisions of the rings, which seemed to be glimpses of the finer circlets of Laplacian conjecture. Charles W. Tuttle and Sidney Coolidge, volunteer observers of Harvard, saw these subdivisions especially in Ring B. Tuttle described it as “minutely subdivided into a great number of narrow rings …not unlike a series of waves.”

Just a few years later, in 1857, James Clerk-Maxwell of Cambridge University convincingly showed, mathematically, that solid ringlets would not remain stable, no matter how finely subdivided. Maxwell asserted, “The only system of rings which can exist is one composed of an indefinite number of unconnected particles revolving around the planet with different velocities according to their respective distances.” Then, in 1867, Indiana University astronomer Daniel Kirkwood—building on work done the year before in which he had shown that gaps in the asteroid belt corresponded with resonance positions with Jupiter--generalized the result by showing that in rings consisted of unconnected particles, as on the Maxwellian model, the orbits of particles at the ½ resonance with Mimas would be rendered unstable and swept clear. This would produce Cassini’s division, between rings A and B. In other places, it seemed that subtle shadings might be formed where Mimas and the other satellites of Saturn had thinned out but not totally removed ring particles. The quest for such ring subdivisions was on, and, as Saturn historian A.F.O’D. Alexander put it, the end of the nineteenth century saw an “outbreak of division finding.”

Percival Lowell seemed to be in a position to investigate the matter, definitively. His eye was well trained to the detection of fine linear markings from his years of recording not only the "canals" of Mars, but linear features on Mercury and Venus. Beginning in 1909, and continuing in 1913-14 as the rings were further opening up, he and assistant astronomer E. C. Slipher had found the B ring, "conspicuously striped amidst its shading, the dark curving lines of its plaided pattern being so definite as to permit of measurement."[8] In addition, his immersion in celestial mechanics—and concern with resonances in the orbits of planets—as he pursued the "X" search motivated him to look for a resonance solution to the ring sub-divisions he and Slipher had been noticing.

The Saturn ring investigation came to a climax in March 1915, when the ring system opened up to its greatest angle of tilt toward the Earth, $26^{o}56'.8$, since 1899. Ring subdivisions were numerous. Lowell's drawing shows about a dozen, nine in Ring B and three in Ring A. Some were conspicuous enough to lay the wire of the filar micrometer on, while others, more delicate, had to be measured off drawings. Lowell found the three principal subdivisions in the B ring to correspond with 3/7, 2/5, and 3/8 resonances with Mimas; the boundary between the C and B rings corresponded with a 1/3 resonance with Mimas. Indeed, a side by side comparison of the divisions in Saturn's rings purportedly due to Mimas with the gaps in the asteroid belt owing to Jupiter shows an uncanny resemblance, so that, as James Elliot and Richard Kerr have written:

> Percival Lowell had not only seen distinct "canals" on Mars, he also glimpsed dark patches and strips beneath the impenetrable clouds of Venus. As might be expected, Lowell found delicate details in the rings of Saturn, too; of course, most coincided with one resonance or another.[9]

Lowell, however, had another trick up his sleeve. He was working on a scheme of planetary evolution that involved the way planets start out homogenous and differentiate and become more heterogeneous before tending back toward the homogeneous again. He expected, therefore, that the interior of Saturn might have already reached the stage of being significantly differentiated, consisting of layers of different density rotating at different velocities. *Voila!* He found in his measures evidence that this was the case. The ring-system, he announced, in each and all of its parts lay slightly too far out as compared with the computed positions of the resonances. In other words, the divisions were too far out for their periods. Though most likely the theoretical expectation preceded the observational confirmation, Lowell presented it as if it had gone the other way around—

that he had first discovered the small discrepancy and then, in order to account for it, had mobilized an impressive array of the French celestial mechanics expert Félix Tisserand's formulae to show that everything would be set right if, beneath the observable oblate spheroid of Saturn, a somewhat complicated internal structure were assumed. His conclusion was that Saturn consisted internally of "concentric confocal spheroids of differing densities increasing inward," with the planet "rotating in layers with different velocities, the inside ones moving faster."[10] He put it even more colorfully. Saturn was like "an onion in partitive motion."[11]

Lowell seems to have been over the moon with this result. "The recent light thrown on the internal constitution of Saturn, brought out by measures on the divisions of the ring, shows the potency of mathematics," he wrote. "Like the Röentgen Rays it renders visible what the unaided eye could never see."[12] Despite invoking Röentgen, he could just as easily have recalled the way Le Verrier had revealed Neptune from his analysis of the observations of Uranus. The X search had failed—it had been the greatest disappointment of his life. Now he could claim vindication in the light he had thrown on the inner parts of Saturn.

Unfortunately, the Memoir on Saturn's rings seems to have attracted about as little attention as his previous memoir on "X." It was, for that matter, not quite the Q.E.D. Lowell had imagined. One need only compare his 1915 drawing with a modern CCD image to see that something is lacking in the proportions and that the divisions do not line up as they should. He was correct in supposing—at Kirkwood had first grasped—that Mimas, a relatively large satellite lying close to the rings, leaves its mark on them. It is responsible for clearing material from the Cassini Division. (Specifically, particles in the Huygens Gap at the inner edge of the Cassini Division are in 2:1 resonance with Mimas.) Also, the boundary between the C and B rings is in a 3:1 resonance with Mimas. However, this is the extent of the agreement with Lowell's 1915 results. The other ring structures have a more complicated origin. And nor, we need hardly add, does Saturn rotate, as Lowell supposed, like an "onion in partitive motion."

