NATIONAL ACADEMY OF SCIENCES

HAROLD LESTER JOHNSON

1921—1980

A Biographical Memoir by

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National Academies Press
washington d.c.

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April 17, 1921–April 2, 1980

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HAROLD JOHNSON, ONE OF the most productive and influential observational astrophysicists of this century, was born in Denver, Colorado, on April 17, 1921, the son of Averill C. and Marie (Sallach) Johnson. He received his elementary and secondary education in Denver schools and went on to the University of Denver, receiving the B.S. degree in mathematics in 1942. His correspondence makes it clear, however, that his mind was already set on becoming an astronomer.

WAR YEARS AND GRADUATE STUDIES, 1942-48

Graduating with a strong physics background shortly after the entry of the United States in the Second World War, Johnson was immediately recruited by the Radiation Laboratory at the Massachusetts Institute of Technology, where he worked on radar interference techniques. Here he met Albert Whitford, an astronomer then applying electronic techniques to photoelectric measurements of the light of stars. Toward the end of the war years Johnson moved to the Naval Ordnance Test Station, Inyokern, California, where he worked with Gerald Kron, also an astronomer engaged in the photoelectric photometry of stars.

After the war, with Kron's support and encouragement, Johnson began graduate studies in astronomy at the University of California in Berkeley. He completed his thesis work in the remarkably short time of two years and received his Ph.D. in 1948. His thesis adviser was Harold Weaver, and his thesis project involved the development of an electronic plate measuring machine. Most of the work was done at Lick Observatory on Mount Hamilton, where further association with Kron turned Johnson's attention to photoelectric photometry. His first two papers, published in 1948-49 in *The Astrophysical Journal* and the *Publications of the Astronomical Society of the Pacific*, dealt with electronic circuitry and with the ultimate sensitivity limit set by quantum noise. These marked the beginning of a lifetime of dedication to high-precision astronomical photometry, a field of which he was to become the leading practitioner.

RESEARCH AT LOWELL, WASHBURN, AND YERKES OBSERVATORIES, 1948-59

Upon completion of his work for the Ph.D., Johnson accepted an offer to join the staff of Lowell Observatory, Flagstaff, Arizona, where he spent the second half of 1948, building an AC electronic amplifier for the observatory solar variation project under a Weather Bureau contract. This first AC amplifier did not work well, however, and it was eventually replaced by a standard DC amplifier. This initial period at Lowell Observatory did not measure up to Johnson's expectations either, and at the end of 1948 he moved to Washburn Observatory as assistant professor at the University of Wisconsin in Madison. There he joined the project started by Joel Stebbins and Albert Whitford to establish a photoelectric calibration for the stars in selected areas then used as standards for the magnitudes of Cepheid variables in local group galaxies. Johnson's expertise was important in extending the sequences to fainter limits. This study showed conclusively that the previous photographic calibration erred by nearly a magnitude (a factor of more than 2 in intensity) at the faint end. The corrections found necessary entered into the ensuing revisions of the cosmic distance scale, which put external galaxies considerably farther away than they had appeared to be in the first estimates. This work confirmed Johnson's determination to push the photoelectric technique to its extreme limits, which he did very successfully over the next ten years.

Johnson moved then to the Yerkes Observatory of the University of Chicago, where he was an assistant professor for two years (1950-52). There he met William W. Morgan, then the leading expert in stellar spectral classification and with whom he would soon begin a momentous research on the combined photometric and spectroscopic properties of stars which, as will be explained below, led to revolutionary advances in astrophysics. Neither the teaching profession nor the murky skies of the Chicago area were much to Johnson's liking, however, although he had access for his observations to the clear skies of McDonald Observatory in West Texas, which was then under the management of the Chicago astronomers. At any rate, upon learning that veteran Lowell astronomer C. O. Lampland (1873-1951) had passed away, Johnson revisited Flagstaff in early 1952 and convinced the elderly director, Vesto M. Slipher, that a second try at using his talents would be in the best interest of the observatory. This was agreed and in August 1952 Harold Johnson returned as staff astronomer to Lowell Observatory, where free of teaching duties and under a favorable sky, he could devote full time to his efforts to push stellar photoelectric photometry to its ultimate limits.

