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GEORGE CARY COMSTOCK

1855–1934

BY

JOEL STEBBINS

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Geo. G. Comstock

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George Cary Comstock was born in Madison, Wisconsin, February 12, 1855, son of Charles Henry and Mercy (Bronson) Comstock. On his mother's side (Doan) his ancestry is traced to the Mayflower; on his father's side he was descended from William Comstock, who settled in Mystic, Connecticut, in 1628. William came from the town of Culmstock, on the river Culm, not far from Exeter, England. His grandfather moved from New England to Norwalk, Ohio, in 1810, and his father was a resident of Madison when the future astronomer was born. There were four children, three boys and a girl, of whom George was the oldest. One of the boys died in infancy; Caroline lived until about 1915; and Louis in 1938 is the Chairman of the Board of the New York Title Insurance Company, New York City. For business reasons the family had moved from Madison to Kenosha, Wisconsin, then to Sandusky, Ohio, and in 1869 they were living in Adrian, Michigan.

In the fall of that year George entered the high school, pursuing what was then known as the Latin-Scientific course. His natural tastes led him, with no advice from others, to select as far as rigid school curricula permitted, mathematics and physics. Quite unbeknown to his parents he was beginning to cherish an ambition to go to Annapolis. His school work was of such high quality that the superintendent of the school encouraged this ambition and brought him into contact with the Congressman of the district, who had the power of appointment on the basis of a competitive examination. In due course, toward the end of his senior year in high school, the examinations for appointment to the Naval Academy were held, and much was the surprise and satisfaction of the family when they learned that George's name headed the list. This was the first news they had had that George had even contemplated taking the examinations.

The appointment came in a few days, but his mother, having gotten over the first flush of joy and excitement, began to won-

der if after all the Navy was a good place for her son. The Civil War at that time had not receded very far into the background, and memories of the boys lost in the war were still green. After pondering over the matter, with some vigorous family discussions, she finally persuaded George to surrender the appointment upon her promise, backed by his father's assent, to give him four years at the University of Michigan. This decision rendered it necessary for the family to move to Ann Arbor so that George might live at home during his college days. The change to Ann Arbor was accomplished just before the beginning of the college year in 1873.

He matriculated that fall and became a candidate for the degree of Ph. B. Almost immediately he became acquainted somewhat as a friend and associate with two professors of mathematics, W. W. Beman and Edward Olney. George's classroom work caused him no worry or anxiety and he was privately consorting with the professors in discussions of advanced mathematics in the evenings. It was during one of these evening meetings with the staff that he was permitted to meet James C. Watson, Professor of Astronomy and Director of the Observatory. Watson at once took a fancy to Comstock, presumably because of his mathematical precocity, and it was Watson who suggested to him the study of astronomy. Into this new field Comstock entered with ardor and zeal.

It was in 1854 that the German astronomer, Francis Brünnow, had been called to Michigan. Trained in the traditions of his home institutions, Brünnow carried to a midwestern college the methods of a German university, and lectured in broken English to despairing and diminishing classes until Watson was his only student. Yet there was developed by Watson, who ultimately succeeded Brünnow, and the others at Michigan, the leading school for the study of astronomy in the country at that time. Of the astronomical graduates during or shortly before Comstock's time may be mentioned R. S. Woodward, Otto Klotz, C. L. Doolittle, and J. M. Schaeberle, and within about the decade following, W. W. Campbell, A. O. Leuschner, and W. J. Hussey. Comstock afterwards referred to Watson as the

cleverest astronomer he had ever met, but one who unfortunately had distributed his energies over too many fields.