If Lowell saw a real mountain peak and not a mere mirage, then it was a peak seen through mists and haze.[13]

The Final Year

The year 1916 was issued into Flagstaff by a huge snowstorm just before the New Year—the snow heaped up 50 inches as measured at V.M. Slipher's residence. Lowell was on Mars Hill at the time. Most years, unless there were a special event like a Mars opposition, he would have been in Boston at the time; but as he drew toward the end of his life, he had come to regard Flagstaff as his first home. He had by now established a "veritable colony" there, with three observing domes, four astronomers' houses (including his sprawling 18-room "Baronial Mansion") and the new administration building and library he and his interior-decorator wife Constance were busy planning together (the first phase of what is now known as the "Slipher Building"). There was also a barn, and a cow. The grandeur of this colony was, as he told his old Harvard friend Frederic Stimson, appropriate to his role of "envoy of Mars to Earth." His staff was unquestioningly loyal—though sometimes apt to compete among themselves, like attention-seeking siblings, for priority of place in his estimation. Lampland, a stoic Swede born in rural Minnesota, was a hardworking polymath who had no desire for an administrative role; generally he was polite and reserved, though he occasionally burst into invective—in Swedish—in his diary, criticizing the Slipher brothers, who never seemed quite to put in the long and unstinting hours that he did. Nor was the competition limited to the male side. His wife Constance seems to have resented Percival's secretary Wrexie, who even after Constance became Mrs. Lowell continued to have a bedroom of her own in the

Baronial Mansion. Percival, understandably given his irregular hours, also had his own bedroom. He was the eldest son, his mother's spoiled favorite, and the center of attention wherever he went. Though capable of thoughtful gestures toward his staff, he was, by nature, formal and aloof, and seems to have been blissfully unaware of the tensions that the three-bedroom arrangement might occasion. Nor did he, apparently, draw any conclusions from the preponderance of ulcers on the hill, especially among the women—as noted above, both Mrs. Lampland and Mrs. Lowell suffered from them. It would seem heartless—but was hardly surprising--that the first order of business Constance would see to on the occasion of her husband's death was the dismissal of Wrexie from the staff. She was sent unceremoniously back East. About one thing Constance was constant: she neither forgot nor forgave.

For Lowell, work was always first. He was an extremely competitive individual, obsessive, driven, perfectionistic, a workaholic. But he had his recreations too. After Lowell's death, Constance reminded Lampland:

"You remember he was an enthusiastic gardener and always had a garden here at the Observatory. He had great success with many flowers and I recall especially fine displays of hollyhocks, zinnias, and a considerable variety of bulbs. Gourds, squashes and pumpkins were also great favorites. You will remember one year the especially fine collection of gourds and that bumper crop of huge pumpkins, many prize specimens being sugar fed. At times Dr. Lowell could be seen in the short intervals he took for outdoor recreation, busy with his little camel's hair brush pollenizing some of the flowers… Then the frequent, almost daily, walks on the mesa. Certainly he knew all the surrounding country better than anyone here. He would refer to the different places such as Wolf Canyon, Amphitheatre Canyon, Indian Paint Brush Ridge, Holly Ravine, Muellein Patch, etc… Trees were an endless source of interest to him … Cedars or junipers seemed to be favorite subjects for study, though other varieties or kinds were not overlooked….

"At every season of the year he always found something in wild life to fascinate him, and you will remember his observations and notes of butterflies, birds, squirrels, rabbits, coyotes, deer and other inhabitants of the mesa. These friends must never be disturbed or harmed. But it was permissible to hunt with a camera! ... The Observatory grounds were a sanctuary for wild life."[14]

Though in most other things he was a dyed-in-the-wool conservative, there was one sterling exception: in the area of conservation he was well ahead of most of his contemporaries. In his far-sighted realization of the fragility of the Arizona desert landscape, to which his views of Mars as a desert planet added piquancy, he resembled John Wesley Powell, and while he shared Theodore Roosevelt's passion for preservation he did not share the compulsive big-game hunter's insatiable blood lust.

Constance continues her personal recollections of the Great Man:

> As you know, it is not easy for the observing astronomer to lead a strictly regular life in that the hours at the telescope often make it necessary to use, for the much needed rest, part of the daily hours usually given to work. His intense occupation with his research problems, however, was broken with great regularity for short intervals before lunch and dinner. These times of recreation were given to walks on the mesa or work in the garden. When night came, if he was not occupied at the telescope, he was generally to be found in his den. It was not always possible for him to lay aside his research problems at this time of day, but he did have some wholesome views on the necessity of recreation and a necessary amount of leisure to prevent a person from falling into the habit of the 'grind.' To those who came to his den the picture of some difficult technical work near his chair, such as Tisserand's *Mécanique céleste*, will be recalled, though he might at the time be occupied with reading of a lighter character. And

occasionally during the evening he might be seen consulting certain difficult parts upon which he was pondering…”[15]

Tisserand’s monumental four-volume work had been, of course, relied on extensively during the search for Planet X. However, Constance’s account could have been written about his activities in 1916, for he was still consulting Tisserand for his investigations of the structure of Saturn’s rings and would be for those into the the motions of the Galilean satellites (his major preoccupation, as we shall see, in the latter part of the year).

