NATIONAL ACADEMY OF SCIENCES

SAMUEL ALFRED MITCHELL

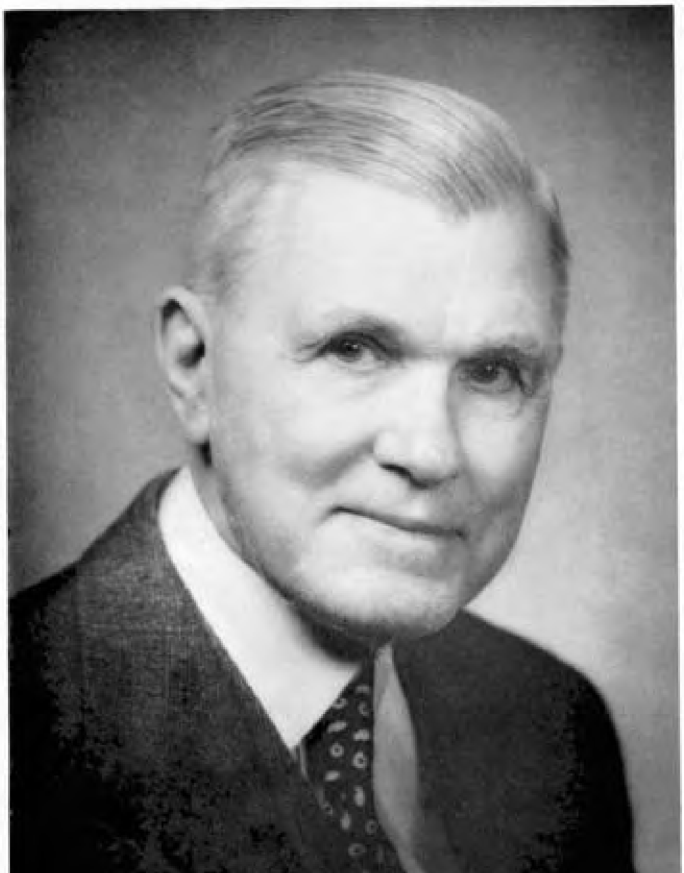
1874—1960

A Biographical Memoir by

C. G. ABBOT

Any opinions expressed in this memoir are those of the author(s) and do not necessarily reflect the views of the National Academy of Sciences.

Biographical Memoir



S. A. Mitchell

SAMUEL ALFRED MITCHELL

April 29, 1874–February 22, 1960

BY C. G. ABBOT

SAMUEL ALFRED MITCHELL, son of John Cook Mitchell, was born at Kingston, Ontario, April 29, 1874. He died at Bloomington, Indiana, February 22, 1960. His father (a tenth child) emigrated to Canada from Austell, Cornwall. His mother, Sarah Chown, born in Kingston, was the tenth child of parents who emigrated to Canada from Devonshire. Alfred was the sixth of the ten children born to his parents.

Well grounded in the 3 R's, at twelve years of age he passed to the Kingston Collegiate Institute. With advanced standing in mathematics, Latin, French, and German, and honored by receiving the Governor General's scholarship in general proficiency, he went on to Queen's University. Here, through slender, he took part in college sports. In his junior year came his first acquaintance with astronomy, which was taught by Reverend James Williamson, a brother-in-law of Sir John A. MacDonald. The subject of astronomy came very naturally after two years of mathematics with Professor Nathan F. Dupuis and two years of physics.

Queen's then had a small wooden observatory, with two instruments on loan from the Royal Astronomical Society of London, a transit instrument, and a 6-inch Clark equatorial. There were two clocks, a sidereal clock and a mean-time clock built by Professor Dupuis, who had been an expert clock maker before he came to be a Professor of Mathematics.

At eighty, Professor Williamson, affectionately called Uncle Billy, found it pleasant and convenient to delegate the care of these instruments to young Mitchell. Thus he early came to know something of the technique of an astronomical observatory.

Mitchell received the degree of Master of Arts in 1894, and was also awarded the medal in mathematics. In the following session he was appointed Tutor in Physics, continuing in charge of the observatory, and in the next session was appointed Instructor in Mathematics. But Professor Dupuis strongly recommended that Mitchell should go to The Johns Hopkins University for graduate instruction with the great mathematical astronomer Simon Newcomb.

Arriving at Hopkins in 1895, Mitchell found that Professor Newcomb had just retired as professor, and that Thomas Craig was head of mathematics and Charles Lane Poor of astronomy. He found Charles Lane Poor's teaching was of very high quality, and his personality very attractive, so that Mitchell became inclined to adopt astronomy rather than mathematics as a life profession. He therefore changed his plans, making astronomy his major subject, physics first minor, and mathematics second minor in working for his degree.

Physics at Hopkins in those days took a very high place under Professor Henry A. Rowland. It used to be said, I know not how truly, that Professor Rowland was once asked in court "Who is the greatest physicist in the world?" "I am", said he. Being asked about it later, Professor Rowland said "I could not say otherwise. I was under oath." Professor Joseph Ames, a superb teacher, was Rowland's collaborator; L. E. Jewell was Rowland's assistant in preparing the great chart and table of the solar spectrum. The mechanic Schneider was Rowland's able aide in perfecting the dividing engine which ruled the famous Rowland gratings for spectroscopy.

