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ROBERT RAYNOLDS MCMATH

1891—1962

A Biographical Memoir by
O. C. MOHLER AND HELEN DODSON-PRINCE

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ROBERT R. McMATH'S extensive contributions to astronomy were summarized in two sentences by Dr. Ira Sprague Bowen in 1963:

> Dr. Robert R. McMath was a creative scientist, sound engineer, and successful business executive. This unusual combination of abilities and backgrounds enabled him to play a large and unique role in the development of American astronomy and in particular its instrumental facilities in the last three decades.

This summary served as an introduction to Dr. Bowen's memoir in the *Yearbook* of the American Philosophical Society; its precision and brevity recommend it for similar use in this memorial.

Robert Raynolds McMath was born in Detroit on May 11, 1891. He was the son of Francis Charles McMath and Josephine Eliza Cook, and the grandson of Robert Emmet McMath and Frances Elizabeth Brodie, and Mary Eliza Raynolds and Otis Lafayette Cook. His father and paternal grandfather were successful and distinguished civil engineers. He set out to emulate their careers by preparing for college in the Detroit University School in Grosse Pointe and by completing his academic preparation at the University of Michigan, where he received a degree of Bachelor of Science (Civil Engineering) in 1913.

McMath's lifelong interest in the production of high-resolution photographs, an interest that was fundamental in his activ-

ities in astronomy, may very possibly have been awakened by his grandmother, Mary Eliza Raynolds; but his grandfather, Robert Emmet McMath, and his father, Francis Charles McMath, seem to have provided the earliest introductions to astronomy. Under Alexander Dallas Bache in the U.S. Coast and Geodetic Survey, Robert Emmet McMath served a number of years filled with extraordinary experiences and acquired a thorough knowledge of the practical astronomy essential for surveying. His grandson was greatly impressed by a story that was part of the family tradition. This tale related the difficulties of making astronomical observations during a survey of the San Juan River from San Juan del Norte (Greytown) to Lake Nicaragua, in Nicaragua, a survey in which the grandfather had been a participant in 1865.

While still a student at the University of Michigan, McMath had worked during summer vacations for the Saint Lawrence Bridge Company, Limited, a Canadian corporation that had been organized by his father for completing, after an early failure by another company, the long-span cantilever bridge over the Saint Lawrence River at Cap Rouge, fifteen kilometers above Quebec. Upon graduation, he went to work full time in this venture. The company originated a now-common technique of constructing the center span on barges that later floated the span into position from which it could be raised to join the cantilevers. After a mechanical failure in the first trial of the method, the second attempt was entirely successful and the bridge was completed in 1917.

In preparation for the entry of the United States into World War I, McMath learned to fly an airplane at Curtiss Field, in Newport News, Va., during 1916–1917, after the engineering work for the Quebec Bridge was finished. In 1917, he enlisted as a second lieutenant in the U.S. Army Air Service. He served as engineer in charge of construction at the developing air bases at Curtiss Field; Buffalo, New York; Mineola, Long Island, New

York; and Wright Field, Dayton, Ohio. He was discharged into the reserve corps at the end of the war with the rank of major.

McMath left the service in poor physical health. He spent 1919–1920 recuperating in Detroit and at the Turtle Lake Club, near Hillman, Montmorency County, Michigan. McMath wrote of this period (University of Michigan Historical Collections):

> The late Willard Pope [1867–1949; B.S. (Engineering), University of Michigan, 1888] had early awakened an interest in things astronomical in both my father, the late Francis C. McMath, and me. I well remember the summer of 1919 at the Turtle Lake Club during which Mr. Pope taught me about as much as I have ever known of the constellations, and taught me how to identify some important, easy-to-see, bright naked eye stars.

Willard Pope was a long-standing business associate of Francis Charles McMath. He had helped in the organization of the Canadian Bridge Company, Limited, of Walkerville, Ontario, in 1901. Both Francis McMath and Willard Pope were highly knowledgeable amateur astronomers. It was through their astronomical avocation and through mutual civic responsibilities in the city of Detroit that they became well acquainted with Judge Henry Schoolcraft Hulbert, another amateur astronomer. In the early 1920s, there were increasingly frequent meetings of the McMaths and Judge Hulbert, who was to play an important part in both of the McMaths' astronomical careers in later years.