Saturn, Mars, and the Genesis of Planets

Astronomically speaking, the beginning of 1916 was devoted to ongoing measures of the divisions in Saturn’s rings. Lowell preferred to keep “banker’s hours” at the telescope, usually cutting out at about 10 pm. The hours from then until midnight—or beyond—were taken up by the young and enthusiastic E.C. Slipher. But Mars also was looming again. It came to one of its biennial oppositions on February 9. It would be Percival Lowell’s last. As an aphelic opposition, the north pole was tilted toward the Earth, but Mars was never very close—though as Lowell’s own observing logbooks testify, the curious planet did not always reveal the most when it was closest. Distance actually seemed to encourage the appearance of the spiderwebs, and in any case, the skies during February 1916 were brilliantly clear, with the seeing often exceptional—Lowell noted nights of 8 or 9 on a scale of 1 to 10. He was joined at the 24" Clark not only by Slipher but by a volunteer observer and keen student of planet, George Hall Hamilton, who had left a position as professor of astronomy at Bellevue College in Nebraska in order to observe with Lowell. (He also would later marry Lowell's head computer on the X search, Elizabeth Williams; he died in 1936.)

Lowell was always good copy, and his observing reports, especially about Mars, were eagerly picked up by newspapers and journals (the *Astrophysical Journal* remaining an exception; it had long since refused his contributions). In addition to regular Bulletins from the Lowell Observatory, he issued observing circulars, such as one that went out on March 30, 1916. The *Journal of the Royal Astronomical Society of Canada* ran it under the heading "The Latest News from Mars":

> A curious set of features, secondary to the main canal network, have become apparent on Mars. Within some of the polygons made by the intersections of the larger canals a tiny dot has been descried at this observatory, joined to a corner and to the sides of the polygon by lines so slender they usually appear as a string of minute beads. The effect

is of a centrally woven web, spun within the borders of the polygon, of a more minute order of tenuity than the polygon itself. Elysium was the first example of this phenomenon with the Fons Immortalis and five connecting spokes.[16]

{His drawings of March 14 and 16, 1916 should be reproduced here}

Perhaps unsurprisingly, both Hamilton and Slipher drew Mars much as Lowell himself did, and until the end of their lives defended his views about the planet. Hamilton, for instance, would write in 1920:

> It is seen … that a globe like Mars might, if inhabited, need an irrigation system of vast proportions to support life, and such a system has been shown feasible, providing that beings who inhabited it were sufficiently advanced to undertake such a project…. This is seemingly the case; for we have every reason to believe that what we see on the surface of Mars shows definite proofs of artificiality.[17]

As Mars and Saturn moved into less opportune positions for observations, Lowell revived a project that had preoccupied him, in one way or another, since his days as a Harvard student, when he had given a graduation dissertation on the nebular hypothesis of Laplace and had first became an enthusiastic devotee of the English philosopher Herbert Spencer. To the end of his life he remained, at heart, a Spencerian.

Spencer was an evolutionist—it was he, not Darwin, who coined the phrase "survival of the fittest." He pursued an evolutionary "System of Synthetic Philosophy" through ten massive volumes, on topics that included biology, psychology, sociology and morality. His basic formula was that "evolution is definable as a change from an incoherent homogeneity to a coherent heterogeneity accompanying the dissipation of motion and integration of matter." As a consequence of the instability of the homogeneous, matter proceeded inexorably from its most simple and homogeneous manifestations (*e.g.*, Laplacian nebulae) to its most heterogeneous and complex (*e.g.*, living organisms, the human mind). Lowell adopted this appealingly intuitive ready-made scheme during his Japanese phase (1882-1893) by contrasting the advanced and individualistic societies of the West with the primitive and impersonal ones of the East, and then, beginning with *Mars* (1895), and continuing on through *Mars as the Abode of Life* (1908) and the *Evolution of Worlds* (1909), based on series of lectures at the Lowell Institute and MIT, respectively, he applied the same general scheme to the evolution of the planets, following the worlds of the Solar System from their birth in the swaddling clothes of the solar nebula through the exuberant restless stage of youth on to old age and utter inanition.

The latter concern he described as "planetology." In an early draft of *Mars and Its Canals* (1906), he described the bones he was attempting to put flesh on:

> Two lines of the long chain of Evolution which leads from star to student have been considered by man: the Meteoric and the Nebular Hypothesis at the far end of it and the Genesis of Species at the near one.
>
> The first deals with the evolution of a nebula into a solar system; the second with the orderly development of organic life. Between the two lies a part of the road not as yet generally surveyed: the career of a cosmic body from a molten mass to a cold inert one, the life-history of what we call a world. Planeteology we may style this inquiry into a missing link in the cosmic evolutionary process….[18]

Lowell hews to the same basic plan in "The Genesis of Planets," written in the first part of 1916. It is likely, had Lowell lived, that he would have developed it into a full-fledged book. We see from his observing log books that he was measuring the subdivisions in Saturn's rings until April 9, 1916, examining the asteroid Vesta on April 18, and making his last observation of Mars—ever—on April 21. Lampland's diary records that on April 23 Lowell and Mrs. Lowell left for Chicago on the Limited.