Toward the end of his freshman year, following the panic of 1873, George saw the necessity of earning some money during the summers. Watson knew of the U. S. Lake Survey, then in progress on the Great Lakes under General Marr of the U. S. Army. Through Watson's influence George went to see General Marr with whom he concluded an arrangement to enter the service of the Survey, then in the Department of War. By the terms of this arrangement George spent six months in the summer, with leave for six months during the winter at the university. From then on his college course was shortened to six months each year, while he practically lived out of doors in a regular army camp for the remainder of the time. He took part as recorder and assistant engineer in the survey of Lakes Ontario, Erie, and Superior. His last year was on the upper part of the Mississippi River. In this work he became very expert in the use of the theodolite and level, an experience which was later to bring forth his text-book on field astronomy for engineers. During this same interval R. S. Woodward was also connected with the Lake Survey, but there is no record of the paths of the two young scientists crossing at this time.

George was graduated from the University of Michigan in 1877, and after an additional year on the Mississippi River and some further work at the observatory at Ann Arbor in connection with Schaeberle, he followed Watson to the University of Wisconsin late in 1879, to be assistant to the newly founded Washburn Observatory of which Watson was the first director. The scientific work of this observatory was scarcely started when Watson's premature death occurred in 1880, in only the second year of his residence at Madison. Edward S. Holden, later to become the first director of the Lick Observatory, took charge of the Washburn Observatory in 1881, and Comstock continued as assistant. During this period under Holden we find the first work of Comstock's in the Publications of the Washburn Observatory. Among the titles are: "A Catalogue of 195 Stars for 1880"; "A Table of Precessions in Right Ascension and Declination for 1880"; "On a New Method of Observing with the

Prime-Vertical Transit"; "Reduction of Observations Made By Two Observers for the Determination of the Latitude of Washburn Observatory by the Zenith Telescope"; "Determination of the Latitude of the Washburn Observatory by Transits of Stars over the Prime Vertical". It is seen that his activities were all in the astronomy of precision. Later under Holden's direction he did most of the work of preparing the "Tables for the Lick Observatory", which appeared in Volume I of the Lick Publications and have long been used at that institution.

Although Comstock was developing rapidly in his professional work, a career in astronomy involved considerable uncertainty, and he devoted his spare time to the study of law. He was graduated from the Wisconsin law school in 1883, and was admitted to the bar but he never practiced. Nevertheless, he later often referred to his legal training as possibly the most valuable part of his education. His precision of speech and his orderly habits were no doubt accentuated during his law studies.

At the age of thirty he was definitely committed to an academic career by an opening at Ohio State University, where he served as professor of mathematics for two years. He spent the summer of 1886 at the Lick Observatory where it was planned that he would take a position on the staff, but in 1887, when Holden left to take up active service at Mount Hamilton, it was President T. C. Chamberlin who called Comstock to take charge of the Washburn Observatory.

Throughout his scientific activity Comstock held an unusually happy balance between theory and practice. Though the observational astronomy of his early days consisted essentially of the visual measurement of angles, he never became a routine observer. The first work which he took up on assuming the directorship was novel in conception. As a substitute for the meridian circle and clock he placed a prism with reflecting surfaces in front of a telescope, and by observing simultaneously pairs of stars separated by arcs of approximately 120° the measures could be carried around the sphere in three steps, with the advantage that the quantities measured were small angles rather than large ones. From this work there resulted one of the best determinations of the constant of aberration made up to that time. Comstock's value

for this constant, 20″.44, differed from the commonly accepted value of Struve by less than its own probable error.

The telescope used in the observations for aberration was Burnham's famous 6-inch refractor, which had been acquired by the Washburn Observatory in the early eighties. This instrument had been taken by Holden to Caroline Island in the South Pacific for the eclipse in 1883, and it was later used by Flint at the 1900 eclipse in North Carolina. The old wooden tube and mounting are in the museum of the Adler Planetarium in Chicago, but the objective with a new mounting is in current use at Madison.