As he was one of ten children some financial help was essential. It was most gratifying, therefore, that an assistantship in astronomy was awarded Mitchell in his second year at Hopkins. His duties consisted mainly in caring for the transit instrument and clocks in the little observatory back of the physics laboratory, and the 9½-inch refractor in the dome of the laboratory roof.

In those years, when the fine Rowland diffraction gratings were becoming available, along with photographic dry plates of ever-increasing sensitiveness and spectral range, astronomic spectroscopy was flowering. Rowland's invention of the concave diffraction grating opened new possibilities. His great and highly accurate map of the solar spectrum demanded equally accurate knowledge of the spectra of the chemical elements, in order to discover the constitution of the sun. In Europe Kayser and Runge, Eder and Valenta, in England Sir Norman Lockyer and Alfred Fowler; in America Henry Crew and others, were gradually filling this gap by their laboratory studies of the arc and spark spectra of the elements. A few years before, George E. Hale at Chicago, and Henri Deslandres in Paris, had independently conceived the device of the spectroheliograph for delineating areas of activity of single chemical elements on the sun. Hale had persuaded the rich merchant, Charles T. Yerkes, to procure from Alvan Clark and Sons what is still the largest refracting telescope in the world, and to found the Yerkes Observatory, with Hale the Director.

In these stimulating times, and being at the home of the Rowland gratings, Mitchell took as the subject of his doctoral thesis the use of the concave diffraction grating for photographing the spectra of the stars. Before that, stellar spectra had been taken exclusively with prisms mounted in slit spectrographs, with the slits fed by telescopes. At the start Mitchell also used a slit at the focus of the 9½-inch telescope. But he was soon led to dispense with the slit and throw the star image directly into the focus of a concave grating. A special grating of 6 inches aperture with lines 2 inches high was ruled on the Rowland dividing engine. Elected to Phi Beta Kappa in 1897, Mitchell was awarded the degree of doctor of philosophy in 1898, and his dissertation, including a theoretical discussion of the amount of astigmatism of a concave grating, used as described, was published in the *Astrophysical Journal.*

Though he had received a fellowship at Hopkins in 1897 and it was continued by courtesy in 1898, Mitchell felt that it would be better to attempt to continue his research in astronomy, and he became a research student at Yerkes Observatory, which had been dedicated the year before. He says in an autobiographical paper written in his last years:

"Looking back over my life, I believe the year spent at Yerkes was one of the finest years of my whole life, for I was able to imbibe a modicum of the enthusiasm for research found there, especially in my good friend of many years, Professor E. E. Barnard." He goes on to say: "The staff of the Yerkes Observatory, so soon after its opening, was very small. . . . Its limited budget was supplemented from time to time by gifts from Mr. Hale himself, who actually was not in residence through the winter months. Professor Edwin B. Frost, who later became director of the Observatory, during the winter was in residence at Dartmouth College. . . . The only senior astronomer was Professor Barnard, though Professor S. W. Burnham came up from Chicago on two nights of each week in order to make measures of double stars with the great 40-inch refractor. Ferdinand Ellerman, who worked closely with Mr. Hale for many years, and G. W. Ritchey who was then very busy in the observatory's basement grinding the two-foot reflector, were both in residence 1898–99. . . . The winter temperatures were frightfully low. . . . In the month of February 1899, the thermometer rarely got above zero Fahrenheit. . . . With the long nights of winter . . . one could make a series of long exposures on stellar spectra. One night these exposures were continued for a period of 13 hours, while Professor Barnard was working at the same time at the 40-inch; and the temperatures in the domes . . . fell to 26° below zero, Fahrenheit.

"In those early days there were no warm clothes heated by electricity. . . . One could put on all the heavy flannels he owned and perhaps borrow a fur coat. . . . One could keep comfortable for a few hours, depending on one's age and vitality, but gradually the cold would start at one's feet and creep up, so that before long one would be numb to the waist. . . . It has always been a surprise that none of the astronomers has been unfortunate to stub his toe when so numbed and weighted down with so much heavy clothing. A fall . . . from the observing floor of the 40-inch when at its highest would have been catapulting a distance of about 60 feet."

In a long voyage to observe the total eclipse of 1901 in Sumatra, and in later association at Mount Wilson Observatory, Professor Barnard has told the present writer how he used to keep awake through those long hours, night after night, with black coffee, while he spent many hours of the days between in photography and examining his beautiful star photographs.

Mitchell's 6-inch concave grating in its box was attached to the 12-inch telescope, used as guiding instrument to bring the star observed to focus for the grating. With the small staff in residence, he was able to use the telescope as many nights per week as he wished. The spectrographs of stars he obtained gave interesting and promising results. Exposures were made on many of the brighter stars, and on the Orion nebula. First and second orders of stellar spectra could be photographed on the same plate, with the direct image of the star between. The results demonstrated that many stars could be observed when gratings with longer lines became available, as they did indeed later.