The McMaths and Judge Hulbert were first officially associated in things astronomical at the time of the total solar eclipse of January 25, 1924, in a path that crossed Michigan, New York, and Connecticut. An eclipse expedition was organized by Judge Hulbert, who was assisted by Professor Ralph Hamilton Curtiss of the University of Michigan. Observations were to be made from a free balloon that fortunately (in view of the weather conditions) burst during the process of inflation at Geneva, New York.

By 1920, Robert McMath had completely recovered from the illness contracted in the course of his military service, but, in

order to continue spending as much time as possible out-of-doors, he took a job as general manager of the Biltmore Forest Estates Company, near Aiken, North Carolina. There he met Mary Ridgely Rodgers, the widow of Robert Thompson Garrison. They were married on December 1, 1921, in New Brunswick, New Jersey, thus completing what McMath often referred to as "the most important and the smartest thing I've ever done." Dr. and Mrs. McMath had one child, a daughter, Madeline McMath Sloan, born on August 13, 1924.

Willard Pope and Francis McMath had in 1921 sold their interests in the Canadian Bridge Company and retired from active business. Among their holdings were controlling shares in the Motors Metal Manufacturing Company of Detroit, a fabricator of sheet metal stampings for the automotive industries. The 1921 recession had its effect on Motors Metal, and Robert McMath was appointed assistant general manager, with instructions from his father to prepare the company for liquidation. He ignored these instructions and so improved the company that it operated in highly profitable fashion for the next four decades. He said it was the first and last time that he ever succeeded in avoiding unpleasant consequences after ignoring his father's advice. He was made president of Motors Metal in 1925 and chairman of its Board of Directors in 1938. He continued as chairman of the board, later as a director, through several transformations of the company in the late 1950s (Abrasive and Metal Products Corporation; The Wakefield Corporation) until his retirement, in 1961.

Late in the 1920s, Francis Charles McMath returned from a European trip with three Nigretti and Sambra alt-azimuth astronomical telescopes. One of these he gave to Willard Pope; one to his son Robert; and the third he kept for himself. Francis and Robert were not pleased with either the mechanical or optical performance of the telescopes, which were promptly superseded by a four-inch, French-made, alt-azimuth portable

telescope. This too was unsatisfactory, and, following the suggestion of his son Robert, Francis McMath purchased a four-inch Bausch and Lomb equatorially mounted telescope that included a spring-powered driving motor. The driving motor was unable to meet the McMaths' standards of mechanical precision, and in 1928 a new construction, embodying a Telechron synchronous clock motor, was built in the Motors Metals shops and adapted to the telescope. Judge Hulbert, because of his intense interest in the moon and the methods for photographing it that were emerging, was an occasional visitor to the budding McMath Observatory, which, in 1928, was located near the McMath summer home on Deer Lake, Clarkston, Michigan.

Judge Hulbert had recommended the McMaths in 1927 to Ralph Curtiss, acting director of the Observatories of the University of Michigan, as amateur astronomers who also were engineers and who might build parts for a fifteen-and-one-half-inch telescope then under construction in the observatory shop. Very shortly thereafter, Motors Metal Manufacturing Company undertook construction of the parts needed by the University of Michigan, and, during the course of the work, Henri Colliau, who was in charge of the instrument shops at the University of Michigan Observatory, made frequent visits to the plant on Milford Avenue, in Detroit. On one of these visits, on August 19, 1928, Robert McMath showed Colliau a motion picture of shadow changes on the moon that had been made with the Bausch and Lomb refractor and its improved electrical driving motor. Colliau asked if he could show the film to Professor Curtiss, and Robert McMath assented.

Professor Curtiss quickly made a trip to Milford Avenue to talk with Robert McMath, hoping to convince the McMaths, father and son, that they should undertake the development of astronomical time-lapse photography. Professor Curtiss was convinced that this technique would have great value for demonstrating to students the nature of astronomical observation and

for showing them phenomena that proceed much too slowly for direct student observation. The motion picture record also was believed to have considerable value in the study of relatively rapid changes, such as changing shadows on the moon and those that were known to occur in active regions on the sun. Francis C. McMath and Robert R. McMath agreed to the undertaking.