A striking confirmation of the precision of Comstock's work was furnished some forty years later by Mr. Harry Raymond of the Dudley Observatory. In a discussion of star places for the Boss General Catalogue, Raymond found that Comstock's measures in the early nineties gave an excellent set of corrections to the system of star places then available. Expressed in equations these corrections took the form

$$\Delta\alpha_\alpha = -0^s.0048 \sin\alpha + 0^s.0063 \cos\alpha - 0^s.0015 \sin 2\alpha + 0^s.0048 \cos 2\alpha \quad \text{(Comstock)}$$

$$\Delta\alpha_\alpha = -0^s.0056 \sin\alpha + 0^s.0069 \cos\alpha + 0^s.0003 \sin 2\alpha + 0^s.0027 \cos 2\alpha \quad \text{(Raymond)}$$

Considering that Comstock's result was only a by-product of other work, the agreement of the respective terms of the two formulae is truly remarkable. Thus we have a modern appraisal of Comstock's skill, ingenuity, and precision.

Involved in the work on aberration was a determination of the atmospheric refraction, which decreases the apparent arc between any two stars in the sky. His measures established the effect of the relative humidity of the air upon the refraction and confirmed the superiority of the Pulkowa tables over the older ones of Bessel. His interest in the refraction was long continued and his retiring presidential address before the American Astronomical Society was entitled "The Atmospheric Refraction". This address was delivered in 1928, nearly forty years after his first published paper on the subject. One of his contentions was that

the effect of the air at low altitudes is not as uncertain as has often been supposed, and that other sources of error have been wrongly attributed to irregularities in the refraction. His simplified formula for the refraction,

$$R = \frac{983\,b}{460 + t} \tan z,$$

where R is the refraction in seconds of arc, b the height of the barometer in inches, and t the temperature in degrees Fahrenheit, gives the result within one or two seconds except under extreme conditions, an approximation sufficiently close for many kinds of work. This simplification of a complicated formula down to its lowest terms was typical of many of his contributions to practical astronomy. Additional terms and constants were devised for cases where greater accuracy was needed, but Comstock's formula for refraction will be remembered and used in its simplest form.

Of miscellaneous investigations extending over the years may be mentioned observations of minor planets and comets, discussion of the variation of latitude, occultations, especially during eclipses of the moon, physical observations of Mars, and a long series of micrometrical observations of Eros for the solar parallax during the opposition of 1900.

Concurrently with other investigations Comstock carried on measures of double stars with the 15-inch refractor for more than thirty years, from 1887, when he took over the directorship, to 1919 when he stopped definitely and collected all measures in a publication of the observatory. His observations were always of the highest quality, exemplifying the truth of the statement that "the precision of a double-star measure bears no direct relation to the size of the telescope with which it is made". He followed a number of interesting binaries and devised new methods of determining their orbits. His vice-presidential address before the Section of Mathematics and Astronomy of the American Association for the Advancement of Science in 1894 was on "Binary Stars". In fact, his interest in double stars was continuous throughout his active career.

Typical of his originality was his experiment on stellar color. By placing a grating of rods or coarse wires in front of the 15-inch objective, a series of spectral images was formed at the focus which was almost indistinguishable from ordinary stellar images. The measures of the separation of these spectra on either side of the primary image gave a numerical determination of the effective wave-length of the light of the star concerned. Thus astronomical colorimetry was placed on a quantitative basis. It was no doubt this interest in color which led him to point out the effect of differential atmospheric dispersion on measures of parallax when the objects concerned were of different spectra.

In fact, Comstock was continually attaching something different to one end or the other of his telescope. He devised a slat-screen apparatus for the meridian circle which reduced the image of a bright star to a multiple diffraction pattern, and this arrangement was used by Flint for many years in parallax and position observations.

Another new device was a double-image micrometer which was applied to the detection of the lunar atmosphere. Though not applicable to general micrometrical work, this instrument enabled him to observe the components of wide double stars close to the moon's rim. As no displacement was found up to the very instant of occultation of one star, he could set an upper limit to the negligible density of the moon's atmosphere.