They were due in Toronto in four days, where Lowell was to present "Genesis." His lecture was scheduled to be given on Thursday, April 27, 1916, at 8 o'clock, in the auditorium of the Central Technical School at Harboard and Lippincott Streets, during a joint meeting of the Royal Astronomical Society of Canada and the the Ontario Educational Association. The public was warned in advance that a "large attendance is expected." Lowell, who was to be inaugurated as an Honorary Fellow of the Royal Astronomical Society of Canada, was identified as the Director of the Lowell Observatory, Flagstaff, Arizona:

> The Lowell Observatory was established over twenty years ago, chiefly for the study of the planets, and the investigations made there have led to the general recognition of Dr. Lowell as our greatest authority on Mars. His researches on the planets have given him a high place in the astronomical world while his books on Mars have had a very wide general circulation. Recently Dr. Lowell has made notable discoveries regarding Saturn and Uranus, and the lecture, which is of a non-technical nature, will include an account of these.

Lowell would certainly have been a hot ticket in any case, but no doubt he also provided a welcome escape, with his "news from Mars," from the usual—and uniformly grim--news from the Western Front. Canada, unlike the United States, was already in the war, and its troops were taking heavy casualties on the Somme. Even the staid *Journal of the Royal Astronomical Society of Canada* felt a need to help with the recruitment effort, and the previous November published a poem, "The Bugle," by the Toronto poet and physician Albert D. Watson that ends with a summons:

> The troopship in the harbor rideth ready,
> The tumult thickens. Hear the scornful word.
> The foe is mocking! Lift the anchor –steady.
> High tide. The ship's away! Are you aboard?[19]

The lecture was not quite of a non-technical nature, since it included mathematical formulae. Lowell began with the origin of the Solar System, which he, and most of his contemporaries, still explained on the basis of the Chamberlin-Moulton theory (Moulton being the same person who had compared Lowell to the mysterious watcher of the night of Poe's Raven). The beginning, he says, was catastrophic. "Two suns met and we were the outcome."[20] The collision of the large heated body, which was then the sun, with another of its kind produced a dismembered body and from the "as yet ungathered remants of the shock" the system of planets, including the Earth, formed. In previous writings--including *The Evolution of Worlds* of 1909 --Lowell had confidently identified the spiral nebulae with these

Solar Systems in formation, but in an unforgivably brief comment, given both its significance to the history of astronomy and to the fact that it had been made by V.M.Slipher, an assistant at his own observatory, he noted, simply, that “the spiral nebulae indicate themselves to be galaxies.”[21] Behind that simple statement lay a great deal that remained unexpressed, including the fact that Slipher had been put to obtaining spectrographs of the spiral nebulae in the first place as Lowell searched for confirmation of the forming Solar System theory; on finding something else, he began to lay the foundation of the concept of the expanding universe. With only a brief nod to the new recognition, Lowell hastens on, relying on what he calls “pure reasoning” to disclose the remote antecdents of the Earth’s history. The galaxies disappear from the remainder of the lecture.

What Lowell calls the first stage in a planet’s history is marked by the way that each planet, as it emerges from the disk of material left by the original catastrophe, acquires spin. The second stage involves the condensing of the matter brought together into an oblate spheroid. As the matter condenses, because of the conservation of angular momentum, the spin also increases in the same way a stone attached to a string goes faster as the string is wound up. The increase in centrifugal force increases the oblateness of the spheroid. As the planet becomes non-homogeneous, the internal layers rotate faster and, says Lowell, their spheroidal shape is accentuated.

Heat is generated in the process of condensation. Indeed, so great are the planetary masses that this results in making them molten. The heat evolved expands through the body and is radiated away at the surface, producing cooling. The third stage is reached when the body has so far cooled as to become liquid or solid throughout. This is a significant transition in the evolution of the planet, and marks the beginning of the end:

> Up to now the planet's spin has been increasing. From this point on its rotational speed diminishes owing to the tidal pull upon its mass by the sun [sic.]. A tidal pull has acted upon it from its birth, but has hitherto been more than counteracted by the increased spin due to its shrinkage.
>
> The end is planetary death, when tidal friction has done its work and caused the body to turn the same side in perpetuity to the Sun. Mercury and Venus have reached this, the fourth stage in planetary evolution and are now white planet corpses, circling unchanging, except for libration, around the Sun.[22]

Summarizing the main points, he says:

> Thus the three stages of a planet's life-history are characterized by different degrees of rotational speed, oblateness and matter-distribution. In the course of the three the spin starts at a certain amount, rises to a maximum and sinks to a minimum at the end. The body's contour does the same, beginning as an oblate spheroid, increasing at first in oblateness, and afterwards diminishing to practical rotundity. Thirdly, the body originates homogeneous, becomes heterogeneous and thence grows more homogeneous again to a certain limit, beyond which it cannot pass.[23]

He illustrates his scheme by pointing to Uranus as an example of the first stage, Saturn of the second, and Mars of the third. With regard to Uranus, a planet that had yielded very little to telescopic inquiry, he produces some genuinely new results. With his spectrograph, V.M. Slipher in 1910 measured the rotation period, and found it to be 10 ¾ hours. Lowell's measures of oblateness showed it to be almost as thickened in the middle as Saturn (its oblateness, from measures with the Clark refractor, was 1/11.5), and from the mass and density he was able to calculate that internally it was more homogeneous than either Jupiter and Saturn. Thus, it was younger than either of them. Saturn's internal differentiation and inhomogeneity, deduced from the divisions in the rings, were evidence that it had reached the second stage. Finally, as he had been writing, and repeating in much the same terms, ever since his first book *Mars* in 1895, Mars was an old world, decrepit, struggling, and on the threshold of planetary death.