Prior to 1950 photoelectric photometry had been a difficult technique reserved to a few skilled practitioners. In these early years the charge generated over a specified time interval was measured with an electrometer, a delicate device transplanted from the physics laboratory to the focal plane of a moving telescope. Paul Guthnick in Germany and Joel Stebbins in the United States were among the few to have successfully mastered the technique. The charge sensitivity fell far short of reaching the quantum noise limit. The thermionic amplifier introduced by Whitford in 1930 considerably increased the sensitivity of photoelectric observations. The development of the electrostatically focused multiplier phototube by RCA in 1940 eliminated the need for a low-level amplifier and provided better cathode response. The greatly simplified technique encouraged a larger number of astronomers to enter the field, including those with smaller telescopes.

Photoelectric photometry was thus just coming of age when Johnson began his two-year period at Yerkes Observatory in 1950. He realized that the inherent linearity of the photoelectric process (favorable for direct subtraction of the superimposed light of the night sky—a large correction when observing faint stars) had to be preserved and that all fluctuations introduced by the equipment had to be reduced to a level below that of the unavoidable statistical fluctuations in the number of photoelectrons released by starlight. He also realized the need for better definition of the measured quantity, the stellar magnitude of the observed object. This required knowing the spectral sensitivity function of the system, including all the optics in front of the detector (atmosphere, telescope, filter).

Early photoelectric observers had attempted to match their measured magnitudes to the international photographic and photovisual systems adopted by the International Astronomical Union in 1922, following extensive measures of a set of stars near the north celestial pole, the "North Pole Sequence," by many astronomers at several observatories and especially by Frederick H. Seares at Mount Wilson Observatory. The photovisual system, based on orthochromatic emulsions and a yellow filter, was intended to match the average sensitivity of the human eye, the first “instrument” used to estimate stellar magnitudes. With a suitable color filter in front of the photocell, a reasonably satisfactory match could be obtained.

Attempts to match the international photographic magnitudes were complicated by the wide spectral range covered by blue-sensitive photographic emulsions, a difficulty that had led to poor agreement between magnitudes measured with different telescopes; the ultraviolet cutoff was dependent on absorption by the flint glass component in refractors or on the falling reflectivity of the silvered mirrors in reflectors. After 1933 the change from silver to aluminum coatings, with their higher UV reflectivity, led to further complications.

Johnson recognized that these difficulties arose from inclusion to a varying degree of the near ultraviolet around λ 0.37-0.38 microns, where the energy distribution in stellar spectra varies rapidly. He demonstrated that a reproducible magnitude system could be established by placing a suitable filter before the photographic plate or photocell to block all wavelengths shorter than λ 0.38 microns. Also, the overall shape of the spectral energy distribution could be better defined by using, in addition to the yellow and blue bands, a third color in the ultraviolet near the head of the Balmer series of hydrogen and thus sensitive to the size of the Balmer jump, a measure of the temperature and density in stellar atmospheres. In collaboration with W. W. Morgan and D. L. Harris, Johnson thus introduced a new standard system of stellar photometry, the U, B, V system, based on ten primary standard stars and, initially, 108 secondary standards well distributed around the northern and equatorial zones of the sky accessible from the McDonald and Lowell observatories where his observations were made. The new system was published in epoch-making papers in *The Astrophysical Journal* in 1953-54 and in *Annales d'Astrophysique* in 1955.