The McMaths and Hulbert decided, with this encouragement, to build a ten-and-one-half-inch-aperture reflecting telescope for the project. They agreed to supply all interchangeable parts between their telescope and the fifteen-and-one-half-inch one already under construction for the university. As far as possible, the two telescopes were to be identical.

The proposed enlargement of the McMath Observatory led to a move to a new location on the north shore of Lake Angelus, directly north of the site of Judge Hulbert's personal observatory and five miles north of the center of the city of Pontiac, Michigan. The McMaths persuaded Judge Hulbert to combine forces with them, particularly in the production of motion pictures of the changes in the shadows on the moon, since Hulbert was an experienced lunar observer. The ten-and-one-half-inch reflecting telescope was finished early in 1930. A building with dome was erected at the new location, the present site of the McMath–Hulbert Observatory at Lake Angelus, and Robert McMath and Judge Hulbert made their first motion pictures of the moon with the new equipment on July 1, 1930.

The observatory had several changes in name in its early years. The first establishment at Deer Lake was called the McMath Observatory; the new observatory at Lake Angelus was first called the Curtiss–McMath Observatory. In October 1930, Heber Doust Curtis, a lifelong close friend of Judge Hulbert, became director of the Observatories of the University of Michigan and replaced encouragement and approval for the projects of the new observatory with active enthusiasm and advocacy. Director Curtis suggested a change in the name of the observatory to the McMath–Hulbert Observatory, a suggestion that

met with immediate approval and adoption by the three collaborating amateurs.

It had become evident somewhat earlier that some sort of official status should be given to the McMaths and Judge Hulbert for their efforts in cooperation with the university, and, accordingly, at their June 1929 meeting, the Regents of the University of Michigan appointed the three astronomers Honorary Curators of Astronomical Observation.

Late in 1931 (December 15) the entire McMath–Hulbert Observatory was deeded to the University of Michigan. By that time, striking results already had been achieved in lunar and planetary photography, and as a result of Francis McMath's suggestions, special devices were being designed for making motion pictures of solar phenomena.

During the first years of the 1930s, the equipment for making astronomical motion pictures was perfected, and the results obtained began to demonstrate the value of the motion picture record for astronomical research. The first solar motion pictures (1932) were spectacular, but a larger telescope was evidently required for full exploitation of the possibilities of solar kinematography.

Director Curtis participated in planning for the construction of a solar tower telescope to have a maximum focal length of fifty feet, and with Judge Hulbert assisted in raising money for the project from local sources, principally the Rackham and McGregor Funds of Detroit. The tower telescope was started on July 16, 1935, and was completed and operating on July 1, 1936.

The tower telescope and the motion picture technique quickly produced unexpected results. First measurements of the films called for substantial revision of prevailing ideas about the interactions of the fields of force on the sun that produce the motions in solar prominences.

Francis Charles McMath died on February 13, 1938. His three children, his widow, and two other generous friends made it possible to convert the ten-an-one-half-inch reflector into a

new telescope with a twenty-four-inch-diameter primary mirror. This telescope was planned as a specialized instrument to be used exclusively for the production of educational astronomical motion pictures in pursuance of the original idea behind the creation of the McMath–Hulbert Observatory, an idea that had persisted in the face of the diverting results of the lunar and solar photography. It proved to be much easier, unfortunately, to raise money for almost any other aspect of the observatory's operations than its educational interests, and eventually the planned movies for classroom use were deferred indefinitely.

The puzzling prominence motions, it was thought, might become more nearly comprehensible if these motions were measured along the line of sight as well as perpendicular to it. McMath designed and built two radial velocity spectroheliographs for recording line-of-sight motions at a large number of points in a solar prominence; and, although these instruments worked very well, the data that they provided were not very helpful in improving the understanding of prominence motions. Attention was turned to photometry and spectroscopy of the prominences and active regions on the solar disk.

Images of large size were expected to be helpful in the photometric and spectroscopic observation of solar features, and a new solar tower telescope was designed to provide them. A solar tower telescope and laboratory–office building were started on September 1, 1939, with the financial assistance of a $100,000 grant from McGregor Fund of Detroit. This construction was hindered by World War II, and in some respects has not yet been finished. Throughout the war years, the observatory continued its most important observations under the sponsorship of the Wave Propagation Committee of the Joint Communications Board. McMath participated in many important defense projects and was awarded the President's Medal for Merit at the conclusion of the war. He continued to serve various federal government departments on advisory and review boards and also served

on committees of the National Research Council of the National Academy of Sciences until his retirement in 1961.