In June, 1899, Mitchell accepted a position as Instructor in Astronomy at Columbia University, and in December of the same year he married the daughter of Professor E. T. Dumble, then State Geologist of Texas, who was later Consulting Geologist of the Southern Pacific Railroad, an expert in petroleum production. The issue of this very happy marriage is Professor Allan C. G. Mitchell, Chairman of the Department of Physics, Indiana University.

Later promoted to Adjunct Professor, Mitchell remained at Columbia fourteen years, associated during that period with Professors John K. Rees, Harold Jacoby, and Charles Lane Poor, who had been his teacher at Johns Hopkins. Mitchell's teaching duties comprised an undergraduate course in descriptive astronomy for students of Columbia, and later for girls from Barnard College, and also a course in geodesy throughout the whole session for third-year students, which was continued through the first semester of the fourth year. There was also a summer camp of six weeks for the civil engineers. All of these contacts, and life in the great city, were very agreeable to him.

In 1900 Mitchell observed his first total eclipse of the sun as a member of the U. S. Naval Observatory expedition to Griffin, Georgia, to observe the eclipse of May 28. In all, he observed ten total solar eclipses, traveling over 100,000 miles. On many of these expeditions he was the guest of U. S. Naval Observatory parties, and used special apparatus which he designed for that Observatory. His large book, *Eclipses of the Sun,* has gone through five editions, and is the foremost authority on solar eclipses, especially in regard to the "flash spectrum."

During Mitchell's fourteen years at Columbia University he devoted such time as he could spare from his teaching duties to the reduction of the results he obtained at the total solar eclipses of 1900, 1901, and 1905 on the flash spectrum. This involved measures on the positions of nearly 3000 flash-spectrum lines photographed with diffraction gratings, and comparing them with the positions of the much more numerous solar lines of Rowland, and the arc and spark laboratory spectra of the chemical elements published by many observers in Europe and America.

Mitchell's papers on this research were published in the *Astrophysical Journal,* 38:407–95 (1912), and 39:166–79 (1914). I quote his summary from *Eclipses of the Sun.*[1]

"As the result of investigations of the chromosphere from spectra taken at the time of an eclipse, it seems safe to make the following general conclusions:

"1. Wavelengths in chromospheric and solar spectrum are probably identical.

"2. Every strong line in the Fraunhofer spectrum is found in the flash spectrum, and every strong line in the latter (with the excep-

[1] 2nd ed. N. Y., Columbia University Press, 1924 (p. 242).

tion of hydrogen and helium lines) is matched by a line in the former.

"3. The flash spectrum may therefore be regarded as a reversal of the Fraunhofer spectrum.

"4. The 'flash' is not an instaneous appearance. At the beginning of totality the chromospheric lines of greatest elevation appear first, and at the end of totality remain the last.

"5. The 'reversing layer' which contains the majority of the low-level lines of the chromosphere is about 600 kilometers in height.

"6. The 'reversing layer' has no existence separate from the chromosphere.

"7. It is the densest part of the chromosphere, lying closest to the photosphere, and it is the cause of the greatest part of the absorption producing the Fraunhofer lines.

"8. The 'Evershed effect' measured in sun-spots and photographs of flocculi, which exhibit vastly different aspects when photographed at various elevations above the phostosphere, proves that the shadings of such strong lines as H and K are caused by absorption at different levels and pressures above the photosphere.

"9. The chromospheric spectrum differs greatly from the ordinary solar spectrum in the intensity of the lines.

"10. The Fraunhofer spectrum is essentially an arc spectrum. The chromospheric spectrum more closely resembles the spark spectrum, and its spectrum corresponds to an 'earlier type' [of star] than the sun.

"11. Especially prominent in the chromosphere are the enhanced lines relatively stronger in spark than in arc spectra of the elements.

"12. The enhanced lines ascend to greater elevations above the photosphere than do the ordinary lines.

"13. The increased elevations cause greatly diminished pressures.

"14. As Saha has shown, the reduced pressures permit the ionization of the atom. As a result the lines of ionized atoms are specially prominent in the flash spectrum. The enhanced lines are produced by the ionized atoms.

"15. The depth of the chromosphere is not constant."

Mitchell was fortunate in enlisting deep interest in eclipses in his friend Edward D. Adams of New York, founder of the Ernest Kempton Adams Fellowship, which is awarded each year by Columbia University for researches in the domain of pure science. At the total solar eclipse of June 8, 1918, observed at Baker, Oregon, Mr. Adams joined the Naval Observatory expedition, and took it upon himself to find the right man to draw and paint the corona. He chose Howard Russell Butler, a portrait painter of note, whose beautiful painting, reproduced in Mitchell's *Eclipses of the Sun,* is owned by the Hayden Planetarium of New York.

In the summers of the years 1909, 1910, and 1911 and for fifteen months of sabbatical leave in 1912–13, Mitchell had the opportunity of working at Yerkes Observatory. In 1905 Dr. Frank Schlesinger, later Director of Allegheny Observatory, using the 40-inch refractor at Yerkes, had demonstrated that stellar distances could be determined photographically with a telescope of great focal length far more accurately than had previously been done with visual observations. This work was taken up again with the 40-inch refractor at Yerkes in 1912–13 by Mitchell and Frederick Slocum. Observation of stellar parallax was to be the major field of Mitchell's later life as Director of Leander McCormick Observatory at Charlottesville, Virginia.