A proposal by Comstock, the technical details of which he left to others to carry out, was the determination of radial velocity of stars by means of objective prisms. This and similar proposals by other astronomers have never worked out in practice, but the suggestions made by Comstock showed that he was alive to the problems of the so-called new astronomy.

The chief outcome of the double-star work was the detection of proper motions of faint stars. One high authority on double stars had stated that there was yet to be brought forth any evidence of the proper motion of a really faint star, but Comstock demonstrated that stars as faint as the twelfth magnitude do move enough to be detected. By the remeasurement of faint companions of bright double stars, observed incidentally by the

Struves and others early in the nineteenth century, he found that, when the known orbital and proper motions of the bright stars were allowed for, the remaining discrepancies were due to the motions of the faint stars. This conclusion was confirmed by a determination of the sun's way from the motions of the faint stars alone. In the work on proper motions he had the cooperation of Albert S. Flint, who determined many of the required modern positions of stars with the meridian circle at Madison.

Struve had found that for stars down to the tenth magnitude there was the empirical relation that the product of the magnitude and the proper motion was a constant, and Comstock extended this relation to the stars two magnitudes fainter. Thus he showed that the twelfth magnitude stars were nearer to us than would be inferred from their apparent brightness. He gave two alternatives: either there is an appreciable absorption of light in space or the stars which he studied are intrinsically fainter than the bright ones. The second alternative has turned out to be the correct one, and the great preponderance of stars of low intrinsic luminosity in a given volume of space, which his work foreshadowed, has been amply confirmed in recent years.

It was Comstock's determination of the proximity of faint stars that led him to the bold suggestion that the Milky Way is an absorption effect. We see farthest in the galactic plane where there is least absorption, while the stars appear fewest toward the galactic poles because their light is largely or totally blotted out in space. This speculation of course had to be abandoned, but it should be viewed in relation to what was current opinion in astronomy at the time. Newcomb had estimated the galaxy to be only ten or twenty thousand light-years across, and in the "Kapteyn Universe" the sun was placed not far from the center. The spiral nebulae still belonged to the galaxy; that they could be external systems of millions of stars had been considered and rejected by expert opinion at the beginning of the century.

The investigation of the aberration and refraction gave Comstock immediately a standing in the profession. When that work was published, appreciation came from various quarters,

notably from Loewy at Paris and Sir David Gill at the Cape, who wrote most friendly letters and discussed different possibilities of the new method.

In 1897 Simon Newcomb, owing to the age limit of the Navy, retired from the directorship of the Nautical Almanac office. Two years later this post was to become vacant again, and Newcomb urged Comstock to be a candidate for a professorship of mathematics in the Navy, with the understanding that he would become director of the Nautical Almanac. The receipt of such a letter as the following from the austere Newcomb must necessarily have been much appreciated.

Washington Jan. 5, 1899
1620 P St.

Dear Professor Comstock:

The post of Director of Nautical Almanac will be vacant next December by the retirement of Professor Harkness. It seems to me you are best available man for it.

Are you not willing to become a candidate for Professor in the Navy if you can look forward to the detail I have mentioned?

I hope you will be here at the proposed meeting of the committee on the Astronomical Society in February.

Very respectfully

S. Newcomb

This letter was followed by further correspondence, but Comstock preferred to remain in Madison.

Comstock was elected to the National Academy of Sciences in 1899, the first of the Wisconsin faculty to receive this honor. He was also a member of the American Academy of Arts and Sciences, and a life member of the Astronomische Gesellschaft.

In 1899 the Secretary of the Navy, John D. Long, appointed the first board of visitors to investigate and report on the conditions of the United States Naval Observatory. The board consisted of two members of Congress and three astronomers, Senator William E. Chandler, Representative A. G. Dayton, and Professors Edward C. Pickering, George E. Hale, and George C. Comstock. After thorough investigation and discussion, which included a canvass of opinion from the leading astronomers of the country, the board made a report which created a stir at

the time, but which was naturally not particularly welcomed by the Navy. The principal recommendation was that the astronomical work of what had become the national observatory should be placed under the direction of an astronomer rather than a naval officer. This reform, since repeatedly urged by scientific men of the country, was never carried out. The Navy has always been able to hang on to this fine place for the shore leave of a captain or rear admiral. Comstock was blamed or complimented for a leading share of the report, which unfortunately accomplished very little.