The Department of Astronomy of the University of Michigan was assigned responsibility for the observatories in 1944–1946, and Dr. McMath was appointed professor of astronomy and director of the McMath–Hulbert Observatory, replacing his 1938 appointment as director of the McMath–Hulbert Observatory.

The observatory made some attempt to resume the programs stopped by the war, but new spectroscopic investigations gradually assumed first priority. New detectors, particularly the rapidly developing photoelectric devices, were investigated to see if they could increase the precision of solar observations. Considerable attention had been directed toward television techniques in 1938–1940, but these procedures then offered no advantages for use in solar astronomy.

A need developed in the 1950s for a spectrograph better matched than the original instrument to the large scale of the solar images provided by the McGregor Tower Telescope. A fifteen-meter-long airtight tank was built to be the container for a new spectrograph so that all disturbances arising from motion of air in the instrument could be eliminated by operation in a vacuum. This instrument was completed in 1955, and it immediately showed higher spectroscopic resolving power and more excellent photographic definition than any earlier solar spectrograph. It made possible spectroscopic studies of small-scale details on the solar surface that had previously been recorded only rarely. The innovation, enclosure of the optical path of a telescope and its auxiliary instruments in a vacuum tank, has been copied in most modern solar installations.

Although the vacuum spectrograph for the McGregor Tower Telescope had been designed for photoelectric recording, Dr. McMath was highly delighted to see his favorite technique, photography, usurp most of the observing time.

The development of the ideas for new devices proposed by Dr. McMath led to the creation of an integrated group of unique instruments, designed for use in unison on the same object of observation. An attempt to make simultaneous observations, rather than the recording of differences in small solar details, became the dominating principle in the observational programs. This approach continues to produce valuable results that are strong testimonials to the excellence of Dr. McMath's engineering designs for the instruments in this use and to the scientific value of having numerous closely connected telescopes all working toward the same observational goal.

Somewhat before the building of the vacuum spectrograph in 1954, Dr. McMath was asked by the National Science Foundation to head a panel of astronomers selected by him for a study of the astronomical needs of the United States. Dr. McMath was thus able to play an important part in the formulation of national astronomical policy, and with great political astuteness he guided the panel into proposing the creation of a large, tax-supported, astronomical institution, to be located at the best available site for observing within the United States. The operation of the new national observatory was to be supervised by a consortium of universities selected by the proposing panel.

This recommendation was approved by the National Science Foundation, and the panel was charged with the organization of an operating corporation and the preliminary search for possible observatory sites. In 1957 the Association of Universities for Research in Astronomy (AURA) was incorporated to construct and operate an observatory for the use of U.S. astronomers particularly, and all astronomers generally. Dr. McMath was the first president of AURA after its incorporation, and at the time of his death was chairman of its Board of Directors.

For many years, starting sometime before 1938, Dr. McMath had discussed and had preliminary plans drawn for a solar telescope intended to develop greater spatial resolution than any

then existing. He incorporated these plans into the proposal for the national observatory recommended by his study panel. He was able to keep his plan for a large solar telescope alive until funds were provided by the U.S. government, although he long held out a hope for the money to come from other sources.

The McMath Solar Telescope of the Kitt Peak National Observatory is the embodiment of an idea that Dr. McMath nurtured for a quarter of a century before a way was found for him to realize it. Dr. McMath often told the staff of the McMath–Hulbert Observatory that he hoped to be able to stand with all of them in the Kitt Peak Tower Telescope on its completion and watch the first beams of sunlight directed into the observing room. His death on January 2, 1962, came ten months before the dedication of the McMath Solar Telescope on Kitt Peak, on November 2.