Leander McCormick, of the McCormick reaper family, was born in Rockbridge County, Virginia. In 1870 he was introduced to Secretary Henry of the Smithsonian Institution by a letter from General R. E. Lee, who stated that McCormick "wishes to erect and provide with superior instruments an Astronomical and Physical Observatory in the State of Virginia." Eventually a Clark 26-inch refracting telescope was procured by him to be installed at Washington and Lee University at Lexington. But difficulties arose, and Professor Simon Newcomb succeeded in obtaining that telescope for the U.S. Naval Observatory at Washington.

Later, however, Mr. McCormick persevered and ordered a 26¼-inch refracting telescope from Clark's. It was made by the younger Alvan Clark, who regarded it as his masterpiece. Mr. McCormick gave $50,000 for the telescope and $18,000 to construct the dome on the top of Mount Jefferson, near the University of Virginia at Charlottesville. Through the efforts of Professor Charles S. Venable an endowment of $75,000 was raised. The Leander McCormick Observatory was dedicated in 1883, and at that time possessed the largest and finest refracting telescope in the world. The first Director was Professor Ormond Stone, who came in 1882 at the recommendation of Professor Simon Newcomb. The budget in President Alderman's time was $4450 a year, permitting the Director's salary to be $3000 a year, leaving $1450 a year for all other purposes. But in honor of Commodore Vanderbilt, who had contributed $25,000 toward the endowment, three scholarships of $35.00 per month for ten months per year were established. These scholarships were prized and were held by many men who later won considerable distinction in astronomy.

Professor Ormond Stone remained Director for thirty years. In 1913 Mitchell accepted the post as his successor. He was retired as Director Emeritus in 1945. Mitchell keenly realized how he was hampered by the paucity of funds for research, and since he was unable to obtain a substantial increase from the University of Virginia, throughout his tenure as Director he devoted much time and effort to obtaining support from outside sources. With his pleasing personality and obvious competence and devotion for his researches, he was quite successful, though he never received such large endowments, in the hundreds of thousands or millions, as have sometimes been made.

Considering what might be his best opportunity for research, though at a disadvantage compared to the long-focus photographic telescopes, by exposures employing color screens he felt that with the excellent 26¼-inch refractor he might yet compete with them in accuracy of observation of stellar parallaxes to determine distances of the stars. In the year 1913, when Mitchell went to Virginia, Director W. W. Campbell of Lick Observatory had written: "A quarter of a century ago we knew the distances on not more than two-score stars . . . even today we possess reliable knowledge of the approximate distances of not over a hundred stars." There was a crying need for knowing the distances of not hundreds but thousands of stars.

With a small balance available from the meager annual funds of the Observatory, Mitchell ordered a double-slide photographic plate carrier, and adjusted it to the refractor. Fortunately Columbia University awarded him the Ernest Kempton Adams research fellowship in July, 1914. With this $1250 he was able to add Charles P. Olivier and Harold L. Alden to the McCormick staff, and the photographic parallax work was started with enthusiasm.

For certain reasons it is not desirable to photograph for parallax within two hours of midnight. So there were four hours available for some other worth-while researches. The Observatory had an excellent micrometer which was used by Olivier for double-star measures. Mitchell and Alden turned to a program on long-period variable stars which eventually grew to large proportions.

Neglecting, for simplicity's sake, the effect of the motion of the whole solar system among the stars, we see that the earth by its motion about the sun occupies positions approximately 186 million miles apart at six-month intervals. Almost all of the stars are so far away that this enormous distance makes no appreciable angular displacement in their apparent positions. But some thousands of stars are near enough to be displaced between 0.05 and 0.2 seconds of arc, and these displacements can be measured. Hence if a series of photographs is made at intervals of six months, such "nearby" stars will be found by measurements of great accuracy to be displaced with respect to the stellar background. Knowing in this way their angular displacements, their distances may be computed by essentially the same method by which a surveyor might fix the distance of a tree beyond a river.

Such was the nature of the main program that Mitchell and his aides carried on at Leander McCormick Observatory after 1914. In 1915 he was assured of the Adams fellowship for another year, but had no assurance of sufficient funds beyond 1916. He had found no prospect of help from the University, and had even been discouraged there from any hope from the McCormick estate. But within a month of his interview at the University a telegram came summoning him to Boston. When he arrived, he arranged with Robert H. McCormick, Jr., in the absence of his father for the day, to go out to Harvard College Observatory to call on Professor E. C. Pickering. That good and able man escorted them about the observatory himself, and inquired what Mitchell was working on. Professor Pickering read a letter he had received from the astronomer Innes in South Africa, asking if it might be possible to buy or borrow the 26¼-inch telescope at McCormick Observatory. Professor Pickering then went on to tell how, as a young man just come to Harvard and in need of funds, some friends had guaranteed him $5000 yearly for five years. Said he: "Mr. McCormick, Mr. Mitchell is in urgent need to carry on his researches. I would recommend that your family treat him in a manner similar to the way my friends treated me a number of years ago."