The system was rapidly adopted and quickly became the de facto international standard of stellar (and, later, galaxy) photometry, a role it has retained to this day. Johnson, alone or in collaboration with Allan Sandage, Richard Mitchell, Braulio Iriarte, and others, made massive applications of this system to galactic clusters, producing well-defined, precise color-magnitude and color-color diagrams, that is, plots of apparent V magnitude versus B-V color indices (resembling the Hertzsprung-Russell diagram of luminosity versus effective temperature) and of U-B color versus B-V. He established the fundamental properties of these diagrams and showed how to use them to disentangle the effects of temperature (intrinsic) and interstellar reddening (extrinsic). After his move to Flagstaff he demonstrated how clusters of different ages have characteristically different color-magnitude diagrams and, in particular, how the "turn-off" point where the stars begin to depart from the "zero-age" main sequence can be used to estimate fairly precisely the ages of the clusters. This striking observational confirmation of theoretical modeling, initially by Martin Schwarzschild, of the paths that stars follow on the color-magnitude diagram in their post-main-sequence evolution opened the way to many investigations of stellar and cluster ages that are continuing to this day. For this work Harold Johnson was awarded, in 1956, the Helen B. Warner Prize by the American Astronomical Society.

During this period in Flagstaff, Johnson was also one of the first (simultaneously with William Baum at Palomar) to push the sensitivity of photoelectric photometry to the quantum noise limit by developing pulse-counting photometers, essentially counting photoelectrons one by one. In his pursuit of the ultimate precision, he also built what was probably the first two-channel photometer, one measuring the star under study and the second simultaneously measuring through an identical aperture the variable luminosity of the night sky in a nearby spot, thus eliminating, by difference, the troublesome fluctuations of the night airglow. By rapidly reversing the roles of the two channels, any systematic difference between the two optical trains and photomultipliers was neatly eliminated. Johnson developed convenient forms to facilitate (in those precomputer days) the reduction of photoelectric observations, designed an ingenious analog-to-digital device to measure the star and sky deflections on chart records of the photo-current, and defined the rigorous procedures to be followed to obtain the highest precision in this type of observation.

During his second period on the Lowell staff, Johnson was also actively engaged with Aden B. Meinel in the site survey for the future National Optical Astronomical Observatory (NOAO), which was eventually built on Kitt Peak near Tucson.[1] In 1956 he actually spent six months in Phoenix, where the initial NOAO office was located at the time. He was even considered by the first director, Leo Goldberg, for a top research position in the new organization but eventually decided to return full time to Flagstaff at the end of 1956.

The author of this memoir was fortunate to become Johnson's colleague and friend during his stay at Lowell Observatory in 1957-58, when he began a long-term program of galaxy photometry in the U, B, V system, initially with Johnson's photometer attached to the 21-inch reflector. This program, since continued at McDonald Observatory (and elsewhere by many others), has provided the basis for the most generally used systems of total magnitudes and colors of galaxies.

AT THE UNIVERSITY OF TEXAS, 1959-62

Toward the end of 1959 Johnson accepted an invitation of Gérard Kuiper, director of the Yerkes and McDonald observatories, to join, as professor of astronomy, the newly formed Department of Astronomy of the University of Texas at Austin. He became briefly its chairman in 1961-62 after Kuiper relinquished his directorship and the chairmanship of the joint Chicago-Texas department to move to the University of Arizona in Tucson, where Johnson was soon to follow him.

Johnson's years at Texas were very productive in the sense that he developed and used much new equipment at McDonald Observatory, but frustrating because he failed to receive from the university administration whole-hearted support for the kind of research and development he wanted to give to the department and, especially, the observatory. He was more interested in the directorship of the observatory than the chairmanship of the department, but the administration saw things differently.

It is during this period in Texas that Johnson first came in contact with Frank Low, who was then a physicist with Texas Instruments in Dallas, where some very sensitive infrared detectors were being developed. Johnson immediately seized on this opportunity to build a photometer extending the U, B, V system to the longer wavelengths of the near infrared, the R, I, J, K, and L bands out to 4 microns. With Low's germanium bolometer, this was later extended to the N band at 10.2 microns. The ability of the longer wavelengths to better penetrate the selectively obscuring interstellar haze opened new avenues of research. The longer wavelength also gave more information on the radiation from cool stars, which, by Wien's displacement law, is mainly emitted in the infrared and is heavily blanketed by molecular absorption bands in the visible. The results were first reported in *The Astrophysical Journal* in 1962.