He ended his lecture to the Royal Astronomical Society of Canada and the Ontario Educational Association, in which he had shown how gratifyingly hand-in-hand theory and observation had traveled together in the study of the Solar System, by insisting:

> Without the precision afforded by the best air the recent discoveries about Uranus and Saturn would have been impossible. It was to get just such first-hand data that the observatory at Flagstaff was founded. For only the best of materials in science can stand the test of time.[24]

Though his Canadian audience was no doubt on its feet and roaring its applause, none of these results has, in fact, stood the test of time. (In the case of Uranus, the rotation period adopted was off by several hours, and instead of an oblateness of 1/11.5, the oblateness, based on spacecraft measures, is much less at 1/49. So all his calculations used erroneous data.)

Above all, the Spencerian framework Lowell used had, by the time he spoke, already become passé. His biographer David Strauss has pointed out that its assumption "that current conditions were the predictable outcome of a single principle working gradually and inevitably from past to present" was increasingly rejected by a new generation of intellectuals because it left no room for "the cataclysm, chance events, or choice … as essential components of the universe."[25] Quaint as Spencer's formulation of evolution as proceeding from homogeneity to heterogeneity through the dissipation of motion may now seem, it did capture, perhaps, as an image in a glass darkly, something of recent (highly mathematical) ideas about chaos theory, and the "intrinsically random" appearance of ordered structures in a system as the consequence of the development of some instability in the system.   Though no one talks any longer of the movement from homogeneity to heterogeneity, Spencer's intuition—and, in astronomy, Lowell's--captured at least the trend of much more sophisticated concepts. For instance, according to Russian astronomers A.M. Fridman and N.N. Gorkavyi,

> In an unstable medium structures such as regular bands, spots, circles, spirals, vortices, solitons, or modons will spontaneously appear…. There are … many examples of self-organisation in the Universe: solar granulation, sand dunes on Mars, vortex formations such as the [Great] Red Spot on Jupiter, spirals in galaxies, and the structure of planetary

rings. Finally, the stars themselves, star clusters, galaxies, and their associations are examples of the organisation of matter which initially was quasi-uniformly distributed.[26]

The Great Northwestern Lecture Tour

It may be pushing things too far, but the preoccupation with celestial mechanics that marked the twilight of Lowell's career seems to reflect a basic feature of his personality—a recalibration back to an earlier set point. He seems to have lacked what the poet John Keats once famously referred to as "Negative Capability, that is when man is capable of being in uncertainties, Mysteries, doubts, without any irritable reaching after fact & reason."[27] He wanted things black and white, clearly defined—no ambiguity. This appears even in his drawings of the planets, where everything—even the notoriously diffuse and nebulous markings on Venus—was depicted as hard, sharp, clearly bounded, well defined. There is nothing of nuance, nothing of shades of grey. Of course, this was the appeal of celestial mechanics as well. Mathematics seemed to offer the promise (in the end disappointed) of a definite solution. Probably his hankering after definiteness and certainty had something to do with the deep-seated Puritanism of his New England culture, but some of it also may have been owing to an obsessive-compulsive personality. He would not tolerate disorder, unpunctuality, delay. He tried to rebel, but in the end these were the categories that formed his thought. There is an analogy with his sister Amy's poetry. She once described the aspiration of her imagist poems; they should be "Hard and clear, never blurred or indefinite."[28] Like mathematics, or Percival's drawings of the planets.

The doubts about his work, which in some cases passed into ridicule, took a toll on him. In his last year, Percival Lowell was not a happy man. Paralleling his brother's comment about the failed "X" search, Lowell's old friend Frederic Stimson would write after his death, "Mars went back on him and was a disappointment."[29] But he always put on a brave—even arrogant—face to the world, and never gave any hint that he thought he would end up on the losing side. Though many of his professional peers might be unimaginative hidebound old fogies, the minds of youth were still open and capable of forming new impressions. It must be admitted that this turn to youth was noble; but much of what he had to say partook somewhat of sour grapes.

He left Boston on September 27 on an ambitious—and tiring--lecture tour of the Pacific Northwest and West Coast. His itinerary included the State College of Washington in Pullman, the University of Washington in

Seattle, Reed College in Portland, the Agricultural College in Corvallis, the University of Oregon in Eugene, and Leland Stanford Junior University and the University of California in San Francisco. In each venue, the audiences were overflowing. The subjects of his lectures were "Mars—Forecasts and Fulfillments," "Great Discoveries and Their Reception," and "The Far Horizon of Science." His standard refrain concerned the resistance of astronomical conservatives to new ideas (such as the idea of life on Mars). The road to discovery was not an easy one, he warned the assembled youth:

> There is to add to its forbiddingness no warm compensating reception at its end, except in one's own glow of attainment. For progress is first obstructed by the reticence of nature and then opposed by the denunciation of man… A really new idea is a foundling without friends. Indeed a doorstep acquisition is welcome compared with the gift of a brand new upsetting thought. The undesired outsider is ignored, pooh-poohed, denounced, or all three according to circumstances. A generation or more is needed to secure it a hearing and more time still before its worth is recognized.[30]

Because of the deep-dyed conservatism of the astronomical establishment, the student would likely not be taught the newer things of science until they had become history:

> Some people seem to think that recently discovered facts are too homeopathic for youth, and that such ideas must not be given to youthful students until they are so old that they are nearly worn out. But I believe in giving young people the newest things which can be found in no other place.[31]