In an interview with Robert Hall McCormick the next day, that suggestion bore fruit. A check for $2000 reached Mitchell in July, 1915, and thereafter a close friendship followed between Mitchell and the McCormicks, father and son. It was continued through Leander McCormick-Goodhart until Mitchell's death.

About this time Dr. Walter S. Adams of Mount Wilson Observatory discovered the spectroscopic method for determining stellar parallaxes. He found, by comparing known trigonometric parallaxes with the spectra of certain types of stars, that certain sensitive spectral lines showed alterations which could be correlated with the absolute brightness of the star observed. Then, knowing by stellar photometry the apparent brightness of the star, the distance could be computed at once, since the apparent brightness falls off as the square of the distance.

When the Adams fellowship from Columbia was soon to expire, Mitchell asked for a further renewal. His friend Edward Dean Adams told him that it was against policy to renew more than once, but that, as Mitchell made so strong a plea, he would consult with Professor George E. Hale during his approaching visit to Pasadena. Hale advocated granting Mitchell's request, for, though the spectroscopic method of determining parallaxes was available for certain types of stars, no matter how distant, that are bright enough to yield satisfactory photographic spectra, this new method needed to be buttressed by as many trigonometric parallaxes as possible. These were needed for accuracy, and if possible to widen application of this spectroscopic method to include more spectral types of stars. As a result Mr. Adams decided to establish a special fellowship of $1000 yearly for five years.

The exacting measures of star positions on the McCormick photographic parallax plates was taken up as an Ernest Kempton Adams research. Two Repsold measuring machines were loaned by Columbia University. With grants from the Henry Draper Fund of the National Academy an especially suitable large measuring machine by Gaertner of Chicago was procured. According to the bibliography appended to this memoir, 2001 stellar parallaxes from McCormick Observatory were published prior to the year 1950. Comparisons with parallaxes duplicated by other observatories indicated that in accuracy McCormick parallaxes were on a par with the best.

Professor E. C. Pickering of Harvard had long been interested in promoting measurements of stellar photometry, the relative brightness of stars. With a small grant from the Rumford Fund of the American Academy of Arts and Sciences he had procured five identical photometers and had secured the use of them on the large refracting telescopes of Harvard, Princeton, McCormick, Lick, and Yerkes Observatories. The object was to measure visually the magnitudes of faint stars surrounding certain long-period variable stars of magnitudes ranging from 12 to 16, so that these newly measured faint stars might serve as a scale for all variable star observers. Part of the work planned had been done, but about 1905 progress upon it stopped for various reasons.

In the year 1917 Mitchell visited Professor Pickering at Harvard, and among other subjects they discussed possible completion of this project. It appeared to be a useful occupation for the 26¼-inch refractor between the hours devoted to parallax photography. Mitchell and Alden together measured the 12th, 14th, and 15th magnitude standard stars, and repeated the measures on the 16th magnitudes which had already been observed at Yerkes and Lick.

But new and highly accurate methods of photographic photometry came into use, and the careful visual work of many men and many years on the Pickering plan, though published, never came to be extensively appreciated. Yet the experience gained by Mitchell and Alden in stellar photometry became the basis for new McCormick projects of great value. They became especially interested in the variable stars of long periods of from 100 to 400 days. There were available at the time a series of charts designed and published by Father Hagen, astronomer at Georgetown Observatory, showing a variable at the center of the chart, and around it neighboring stars represented by circles of differing diameters to distinguish their magnitudes. Some observations made at McCormick were compared with the Hagen charts, and stars fainter than those printed on the charts were added in pencil, but their magnitudes were unknown.

It seemed best to improve the basis for their long-period variable observing. A collection of 200 photographs was obtained from Harvard and Yerkes covering the regions of as many long-period variables as possible. These regions were then photographed with the 26¼-inch refractor, and each photograph marked in ink with the Harvard magnitude of each comparison star known. When Mitchell and Alden began to use these photographs they found discrepancies in magnitudes, and for stars fainter than 12th magnitude decided discordances. So they understook to reobserve visually these magnitudes with the wedge photometer and the 26¼-inch refractor. Then they formed a scale of steps of tenths of magnitudes for all companion stars of a sequence, carrying the scale to about one-half magnitude below the faintest phase of the variable star. Details of the procedure were explained in Volume VI of the Leander McCormick Publications.

As the limit of the 26¼ refraction for visual observation is 16th magnitude, and many of the long-period variables at faintest reach that magnitude, Mitchell was invited by Director W. S. Adams of Mount Wilson Observatory to use the 60-inch reflector on certain nights to perfect the scale.

In 1934 McCormick Observatory was presented with a 10-inch Cooke photographic telescope, as a gift from Mount Wilson Observatory, the Carnegie Institution of Washington, and the Carnegie Corporation. Using ordinary plates, it portrays the stars in so-called photographic light. With yellow-sensitive plates and a yellow color filter, the portrayal is "photo-visual." When a thin prism is placed over the objectives it becomes a "prismatic camera" yielding as many as 2000 spectra on an 8 × 10 plate. This instrument was highly useful in the long-period variable program of Mitchell and Alden.