Dr. McMath's scientific achievements, and his great contributions to U.S. astronomy in the formulation of national astronomical policy ultimately leading to great increases in the number of available telescopes and hours of observing time, were widely recognized during his lifetime by numerous citations, honors, and medals. He found special satisfaction in an award of an honorary degree, Doctor of Science, by the Pennsylvania Military College in 1941. It was pleasing to him that the award was made in Chester, Pennsylvania, not many miles from the homesite of an ancestor, Alla McMath, who had emigrated from Ireland to Chester County in 1756. Dr. McMath became a member of the American Philosophical Society in 1942 and the National Academy of Sciences in 1958. He served as president of the American Astronomical Society from 1952 to 1954.

His own evaluation of his honors and his career, written in a manuscript of biographical notes, was:

> Coming along the road it was always exceedingly difficult for me, as well as Harry (Judge Henry Schoolcraft Hulbert), and father, to evaluate the work we were doing. This, of course, was very natural, as no one of the

three of us had any formal training in astronomy. There was an almost constant stream of distinguished professional scientific visitors at Lake Angelus during the first half of the 1930 decade. Their enthusiasm for the work was very stimulating, and, in retrospect, gave us an outside evaluation of the work. The net effect was of tremendous importance; that is, it kept us going and growing.

In April of 1942, I was elected to the American Philosophical Society. This, of course, was tangible evidence of the fact that the Lake Angelus work was considered of importance by other scientists. During the same year, the Royal Astronomical Society conferred associate status on me, tantamount to honorary life membership here in the States. I found this foreign recognition a great stimulus. Actually, it is my opinion that the recognition which came to me should be shared by everybody who was associated with the enterprise. I was just the lucky one. In fact, in retrospect, I was pretty lucky most of the time.

BIBLIOGRAPHY

KEY TO ABBREVIATIONS

Astrophys. J. = Astrophysical Journal
Astron. J. = Astronomical Journal
Pop. Astron. = Popular Astronomy
Proc. Am. Philos. Soc. = Proceedings of the American Philosophical Society
Publ. Am. Astron. Soc. = Publications of the American Astronomical Society
Publ. Astron. Soc. Pac. = Publications of the Astronomical Society of the Pacific
Publ. Obs. Univ. Mich. = Publications of the Observatories of the University of Michigan
Phys. Rev. = Physical Review
Sky Telesc. = Sky and Telescope

1930

The McMath–Hulbert teleschron driving clock for moderate sized equatorial mountings. Pop. Astron., 38:460–66.

1931

With Francis C. McMath and Henry S. Hulbert. Preliminary results on the application of the motion picture camera to celestial photography. Proc. Am. Philos. Soc., 70:371–79.

With Francis C. McMath and Henry S. Hulbert. Some new methods in astronomical photography, with application to moving pictures of celestial objects. Publ. Obs. Univ. Mich., 4:53–73.

1932

Motion pictures enter astronomy. The Telescope (A Quarterly Review of the Perkins Observatory), 8:4–6.

1933

With Robert M. Petrie. The spectroheliokinematograph. Publ. Obs. Univ. Mich., 5:103–17.

1934

With Walter A. Grieg. A new method of driving equatorial telescopes. Publ. Obs. Univ. Mich., 5:123–31.

With R. M. Petrie. A short-lived solar disturbance. Publ. Obs. Univ. Mich., 6:43–44.

1935

With Robert M. Petrie and H. E. Sawyer. Relative lunar heights and topography. Publ. Obs. Univ. Mich., 6:67–76.

The new solar tower of the McMath–Hulbert Observatory. Publ. Am. Astron. Soc., 8:215–16.

1937

The tower telescope of the McMath–Hulbert Observatory. Publ. Obs. Univ. Mich., 7:1–56.

With Edison Pettit. Prominences of the active and sun-spot types compared. Astrophys. J., 85:279–303.

With Edison Pettit. Some new prominence phenomena. Publ. Astron. Soc. Pac., 49:240–41.

With Edison Pettit, H. E. Sawyer, and J. T. Brodie. An eruptive prominence of record height and velocity. Publ. Astron. Soc. Pac., 49:305–8.

1938

With Edison Pettit. Motions in the loops of prominences of the sun-spot type, class III b. Publ. Astron. Soc. Pac., 50:56–57.

With Edison Pettit. Prominence studies. Astrophys. J., 88:244-77.

With Edison Pettit. A quasi-eruptive prominence observed in hydrogen. Publ. Astron. Soc. Pac., 50:240-41.