Of course, his ideas about Mars were of greatest interest. Though they were, in Lowell's view, among the resisted "new ideas," in his mind, at least, they had long since set. "Our observations have convinced us without a doubt that the lines on Mars which have caused so much discussion, are canals," he said. "There is some form of intelligence on Mars. I do not mean human beings, but some intellect capable of accomplishing these feats."[32] As opposed to this matter-of-fact statement, he was more than capable of working up a battening of beautiful prose, as in the following passage which seems almost to echo John Van Dyke's *The Desert,* though it must have been largely drawn from his experience of the desert landscapes around Flagstaff:

… Our terra firma gives to our globe its sense of home; partly for its very antithesis to the undomiciliate sea… To lack a contrast is to be sensible of a loss. On Mars we should miss the ocean….

Such sameness of surface is deepened by the dead level of the land. As there are no oceans, so are there no mountains on Mars. The plainness of its features is unrelieved by piquancy of profile. Plateaus are the height of its attainments: something resembling probably the mesas of our southwestern deserts….

To those who really commune with nature there is grandeur in this uniformity. It is the grandeur of vast expanse, bare of interposed detail to detract from its own unique impression, or to bar vision from its would-be range. The horizon may in truth be nearer, yet it seems more far. We have it in our deserts, whose very nakedness adds to their sublimity. Such accentuation of solitude is typical of Mars. For Mars is one vast desert relieved only here and there by tracts of vegetation. Our deserts grow in grandeur as one sees them more; so as one contemplates that desert world across the void of space its impressiveness increases. Distance robs it of its dread and in its opalescent sheen we see its beauty unmarred by sense of what its pitilessness represents.[33]

The train finally pulled into Flagstaff on October 19, and without allowing himself any time to rest or acclimatize to the altitude, he threw himself into a heavy schedule of work. His first priority was the continuation of a series of observations begun the previous fall, in which he had often been joined by E.C. Slipher. This involved taking micrometer measures of the positions of the Galilean satellites of Jupiter but also of the fifth, Amalthea, discovered by E. E. Barnard in September 1892. Even with the full aperture of the 24-inch Clark, Amalthea was only disclosed from out the glare of the giant planet by means of an eyepiece occulting bar. The project sounds pedestrian, but it was not mere stamp-collecting. He was hoping (apparently) to show that, like Saturn, Jupiter had a highly differentiated interior, and might even be like the ringed planet, "rotating like an onion in partitive motion." Little Amalthea, close to the giant planet's oblate sphere, would be a singularly good probe of any gravitational anomalies such as those that (he thought) he had found from his scrutiny of the positions of the subdivisions of Saturn's rings. The first theory describing Amalthea's motion, taking into account first-order secular perturbations due to the oblateness of Jupiter for an equatorial elliptical orbit, had been published, in fact, within a year of Barnard's discovery by Tisserand.[34] By the time Lowell got interested, an empirical model of a precessing ellipse (frequently reduced to a circular orbit) had been adopted, using orbital elements determined by Hermann Struve of the Pulkova Observatory, but still, the motion was far from satisfactorily determined. (A solution looking at the influence of factors other than Jupiter's potential, such as perturbations by the Galilean satellites, was not forthcoming until 80 years after Lowell's death.[35] Under the circumstances, Lowell's investigation might be considered, like his investigation of Saturn's rings, singularly premature, and it is quite likely he would have been able to torture from his data any result he wished.)

Lowell made his first observations of Amalthea—of an eastern elongation—on the evening of the same day he had returned from the grand lecture tour. He was fortunate—or unfortunate—in having a continuous streak of clear weather for the next several weeks, and measures of Amalthea and the Galileans were taken by him or Slipher or both on October 19, 20, 21, 25, 26, 27, 28, 30, 31, November 1, 2, 3, 4, 6, 9 and 10. (On the nights of November 4, 6, and 9, Slipher observed alone.) It is worth bearing in mind that at 7,000 feet altitude, October and November nights can be very cold. It is certain that Lowell did not dress for the telescope as he had done when posing for the observing Venus by daylight portrait taken in October two years before.

During the day of November 11, Lowell received a package from Boston, sent by his youngest sister, Amy, who had never attended college because the family did not consider it proper for a woman to do so, but had acquired a taste for literature (and, from her far-traveling and much-admired older brother, the Far East). In 1916 she was ensconsced in the Sevenels mansion in Brookline, which she had purchased from her siblings after her father's death. Massively overweight because of a glandular problem, a close companion (and rumored lesbian) living with the actress Ada Dwyer Russell, and constantly smoking cigars (again, like her brother), she was rapidly achieving fame as a poet. The package contained her latest (third) volume of poetry, *Men, Women, and Ghosts*, which opens with what would become her most famous poem, "Patterns." Percival wrote a note of appreciation for the "visitor":

> Thank you for the thought of the thing, the thing being thought, well paged, and attended, that walked into my eyry in the remote, and I then introduced the welcome visit to Constance and she read to me the tale of the lone farmer's wife as I sat receptive of the comfort of my wood fires. It always pleases me to think how far one's printed thought travels—so may it to you whose child has entered where you never have.[36]

That night he made the short walk from the Baronial Mansion to the Clark, where Slipher was already observing. At a few minutes before 9 pm, with a watch that was, he noted, 2 seconds slow, he recorded the reappearance of a satellite from eclipse:

November 11, 1916

P.L.