The American Astronomical Society grew out of the conference of astronomers and physicists held in connection with the dedication of the Yerkes Observatory in 1897. Comstock was one of the organizers of the society, and served for ten years as its first secretary. Later he held the office of vice-president, and in 1925 he was called from retirement to serve a term as president. He was always a prominent figure at the meetings, taking a leading part in the discussions, whether on business or on scientific questions. He was an admirable presiding officer, and he once remarked that it was the function of the administration to pick out and develop undiscovered talent among the younger men.

He was the chairman of the committee of the society appointed to coordinate the observations of Halley's comet in 1910. On the initiative of this committee an expedition in charge of Ellerman was sent to Hawaii to attempt the observation of the head of the comet which projected against the sun's disk. The report of the committee appeared in Volume 2 of the society's *Publications*.

It was during Comstock's term as president that the society was incorporated under the laws of the State of Illinois. The informal status of the organization had been repellant to his mind, and moreover it was just as well for the society to be in a position to receive donations without legal difficulties.

Throughout his career Comstock carried on instruction as well as research. The number of his students was never large, but he was known to those who came to him as a master of clear and apt expression. When the present writer was a gradu-

ate student he thought that Comstock was the best teacher he had ever had, a judgment which has changed little over the years. Yet in the ordinary sense Comstock did very little teaching for his advanced students. They went along much on their own until difficulties arose, and then his ability to elucidate obscure points would be shown. A student learned from him through inspiration and by imitation. He was a methodical observer and an expert computer, and one needed only to be around and watch him to get some of the intangibles which make for successful scientific work. An occasional phrase or sentence, such as "I believe in an astronomer's making his own instruments", was worth more than an hour of formal instruction.

Much of his success with students was due to his linguistic ability. For years the precision and elegance of his English were noted in the university community. He also was fluent in German, French, and Italian.

The relations with students naturally brought out several papers covering problems of instruction. He contributed notes on the adjustments of a sextant, on the establishment of a meridian line, on the graphical representation of a comet orbit, and on the motions of comets when far from the sun. He was an expert in time determinations with small instruments, and he showed that the precision attained with a 3-inch broken transit with a reversal of the instrument on each star was comparable with the best results of large meridian circles, a conclusion amply confirmed by modern experience in longitude determinations.

In the course of his teaching he also had occasion to write several text-books. The first appeared in 1890, a little work entitled "An Elementary Treatise upon the Method of Least Squares, with Numerical Examples of its Application". He boldly assumed without proof the fundamental equation of the law of errors, pointing out that after all the real justification of the method is that it agrees with experience. Though this little work is out of print, there is still no better place for the novice to look up the essentials of least squares, and how to proceed in a simple practical case.

The "Text-Book of Astronomy" was written in 1901 for

students of high school or junior college grade, and was accompanied by a manual with numerous suggestions for the teacher. Illustrative exercises with simple apparatus were proposed, as it was known that many teachers without previous training in astronomy were being called upon to give an elementary course in the subject.

For many years all of the students majoring as civil engineers at Wisconsin were required to take the course in practical astronomy. The attitude of the engineering faculty was that they were not so anxious to have the students learn astronomy as they were to have them get the unusual training in observation and computation under Professor Comstock. In his textbook of "Field Astronomy for Engineers", which appeared in 1903 with a second edition in 1908, he combined the sound instruction in tested methods of practical astronomy with new applications to the ordinary engineer's transit in the field. He showed that the determination of time, azimuth, latitude, and longitude with small instruments could be made much more precise than was ordinarily assumed. In 1919, as part of his war service, Comstock's experience in teaching navigation to prospective mariners led him to get out a little work on "The Sumner Line".