It was also during his stay in Austin that Harold Johnson became aware of the remarkable work of Larry Mertz, at Harvard Observatory, where he had built the first experimental Fourier-transform interference spectrometer (1958-59). This author, who was there at the time, remembers vividly how the Harvard faculty failed to appreciate the significance of what Mertz was doing and dismissed him as a mere "tinkerer." Made aware of Mertz's work, Johnson immediately grasped the enormous potential of interference spectrometry, particularly for the infrared, and before leaving Texas proceeded to build the first successful Fourier-transform stellar interferometer working in the near infrared. He was to greatly improve and develop this technique after his move to Arizona.

AT THE LUNAR AND PLANETARY LABORATORY, UNIVERSITY OF ARIZONA, 1962-69

In February 1962 Johnson accepted Gérard Kuiper's invitation to follow him to join the newly created Lunar and Planetary Laboratory (LPL) at the University of Arizona in Tucson, where he served as a research professor (1962-67) and then associate director (1967-69). Although Johnson did make some applications of his early version of the Fourier-transform spectrometer to the infrared spectra of the major planets, he was free to pursue his main line of interest—namely, the infrared photometry and interference spectroscopy of stars. He used to joke that he was the "stellar division" of the Lunar and Planetary Laboratory. It is fortunate for astronomy that Kuiper was a far-seeing scientist able to accept on his staff a gifted and productive individual, even if he was not working on the main line of interest to the institution.[2]

Among the many contributions made by Johnson in this atmosphere of freedom under the favorable skies of southern Arizona, where Kuiper had established a fine high-altitude observatory in the Catalina Mountains northeast of Tucson, we may mention major papers on the infrared photometry of late-type and carbon stars, studies of atmospheric and interstellar extinction, massive catalogs of eight- and later thirteen-color photometry of bright stars (in collaboration with R. I. Mitchell, W. Z. Wisniewski, and B. Iriarte) published in the *Astrophysical Journal* and *Communications of the Lunar and Planetary Laboratory* between 1962 and 1969. Johnson, not satisfied with the differential measurements of stellar magnitudes, also undertook the more difficult task of performing an absolute calibration of stellar magnitudes in terms of energy fluxes. He was thus able to produce absolute energy curves, eventually extended up to 20 microns, for all sorts of important categories of stars: subdwarf stars, cepheids, M stars, carbon stars, infrared objects, and even circumstellar shells.

One of the most important discoveries made by Johnson during this period was the great intensity of the infrared emission of the prototype quasar, 3C273, surpassing even its visible emission. This result was soon found to be a general property of the radiation from quasars and other active nuclei of galaxies.

During the same period Johnson utilized the accumulated observational data on the spectral energy distributions of stars of all types to derive a new set of bolometric corrections to their visual magnitudes and then to establish a revised temperature scale more directly based on observed energy distributions. He also used observations of reddened stars in galactic clusters to discuss the wavelength dependence of extinction by interstellar dust. The infrared excess at the longest wavelengths in certain clusters over the normal absorption was, in the end, identified as radiation from warm circumstellar dust shells, rather than abnormal properties of the interstellar dust particles. The fundamental contributions were summarized in classical review papers in *Annual Reviews* and in the standard compendium *Stars and Stellar Systems*, where Johnson also described in some detail the construction of his stellar photometers. Many photometers built after Johnson's design are still in use around the world. Johnson's election to the National Academy of Sciences in 1969 recognized his major influence on the progress of astronomy during the previous twenty years.

During this same period also Johnson began to be interested in the design and construction of low-cost medium-size reflectors, specially designed for infrared photometry and Fourier-transform spectroscopy. An experimental 60-inch reflector made of spun aluminum was successfully built and tested under his direction at the Catalina station. It was later transferred to the Mexican National Observatory in Baja California. The "poor" optical quality (by ordinary standards) was quite good enough to feed most of the energy of the infrared image of a star into the rather large entrance aperture of the photometer or spectrometer. His ideas of building cheap telescopes for specialized tasks were not without their detractors, but Johnson was more interested in doing "great" science than "big" (meaning expensive) science. If results of equal significance could be gotten more cheaply, he would prefer the latter, a case of brain versus brawn, which proved itself a decade later in his contributions to Mexican astronomy.