With Edison Pettit. The development of eruptive prominences. Publ. Am. Astron. Soc., 9:159–60.

The surface of the nearest star. Scientific Monthly, 47:411–20.

Recent studies in solar phenomena. Proc. Am. Philos. Soc., 79:475–98.

1939

Motion pictures of small chromospheric flocculi. Monthly Notices of the Royal Astronomical Society, 99:559–60.

With Edison Pettit. The Doppler effect in an eruptive prominence. Publ. Astron. Soc. Pac., 51:154–57.

With Harold E. Sawyer. Location of velocity changes in a class IIIb prominence. Publ. Astron. Soc. Pac., 51:165–66.

With Harold E. Sawyer. A review of Lake Angelus prominence observations. Publ. Obs. Univ. Mich., 7:191–208.

1940

Solar prominences in motion. Annual Report of the Smithsonian Institution, no. 3634:121–29.

The *McGregor Building and tower telescope of the McMath–Hulbert Observatory.* Nature, 146:387–88.

With H. E. Sawyer, John Brodie, and Orren C. Mohler. A report on the solar prominence radial velocity program of the McMath–Hulbert Observatory. Publ. Am. Astron. Soc., 10:59–60.

With H. E. Sawyer, Orren Mohler, and J. Brodie. A method of measuring radial velocities in solar prominences. Publ. Obs. Univ. Mich., 8:57–59.

1941

The Francis C. McMath memorial 24-inch reflecting telescope of the McMath-Hulbert Observatory. Publ. Obs. Univ. Mich., 8:95–101.

With H. E. Sawyer and Orren C. Mohler. The measurement of space motions of solar prominences. Publ. Obs. Univ. Mich., 8:123–32.

The Julius F. Stone spectroheliograph for the determination of solar atmospheric radial velocities. Publ. Obs. Univ. Mich., 8:141–47.

1942

Heber Doust Curtis, 1872–1942. American Philosophical Society *Yearbook*, pp. 339–44.

1947

Photographing solar prominences. Journal of the Photographic Society of America, 13:97–101.

With Orren C. Mohler, Arthur Adel, and Leo Goldberg. New atomic lines in the infra-red solar spectrum. Phys. Rev., 72:644–45.

With Orren C. Mohler. High-dispersion solar spectrum in the 10,000 A to 20,000 A region. Publ. Astron. Soc. Pac., 59:267–69.

1948

With Orren C. Mohler. Solar infrared reflecting spectrometer. Sky Telesc., 7:143–44, 158.

With Orren Mohler. New bands in the telluric spectrum. Publ. Astron. Soc. Pac., 60:119–20.

With Leo Goldberg and Orren C. Mohler. Telluric bands of methane in the Fraunhofer spectrum. Phys. Rev., 73:1203–4.

With Orren Mohler. Simultaneous observations of solar flares, surges, and high-speed dark flocculi. Observatory, 68:110–11.

With Leo Goldberg and Orren C. Mohler. Spectroscopic evidence for ammonia in the earth's atmosphere. Phys. Rev., 74:352–53.

With Orren C. Mohler and Leo Goldberg. The abundance and temperature of methane in the earth's atmosphere. Phys. Rev., 74:623-24.

With Leo Goldberg and Orren C. Mohler. Isotopes of carbon and oxygen in the earth's atmosphere. Phys. Rev., 74:1881–82.

With Helen W. Dodson. Solar filament of September 7, 1948. Publ. Astron. Soc. Pac., 60:366–67.

1949

With Orren C. Mohler and Leo Goldberg. Excited-state bands of atmospheric CO_2. Phys. Rev., 75:520–21.

With Orren C. Mohler and Leo Goldberg. Telluric bands of CH_4 in the solar spectrum. Astrophys. J., 109:17–27.

With Leo Goldberg and Orren C. Mohler. New solar lines in the spectral region 1.52–1.75μ. Astrophys. J., 109:28–41.

With Orren C. Mohler. Solar spectroscopy with a Cashman cell. Journal of the Optical Society of America, 39:903–7.

With Leo Goldberg. Recent exploration of the infrared solar spectrum at the McMath-Hulbert Observatory. Proc. Am. Philos. Soc., 93:362–72.

Wtih Leo Goldberg, Orren C. Mohler, and A. Keith Pierce. Carbon dioxide in the infra-red solar spectrum. Phys. Rev., 76:1848–58.