The most accurately determined magnitudes in the whole sky are those about the North Pole called the North Polar Sequence. With the 10-inch Cooke telescope photographs including the North Polar Sequence and the region of a long-period variable of equal altitude above the horizon could be made on the same plate. Measures with a microphotometer on 10-inch and on 26¼-inch plates furnished accurate magnitudes so acquired. Yellow-sensitive plates exposed through yellow-color filters made the magnitudes "photo-visual." Visual magnitudes plotted against these photo-visual ones fell on straight lines, and it was found that the two sorts are indeed indistinguishable the one from the other in McCormick observations.

After the work was well along, the McCormick magnitudes were put on a photograph of the long-period variable region and sent to the chairman of the Chart Committee of the American Association of Variable Star Observers. He draughted a tracing from which blueprints were made for the members of the Association. In the course of twenty years of this friendly cooperation over 8000 charts have been derived, and are adapted for the 450 stellar regions that are under continued observation by members of the Association. At the international conferences of variable-star observers at Harvard in 1932, Paris in 1935, and Stockholm in 1938, Director Mitchell was invited to preside.

This and other researches were sandwiched between the hours of stellar parallax work under Mitchell's directorship at Leander McCormick Observatory. The parallax work, his leading research, comprised observation of: (1) The brightest stars of all spectral types down to magnitude 5.0 and some even fainter. (2) Stars of notable proper motions of 0.5 seconds of arc per year or less. (3) Double stars. As already stated, parallaxes of 2001 stars were published by Mitchell by the year 1950.

Eleven observatories with large telescopes located in both hemispheres observed trigonometric stellar parallaxes. There are many duplicated stars. Comparisons indicate that McCormick parallaxes are on a par with the best. Great numbers of spectroscopic parallaxes have also been published. To give them a proper basis for converting absolute luminosity determinations into stellar distances they require numerous trigonometric parallaxes for each spectral type employed. As sensitive lines were later discovered in spectral types not at first found suitable, the call went out for new trigonometric parallaxes not formerly on parallax programs. This led to close cooperation between Directors Adams of Mount Wilson and Mitchell of Leander McCormick.

Among the stars of special spectrum types whose trigonometric parallaxes were desired were the so-called giants, like Betelgeuse, which are mostly at very great distances. Also desired were parallaxes for the dwarf M-type stars, which may be near, and if so will be stars of large proper motion. The prismatic 10-inch camera at McCormick in the skillful hands of Dr. A. N. Vyssotsky can provide spectroscopic parallaxes and can detect the difference between giant M and dwarf M spectral types. With 2000 spectra of stars on one plate it takes time to ferret out the stars of special interest. When detected, a dwarf M must be sought on the records of other observers, and its proper motion determined before deciding to put it on the McCormick parallax list for observation. On four summer visits to Mount Wilson, Director Mitchell was able to use the 60-inch reflector to secure spectra of faint stars on the McCormick program.

This spectroscopic adjunct to the parallax research called for proper motions, and led to the publication, in Volume 10 of McCormick Publications, of the proper motions of over 70,000 stars as catalogued by Dr. and Mrs. Vyssotsky. The catalogue covers seven-eighths of the whole sky from pole to pole, and yields the following important astronomical results: (1) The motion of the sun has been determined with reference to stars of different colors and different magnitudes. (2) The period of rotation of the Galaxy (at about 200 million years) is given with higher precision. (3) The constants of the precession of the equinoxes are fixed with great exactitude.

Mitchell's scholastic and honorary degrees included: M.A., Queen's University, Ontario, 1894; Ph.D., The Johns Hopkins University, 1898; L.L.D., Queen's University, 1924; L.L.D., University of Western Ontario, 1940.

He was a member of the following societies: National Academy of Sciences (elected in 1933); American Association for the Advancement of Science (Vice-President, 1921); American Astronomical Society (Vice-President 1925–27); American Philosophical Society (Fellow); American Association of University Professors (President 1934, 1935); American Academy of Arts and Sciences (Fellow).

He received the James Craig Watson Medal of the National Academy of Sciences in 1948.

KEY TO ABBREVIATIONS

Astron. J. = The Astronomical Journal
Astron. N. = Astronomische Nachrichten
Astrophys. J. = Astrophysical Journal
Columbia Contr. Phil. Psych. = Columbia University, Contributions to Philosophy and Psychology
Hand. Astrophys. = Handbuch der Astrophysik
J. Roy. Astron. Soc. Canada = The Journal of the Royal Astronomical Society of Canada
Leander McCormick Pub. = Leander McCormick Observatory Publications
Mem. Am. Acad. Arts Sci. = Memoirs of the American Academy of Arts and Sciences
Monthly Notices Roy. Astron. Soc. = Monthly Notices of the Royal Astronomical Society
Obs. = The Observatory
Pop. Astron. = Popular Astronomy
Pop. Sci. Monthly = Popular Science Monthly
Proc. Am. Phil. Soc. = Proceedings of the American Philosophical Society
Pub. Astron. Soc. Pac. = Publications of the Astronomical Society of the Pacific
Pub. Nat. Geog. Soc. Eclipse Pub. = National Geographic Society, Solar Eclipse Series
Sci. Am. = Scientific American
Smith. Inst. Pub. = Smithsonian Institution Publications
Yerkes Pub. = Yerkes Observatory, Publications

BIBLIOGRAPHY

1898

Notes on the Concave Grating. Astrophys. J., 8:102.
With Charles Lane Poor. The Concave Grating for Stellar Photography. Monthly Notices Roy. Astron. Soc., 58:291–95.