8^h	52^m	10	Eclipse – Reappearance
	54	10	½
	56	10	Last Contact
	56	50	Certainly now

Those were the last observations Percival Lowell ever made. (They were long lost, but were rediscovered by Michael Kitt in a cigar box, where they had been carefully placed by E.C. Slipher, when the latter was clearing piles in the Slipher building to identify material worth preserving in the new Putnam Collection Center.)

The next morning, a Sunday, a cerebral aneurysm exploded in his brain. (It was another family trait; his sister Amy, at age 52, and his cousin Guy, the first Sole Trustee of the observatory, at 57, would also die of cerebral hemorrhages). The doctor was called, but Lowell never regained consciousness. He passed away at 10 pm that evening. He had reached the age of 61 years, 5 months.

(That same fateful day, in France, the last action on the Somme of 1916 was getting underway, as General Hubert Gough ordered the II Corps to drive forward towards St Pierre Divion and thereby clear the south bank of the river Ancre, while the V corps was to attack along the front from Serre to Beacourt north of the Ancre where it was to establish a common front line with the II Corps. At almost the exact moment that Percival Lowell was expiring on the green couch on Mars Hill, in France there was a "'Bang! Bang! Bang!'" and "all of a sudden, behind us," wrote one of the soldiers involved, "the whole sky was red.")[37]

V.M. Slipher would take charge of the direction of the observatory—to C.O. Lampland's considerable chagrin. Lampland thought he was the better source. The two women in Percival's life would be left to mourn him the rest of their lives. Wrexie would later write a book of fond reminiscences, *Percival Lowell: An Afterglow*, whose epigraph reads:

Preambient light—
Waning, lingers long
Ere lost within.
Just, kind, masterful:

Life’s sweet constant,

Farewell.[38]

By then she was long since gone from Mars Hill. Indeed, now that Percival was dead, Constance had the upper hand, and one of her first orders of business, along with ordering a coffin for her late husband (based on her information that he was 6’0” tall) was to dismiss Wrexie; within hours of Percival’s death, and with a promptness that suggested premeditation, Constance ordered her rival off the premises. Constance donned black clothes, a black hat and a black veil or shawl, which she would continue to wear for the rest of her life, and made sure the bedroom in which her husband had died was carefully preserved just as it was—a chalk inscription on the wall recording that “Percival Lowell’s earthly existence terminated in this chamber upon the green couch.” It was rumored that in later years she occasionally held séances in the attempt to summon him from the Beyond, though the poltergeist-like nocturnal knocking about the Baronial Mansion was apparently owing to her habit of shifting her own presence restlessly from bedroom to bedroom. Her eccentricities concealed a dark, grasping nature; and she proceeded to engage in a series of legal maneuvers to retain control of his estate that “showed a seldom equaled record of sustained litigation,” at any rate this side of Dickens’s *Bleak House*. By the time the litigation was finally settled and the lawyers were paid off in December 1925, the net value of Percival's once-substantial estate had been cut in half, and his observatory, carrying on under the direction of Slipher was famously broke. During those years Percival's hardworking staff struggled in want and uncertainty. V.M., though still serving in the role of director as he would until he finally retired in 1954, devoted much more of his time to his real estate and business interests than to astronomy, and eventually became a very wealthy man. In the end, the observatory's future was secured only by the timely appearance in February 1930 of a moving speck in trans-Neptunian space discovered on a pair of plates exposed by another modest and hardworking Midwestern farm boy, Clyde Tombaugh, during the observatory's continuation of the long-suspended search for Planet X. This, of course, was Pluto, the planet that Constance wanted to name "Percival."

After Wrexie moved back east, she lost money in the stock market crash of 1929, and spent her last years in the state hospital in Medford, Massachusetts. Constance lived on until her eighties in their house at 11 West Cedar (as well as 102-104 Mount Vernon Street around the corner) on Beacon Hill, appearing, says William Lowell Putnam III, like a "benign witch," and living in "opulent squalor" as her relatives by marriage kept a cool distance from her and those by blood hovered, she said, “like buzzards … waiting for me to die.”[39] The Baronial Mansion went from rambling to shambolic, and was torn down as a fire hazard in the late 1950s.

A hundred years after Percival Lowell’s death, despite Constance having done her worse, his observatory still lives.

NOTES

[1] P. Lowell, "Great Discoveries, and Their Reception," lecture text, ca. Aug. 1916, Lowell Observatory archives.
[2] ibid.
[3] ibid.
[4] P. Lowell to V.M. Slipher, Aug. 11, 1914; Lowell Observatory archives.
[5] P. Lowell to J. Trowbridge, Dec. 9, 1914; Lowell Observatory archives.
[6] P. Lowell to E. B. Wilson, Feb. 4, 1915; LOA.
[7] R. A. Proctor, *Saturn and Its System*. London, Chatto & Windus, 2nd ed., 1882, pp. v-vi.
[8] P. Lowell, "Memoir on Saturn's Rings," *Memoirs of the Lowell Observatory*, vol. 1, no. 2 (1915), p. 3.
[9] James Elliot and Richard Kerr, *Rings: discoveries from Galileo to Voyager*. Cambridge, Mass.: MIT Press, 1984, p. 32.
[10] P. Lowell, "Memoir on Saturn's Rings," p. 22.
[11] P. Lowell, "The Genesis of Planets," *Journal of the Royal Astronomical Society of Canada*, 10, 6 (July-August 1916), 281-293:290. The text was of an address Lowell gave in Toronto to the Royal Astronomical Society of Canada on April 27, 1916.
[12] P. Lowell, "Great Discoveries."
[13] According to our current understanding of the rings, there are several other features that involve directly or indirectly resonances with Mimas. The bright inner edge of the tenuous G ring (unknown in Lowell's time) contains the half-kilometer moonlet Aegaeon, which is held in place by a 7:6 co-rotation eccentricity with Mimas. (The ring's inner edge is about 15,000 kilometers inside Mimas's orbit). Mimas is in a 2:1 mean-motion resonance with the larger moon Tethys, and in a 2:3 resonance with the shepherd moonlet Pandora, which helps herd in the particles making up the F ring. In the A ring, the encke and Keeler gaps are cleared by 1:1 resonances with the embedded moonlets Pan and Daphnis, while the A Ring's outer edge is maintained by a destabilizing 7:6 resonance with the small moon Janus.