With Orren C. Mohler, A. Keith Pierce, and Leo Goldberg. Note on Methane in the infra-red solar spectrum. Phys. Rev., 76:1533–34.

1950

With A. Keith Pierce, Orren C. Mohler, Leo Goldberg, and Russell A. Donovan. N_2O bands in the solar spectrum. Phys. Rev., 78:65.

With Leo Goldberg, Orren C. Mohler, and A. Keith Pierce. The $3\nu_3$-band of telluric CO_2 in the solar spectrum. Phys. Rev., 78:74.

With Leo Goldberg, Orren C. Mohler, and A. Keith Pierce. New

solar lines in the spectral region 1.97–2.49μ. Astrophys. J., 111: 565–71.

With A. K. Pierce, Leo Goldberg, and O. C. Mohler. Observations of solar limb darkening between 0.5 and 10.2μ. Astrophys. J., 112: 289–98.

With O. C. Mohler, A. K. Pierce, and L. Goldberg. *Photometric Atlas of the Near Infrared Solar Spectrum from* $\lambda 8465$ *to* $\lambda 25{,}242$. Ann Arbor: University of Michigan Press. viii + 234 pp.

1951

With Francis C. McMath and Henry S. Hulbert. The McMath–Hulbert Observatory. In: *The University of Michigan: An Encyclopedic Survey*, vol. 2, part 3, pp. 483–88. Ann Arbor: University of Michigan Press.

1952

With Helen W. Dodson. The limb flare of May 8, 1951. Astrophys. J., 115:78–81.

With Leo Goldberg, Orren C. Mohler, and A. Keith Pierce. Identification of CO in the solar atmosphere. Phys. Rev., 85:140.

With Leo Goldberg, Orren C. Mohler, and A. Keith Pierce. The abundance of CO in the sun and in the earth's atmosphere. Phys. Rev., 85:481–82.

Solar research at the McMath–Hulbert Observatory. Publ. Astron. Soc. Pac., 64:151–64.

1953

With Orren C. Mohler, A. Keith Pierce, and Leo Goldberg. Table of infrared solar lines, 1.4–2.5μ. Astrophys. J., 117:41–65.

Tower telescopes and accessories. In: *The Solar System*, ed. G. P. Kuiper, vol. 1, chap. 9, sect. 4, pp. 605–26. Chicago: The University of Chicago Press.

1955

With Orren C. Mohler and A. Keith Pierce. Doppler shifts in solar granules. Astrophys. J., 122:565–66.

1956

Solar spectroscopy with a vacuum spectrograph. Astrophys. J., 123: 1–8.

With Helen W. Dodson and E. R. Hedeman. Photometry of solar flares. Astrophys. J., Suppl. no. 20, 2:241–70.

With Orren C. Mohler, A. Keith Pierce, and Leo Goldberg. Preliminary results with a vacuum solar spectograph. Astrophys. J., 124:1–12.

1958

McMath–Hulbert Observatory. In: *The University of Michigan: An Encyclopedic Survey*, vol. 4, part 8, pp. 1675–77. Ann Arbor: University of Michigan Press.

1960

With Orren C. Mohler and Helen W. Dodson. Solar features associated with Ellerman's "solar hydrogen bombs." Proceedings of the National Academy of Sciences of the United States of America, 46:165–69.

With A. Keith Pierce. The large solar telescope at Kitt Peak. Sky Telesc., 20:64–67, 132–35.

Astronomical telescopes. In: *McGraw-Hill Encyclopedia of Science and Technology*, 13:449–52. New York: McGraw-Hill Book Company, Inc.

Spectrohelioscope. In: *McGraw-Hill Encyclopedia of Science and Technology*, 12:581. New York: McGraw-Hill Book Company, Inc.

With O. C. Mohler. Telescope driving mechanisms. In: *Stars and Stellar Systems*, ed. G. P. Kuiper and B. M. Middlehurst, vol. 1, pp. 62–79. Chicago: University of Chicago Press.

1962

With O. C. Mohler. Solar instruments. In: *Encyclopedia of Physics*, ed. S. Flügge, vol. 54, pp. 1–40. Berlin: Springer-Verlag.