THE ARIZONA-MEXICO CONNECTION, 1969-80

Harold Johnson had for many years collaborated with Mexican astronomers Braulio Iriarte and Eugenio Mendoza, among others, informally assisting them in their research with advice and the loan of photometers. In 1969 this association was formalized when he became a part-time member of the scientific staff of the Institute of Astronomy of the National University of Mexico, eventually becoming a full-time professor in 1979 when he actually moved to live in Mexico City. In 1973 he was one of the founders and in 1975 became head of the Department of Applied Physics of the newly created Center for Scientific Research and Higher Education in Ensenada, Baja California Norte. He maintained, however, his ties to Arizona, where in 1969 he transferred to the Optical Sciences Center (then headed by Aden B. Meinel) as research professor and to the Steward Observatory (then headed by Bart J. Bok, 1906-83) as astronomer. He maintained this dual connection with Mexico and Arizona until the end.

Johnson's active involvement in Mexican astronomy began in 1964 with his participation in multicolor observations of bright stars with the 1-meter (40-inch) reflector of the Tonantzintla Observatory near Puebla. He helped with the search for the best location for the new national observatory. His support of a proposal by E. E. Mendoza to then director G. Haro, identifying a peak in the Sierra de San Pedro Mártir, Baja California, at an altitude of 2,800 meters (9,200 feet) among the pine trees of a protected national forest, as suitable for the proposed observatory, was crucial—according to Mendoza, "Without his help, no SPM observatory, most likely." Of special importance and of interest to Johnson was the low water vapor content of the atmosphere, making it very suitable for work in the infrared. The main telescope, with a 2.1-meter main mirror, embodying many of Johnson's ideas, was dedicated and began operation in 1979. In grateful recognition of his role in this project and in the development of Mexican astronomy in general, the National University of Mexico conferred him the degree of doctor honoris causa in 1979 and, after his untimely death the next year, the Universities of Mexico and Arizona named after him the 1.5-meter aluminum-mirror infrared telescope Johnson had brought from Arizona to Mexico. Symposium 96 of the International Astronomical Union on Infrared Astronomy held in 1980 was dedicated to Harold Johnson's memory.

Building on the laboratory facilities he had in Tucson, where he remained active during his Mexico years, Johnson perfected a high-resolution Fourier-transform infrared spectrometer, using as its core a Michelson interferometer built by the Block Engineering Company of Boston, under the direction of Larry Mertz. Johnson and his associates, F. F. Forbes, R. I. Thompson, and D. L. Steinmetz of the University of Arizona and O. Harris of the National University of Mexico, used it on several telescopes in Arizona and on the NASA Lear jet stratospheric observatory to produce high-resolution spectra of the sun and bright stars in the spectral range of 1.0 to 4.0 microns (stars) and 5.6 microns (sun). The results were first reported in the *Publications of the Astronomical Society of the Pacific* in 1973. Later the results were collected in a comprehensive *Atlas of Stellar Spectra.* The resolution of 0.5 centimeters^{-1} corresponds to about 0.1 angström unit in the middle of the range, possibly the highest resolution ever achieved on astronomical sources in this spectral region. The tracings of the infrared spectra of bright stars and planets, displayed in Johnson's Tucson laboratory, covered several tens of meters on the walls!

Toward the end of his life Johnson became increasingly interested in the design and construction of mirror arrays, that is, multiple-mirror telescopes, as a way to realize large apertures at a fraction of the cost of solid monolithic mirror telescopes. In this field too he was a pioneer, and he proposed to build for Mexico an array of twenty 2-meter telescopes—"Mextels," as he called them—to provide the light-gathering power of a 10-meter telescope at half the cost. A prototype was built and installed at the national observatory site. The multimirror scheme has now been widely accepted and implemented around the world as the way to build super-large telescopes.