1901

Examinations of the Pleiades and Eros Plates Taken with the Crossley Reflector of the Lick Observatory. Astrophys. J., 13:48.
The Government Eclipse Expedition. Science, 84:226.
Total Eclipse of the Sun. Science, 14:802.
Focal Singularities of Plane Gratings. Astrophys. J., 14:331.
The Flash Spectrum, Sumatra Eclipse, May 18, 1901. Science, 15:257.

1902

The Flash Spectrum, May 18, 1901. Wave-length Determinations and General Conclusions Regarding the "Reversing Layer." Astrophys. J., 15: 97.

1903

The New Gases, Neon, Argon, Krypton, and Xenon in the Chromosphere. Astrophys. J., 17:224.

The Sumatra Eclipse, 1901. Spectroscopic Study of the Flash Spectrum. New Gases in the Sun. Columbia Contr. Phil. Psych., 20, 42 pp.

1904

Comet 1903 Borrelly and Light-pressure. Astrophys. J., 20:63.

1905

Purposes and Plans of the Solar Eclipse Expedition of August, 1905. Science, 21:918.

Preliminary Account of Flash Spectrum taken 1905, August. Monthly Notices Roy. Astron. Soc., 66:326–28.

1906

Preliminary Results of United States Naval Observatory Eclipse Expedition in 1905. Astrophys. J., 23:128.

1907

"Knots" in the Rings of Saturn. Sci. Am., 97:376.

1908

An Eclipse Expedition to Spain. Pop. Sci. Monthly, 68:551–63.

1909

Photographing a Star Spectrum. Sci. Am., 101:495.

Seven Spectroscopic Binaries. Astrophys. J., 30:239–42.

Peculiar Behavior of Morehouse's Comet. Sci. Am., 100:26.

1910

A Great Open-air Telescope. Pop. Astron., 18:296.

Other Worlds in Space. Sci. Am., 102:160.

Telescope Lenses and How to Test Them. Sci. Am., 102:363.

An Interesting Spectroscopic Binary. Pop. Astron., 18:581.

1911

The Radial Velocities of 96 Hercules. Science, 34:529.

1912

Radium and the Chromosphere. Astron. N., 192:265–70.

Wave-lengths of the Chromosphere from the Spectra Obtained at the 1905 Eclipse. Astrophys. J., 38:407–95.

Brooks' Comet. Sci. Am., 105:299.

1913

Is Radium in the Sun? Pop. Astron., 21:321–31.

1914

The Depth of the Reversing Layer. Astrophys. J., 39: 166–79.

With F. Slocum. Stellar Parallaxes from Photographs Made with the 40-inch Refractor of the Yerkes Observatory. Astron. N., 197:81.

1915

Stellar Parallax Work at the McCormick Observatory. Astrophys. J., 42: 263–70.

1916

Systematic Observations of Meteors. Sci. Am., 113:48.

Preliminary Parallax of Barnard's Star with the 26-inch Refractor of the Leander McCormick Observatory. Astron. J., 30:75.

1917

With F. Slocum. Parallaxes of Forty-two Stars from Photographs Made with the Forty-inch Refractor. Yerkes Pub., 4(pt. 1):5–27.

1919

The Total Solar Eclipse of 1918. Natural History, 19:244–71; Leander McCormick Pub., 2(pt. 6):245–63.

1920

Parallaxes of 260 Stars Derived from Photographs. Leander McCormick Pub., 3:1–677.

The Parallax of Krueger 60. Astron. J., 33:177–79.

1921

With H. L. Alden. Observations of SS Aurigae and Observations of Faint Comparison Stars. Astron. J., 33:87–91.

1922

Trigonometric Parallaxes of Stars of A and B Types; 19 B Stars and 50 A Stars. Pub. Astron. Soc. Pac., 34:254–57.

Trigonometric Parallaxes of Twenty-two Cepheids Measured at the McCormick Observatory. Obs., 45:294–96.

1923

Eclipses of the Sun. N. Y., Columbia University Press, xviii + 425 pp.

How the Sun's Atmosphere Is Studied at Eclipses and the Interpretation of the Results through the Aid of Modern Physics. Pop. Astron., 31:652.

1924

With H. L. Alden. Photometric Standards of Faint Standard Stars Measured Visually at Harvard, Yerkes, Lick and McCormick Observatories. Mem. Am. Acad. Arts Sci., 4:209–307.

Eclipses of the Sun, 2nd ed. N. Y., Columbia University Press. xvii + 452 pp.

1925

Trigonometric Parallaxes of Two Hundred Stars of Large Proper Motion. Pub. Astron. Soc. Pac., 36:185–91.

1926

McCormick Parallaxes of Stars of B Type. Pub. Astron. Soc. Pac., 38: 101–6.

Trigonometric Parallaxes of Forty-seven Stars. Astron. J., 36:143–44.

With H. L. Alden. The Photometric Scale of the Leander McCormick Observatory. Monthly Notices Roy. Astron. Soc., 86:356–60.