To a faculty member with Comstock's qualifications there naturally came many important university duties. He was chosen chairman of the committee of arrangements at the time of the Jubilee, the fiftieth anniversary of the founding of the University of Wisconsin. One of the important measures of the first year of the administration of President Van Hise at the university in 1904 was the definite organization of the graduate school. He selected Comstock to be the head of the school, and placed on him the task of working out the problems of a new division of the university, one that was growing rapidly both in size and in importance. He held this position until 1920, as chairman, director, and dean, showing in it his qualities of quiet efficiency and breadth of view. He received a school without definite organization and with about one hundred and fifty students; he left it fully organized for teaching and for research and with its number nearly quadrupled.

Early in his work in the graduate school Comstock once re-

marked humorously that he was somewhat handicapped in the making of Ph. D's. by his own lack of a doctor's degree. This defect was remedied in due time by the award of the honorary degree of LL.D. by the University of Illinois in June, 1907, and of Sc.D by the University of Michigan a week later on the thirtieth anniversary of his graduation.

The duties of the graduate school naturally interfered with his scientific work, but probably the most important of all his investigations, that on the proper motions of faint stars, was carried on amidst other duties of administration and instruction. On relinquishing the deanship he continued active for two years more before retiring from the observatory in 1922 at the age of sixty-seven. Although he could have served several years longer he decided to retire, and this decision like all others of his career was clean cut and final. He finished and published the researches on which he had been engaged, leaving no loose ends about to bother his successor.

Comstock was very fortunate in his family life. In 1894 he married Esther Cecile Everett of Madison who with their daughter Mary, now Mrs. George Carey, survives. The home on Observatory Hill was long known as a center of hospitality, especially to the graduate students, in whom the dean and his wife took a personal interest. Perhaps the explanation of his wide sympathies and interest in people and in current events was the fact that he left astronomy behind each day when he closed the observatory door. After his retirement from university service, Professor and Mrs. Comstock traveled around the world, renewing friendships with scientific colleagues in many countries; they returned to settle in Beloit, Wisconsin, just around the corner from the great attraction of three grandchildren. Here he spent the last dozen years of his life.

Despite his dignified or even austere manner Comstock had a keen sense of humor, which combined with a promptness of decision made him equal to any occasion. At the time of the appearance of Halley's comet in 1910, when he saw the popular interest that was impending, he arranged with the university authorities to make a small admission charge on some of the nights when the observatory would be open to the public for

viewing the comet. On one of the days during this rather hectic astronomical period he was called to the telephone by an inquiring taxpayer. The question was: "Professor, what are you going to do with the money you are collecting for a view of Halley's comet?" Promptly came the response: "Madam, we are going to get a new tail for Halley's comet." The reply seemed to be entirely satisfactory.

In his youth Comstock had been a serious individual with little aptitude for play or sports, but in mid-life he took up golf on the insistence of his family. In his later years he became an ardent member of the Rotary Club of Beloit, and was made an honorary life member of the organization. He had the pleasure of visiting and afterwards reporting on various Rotary Clubs in Europe. At home he was in constant demand as a speaker before service clubs, his topics ranging from club education programs and popular talks on astronomy to philosophical discussions of a more severe order.

He was fortunate in maintaining his physical and mental vigor up to the end. He gave a public address just two weeks before he died, and at the last he was ill for only a few days, being taken by an embolism following a minor operation. The end came quickly on May 11, 1934, in his eightieth year. As has been aptly said, there is always an old school in a progressive science. Comstock lived to become one of the old school in point of years, but his outlook was always forward. He saw the astronomy of his youth grow into the astrophysics of the present, but his conception of all science was like that of the heavens described in his own text-book, "A universe which is ever becoming something else and is never finished."

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