HAROLD JOHNSON AS FRIEND AND COLLEAGUE

Little is known of the private life of Harold Johnson. He was married to Mary Elizabeth Jones in 1954. They had two children: August Harold and Selma Marie. After Harold's untimely death in 1980 in Mexico City, Mary returned to Tucson, where she lives in retirement.

To those who did not know him well, Harold Johnson may have seemed to be often blunt, brusque, and lacking in the suave polish necessary to become a successful academic. He did not care much for formal teaching. It may be true that as a colleague Johnson was occasionally difficult to live with, but it was well worth the effort. He suffered all his life from breathing problems that got worse with time and may well have influenced his personality. But he was a fundamentally honest man, with a strong religious bent (once he even attended a revival meeting) and a profound dedication to the truth in science as well as everyday life. He was impatient with mediocrity, and all his life was dedicated to striving for the ultimate precision and exactitude in his several fields of endeavor, in each of which he made fundamental contributions. He was always willing, even eager, to share his profound knowledge of photometry and electronics with students, associates, and colleagues. He had an extraordinary skill in designing and building new instruments; he had "electrons in his finger," as an envious and admiring competitor remarked once. He knew better than anyone how to build amplifiers whose response was linear over an enormous range of intensities; he built one at McDonald Observatory with which he could measure with the 2.05-meter reflector without loss of linearity from Sirius to 22-nd magnitude stars—that is, an interval of 2.5 billions to 1 in light flux.

EPILOGUE

Harold Johnson brought extraordinary instrumental and electronic talents to devising equipment that utilized to maximum advantage newly developed photoelectric detectors as they became available. His measurements of the colors and magnitudes of stars in galactic clusters on the precisely defined system he devised in collaboration with W. W. Morgan led to age determinations that opened the way to exploitation of the color-magnitude diagram as a diagnostic in studies of stellar evolution. He had a leading role in the use of new infrared detectors in the photometry of stars and galaxies. With his colleagues he measured thousands of stars that became reference standards.

Johnson applied these measurements to calibrate spectral energy distributions of stars and thus provide an improved observational basis for the stellar temperature scale and the bolometric corrections to visual magnitudes. He was the first to apply Mertz's concepts to build practical stellar Fourier-transform spectrometers; for cool stars, in particular, these gave unsurpassed resolution in the infrared. These fundamental contributions to observational astrophysics constitute Harold Johnson's enduring scientific legacy.

The twenty-five titles in this memoir's selected bibliography are among the most important of some 135 papers published by Johnson between 1948 and 1980, but many of the others were no less significant and influential. His last two papers appeared posthumously in 1981 in the proceedings of the symposium "Recent Advances in Observational Astronomy (UNAM, 1981)," which he helped organize. He died of a heart attack in Mexico City on April 2, 1980.

THIS MEMOIR HAS BENEFITED ENORMOUSLY from the generous collaboration of Albert Whitford, who not only provided his own reminiscences of Harold Johnson's early scientific contributions but also communicated copies of letters in the Lick Observatory Mary Lea Shane archives and secured a valuable testimony from Gerald E. Kron, all referring to Johnson's period as a graduate student at Lick and Berkeley. Whitford kindly revised, corrected, and enlarged several sections of this memoir but modestly declined to be named as a coauthor. I am deeply grateful for his contribution. I also acknowledge valuable communications from H. C. Giclas, Lowell Observatory; E. E. Mendoza V, University of Mexico; and W. Z. Wisniewski, University of Arizona at Tucson. The frontispiece photograph of Harold Johnson, taken in 1965 at LPL by D. Milon, was kindly provided by E. A. Whitaker, University of Arizona at Tucson.

NOTES

1. The writer remembers that Johnson's own preference for the site of the new observatory was an isolated peak, Slate Mountain, in the desert northwest of Flagstaff as a better, darker, and dryer site than Kitt Peak and likely to remain free of light pollution for many years, but practical considerations of accessibility, development costs, and living convenience for the staff prevailed in the end.

2. A very readable account of the founding and early years of LPL written by Ewen A. Whitaker (University of Arizona, 1985) includes a section on Johnson's contributions.

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