1927

With C. G. Abbot. The Fundamentals of Astronomy. N. Y., Van Nostrand, ix + 307 pp.

1928

With C. P. Olivier and H. L. Alden. Trigonometric Parallaxes of Four

Hundred and Forty Stars. Leander McCormick Pub., 4:349 pp.
The Distances of the Stars. Proc. Am. Phil. Soc., 67:267–86.

1929

Eclipses of the Sun. Hand. Astrophys., 4:231–355.
The Relation between Corona and Sun-spots. Pop. Astron., 37:192–98.
Systematic Errors of Parallaxes. Pop. Astron., 37:271.
Trigonometric Parallaxes of Thirty-one Stars. Astron. J., 39:83–84.
Atlas Stellarum Variabilium, Series VII. Monthly Notices Roy. Astron. Soc., 89:654–58.
Trigonometric Parallaxes of Thirty-one Stars. Astron. J., 39:89–90.

1930

Recent Achievements in Measuring Stellar Distances. Scientia, 48:217–26, 291–301.
The Spectrum of the Chromosphere. Astrophys. J., 71:1–61.
Heights in the Chromosphere. Astrophys. J., 72:146–86.

1932

Eclipses of the Sun, 3rd ed. N. Y., Columbia University Press. xvii + 490 pp.
Spectroscopic Discoveries at the Recent Total Eclipse. Proc. Am. Phil. Soc., 71:343–48.

1933

With E. T. R. Williams. Relative Distribution and Abundances in the Lower Chromosphere. Astrophys. J., 77:1–43.
Heights in the Chromosphere from Fixed and Moving Plates. Astrophys. J., 77:157–85.
Trigonometric Parallaxes of Twenty-three Stars. Astron. J., 43:63.

1934

Systematic Errors of Parallaxes. Astrophys. J., 80:200–228.
Eclipses of the Sun, 4th ed. N. Y., Columbia University Press. xvii + 520 pp.

1935

The Magnitudes of 6284 Stars in the 350 Regions of Long-period Variables. Science, 82:624.

With C. A. Wirtanen. A Comparison Sequence for Nova Herculis. Astron. J., 45:31–32.
Observations of Nova Persei (1901). Leander McCormick Pub., 6:51–52.
Observations of Nova Cygni (1920). Leander McCormick Pub., 6:161–62.
Observations of Nova Tauri (1927). Leander McCormick Pub., 6:65.
With C. A. Wirtanen. Observations of Nova Herculis. Astron. J., 40:31.
With H. L. Alden *et al.* Observations of Long Period Variables. Leander McCormick Pub., 6(pt. 1):3–197.
Magnitudes and Coordinates of Comparison Stars Made with the 26-inch Refractor of the Leander McCormick Observatory. Leander McCormick Pub., 6(pt. 2):199–306.

1936

Eclipses of the Sun. Hand. Astrophys. 7:382–408.
The Total Solar Eclipse Observed on Canton Island. Pub. Astron. Soc. Pac., 50:23–30.

1938

Discoveries from Solar Eclipse Observations. Smith. Inst. Pub., 3453:145–67.
With an Astronomer on an Eclipse Expedition. Proc. Am. Phil. Soc., 79:341–60.
With C. A. Wirtanen. A Comparison Sequence for Nova Lacertae. Monthly Notices Roy. Astron. Soc., 99:40–41.

1939

Nature's Most Dramatic Spectacle. Pub. Nat. Geog. Soc. Eclipse Pub., 361–94.
With C. A. Wirtanen. Magnitudes and Comparison Stars of Fifty Long-period Variables. Leander McCormick Pub., 9:(pt. 5):59–88.

1940

With D. Reuyl. The Trigonometric Parallaxes of 650 Stars. Leander McCormick Pub., 8, 749 pp.

1941

With A. N. Vyssotsky and P. van de Kamp. The Trigonometric Parallaxes of Thirty-seven Stars. Astron. J., 49:129–31.

1942

Early American Astronomers. J. Roy. Astron. Soc. Canada, 36:345–60.

1944

With C. Beddow. Trigonometric Parallaxes of One Hundred and Thirty-one Stars. Astron. J., 51:93–96.

1945

With D. Watson. Trigonometric Parallaxes of 88 Stars. Astron. J., 51:182–84.

1946

Chromospheric Spectrum from Ten Eclipse Expeditions. Astrophys. J., 105:1–35; Leander McCormick Pub., 9(pt. 18):213–47, 1947.

1947

The Observation of Ten Total Eclipses. Leander McCormick Pub., 9:(pt. 17):203–11.

1948

With A. H. Joy. Spectroscopic Observations of 90 Stars. Astrophys. J., 108:234–36.

1949

With C. Beddow and D. Watson. Trigonometric Parallaxes of 28 Stars, Determined by Photography with the 26-inch McCormick Refractor. Astron. J., 54:95.

1951

Eclipses of the Sun, 5th ed. N. Y., Columbia University Press. xv + 445 pp.

1958

With D. Reuyl, C. M. Anderson, *et al.* Trigonometric Parallaxes of 432 Stars. Leander McCormick Pub., 14:(pt. 1).