It goes without saying that the interior of Saturn does not, in fact, rotate "like an onion in partitive motion." As with Jupiter, its atmosphere has a diffferent rotation period than its core. The latter is deduced on the basis of periodic radio outbursts emanating from the rotating core's magnetic field, and must represent the bulk rotation. A recent analysis of Cassini data, in which measurements of Saturn's oblateness were relied upon instead of the radio outbursts, seemed to indicate the bulk rotation period was 10 hours, 33 minutes. This rotation period implied that the latitudinal wind structure was more symmetric than had previously been thought, containing both easterly and westerly jets, as on Jupiter.
[14] Constance Lowell to C.O. Lampland; quoted in A. L. Lowell, *Biography of Percival Lowell*, pp. 153-154.
[15] Constance Lowell to C.O. Lampland, in Lowell, *Biography of Percival Lowell*, p. 155.
[16] [Unsigned} "The Latest News from Mars," *Journal of the Royal Astronomical Society of Canada*, vol. X, no. 5 (May-June 1916), 265-266.
[17] G. H. Hamilton, "Mars Our Neighbor in Space," *Popular Astronomy*, Vol. XXVIII, No. 3 (March 1920), p137-140.
[18] P. Lowell, early draft of preface of *Mars and Its Canals*, 1905; Lowell Observatory archives.
[19] Albert D. Watson, "The Bugle," *Journal of the Royal Astronomical Society of Canada*, Vol. X, No. 2 (February 1916), p. 41.
[20] P. Lowell, "The Genesis of Planets," p. 281.
[21] ibid.
[22] ibid., pp. 283-284.
[23] ibid., p. 284.
[24] inid., p. 293.
[25] David Strauss, Percival Lowell, p. 267. Among the thinkers who saw a need to include chance or choice in their system—and who rebelled against the rigid determinism of Spencer's system—was Charles Sanders Peirce, a founder of "pragmaticism." Peirce was the son of Lowell's Harvard math teacher, Benjamin Peirce.

[26] A.M. Fridman and N. N. Gorkavyi, *Physics of Planetary Rings: Celestial Mechanics of Continuous Media*, trans. D. ter Haar. Heidelberg: Springer, 1999, pp. 285-286.
[27] John Keats to George and Thomas Keats, 21, 27(?) December 1817.
[28] Hattie Bundy, sister of Bill and Mac Bundy, once said of her mother, Katharine Lawrence Putnam Bundy, Percival's niece, "Mother's sense of righteousness was very deep… How well I remember our fights over the dining room table…. For her, things were black and white. It's an outlook that descends directly from the Puritans and we all have it." Quoted in Kai Bird, *Color of Truth*, p. 36.
[29] F. Stimson to B. Wendell, undated; Houghton Library of Harvard University.
[30] P. Lowell, "Great Discoveries and Their Reception," lecture text ca. August 1916; Lowell Observatory archives.
[31] P. Lowell, "The Far Horizon of Science," *The Stanford Daily*, October 18, 1916.
[32] ibid.
[33] P. Lowell, "Mars and the Earth," lecture text ca. August 1916; Lowell Observatory archives.
[34] F. Tisserand, *C.R. Acad. Sci. Paris*, 117 (1893), 1024.
[35] S. Brieter, "The theory of motion of JV Amalthea. I. Analytical Solution. *Astronomy and Astrophysics* 314 (1996), 966-976.
[36] P. Lowell to Amy Lowell, November 11, 1916; Houghton Library of Harvard University. The poem that Constance read to Percival by the wood fire was probably "Pickthorn Manor."
[37] Peter Hart, *The Somme: the darkest hour on the Western Front* (New York: Pegasus Books, 2008), p. 510.
[38] Note: Preambient light = Percival Lowell
Waning, lingers long = Wrexie Louise Leonard
Ere lost within = Elizabeth Langdon Williams
Just, kind, masterful = John Kenneth McDonald
Life's sweet constant = Lowell Savage Constance.
Williams and McDonald were the most dependable computers on the "X" search. Lowell's great-nephew and sole trustee William Putnam III notes that Constance's name is the only one for whom the letters are reversed; she was, he says, "the one who almost succeeded in completely negating [Lowell's] life work," through the endless lawsuit that she initiated after his death.
[39] William Lowell Putnam, III, *Explorers of Mars Hill* (Kennebunkport, Maine: Phoenix Press, 1994), p. 104.