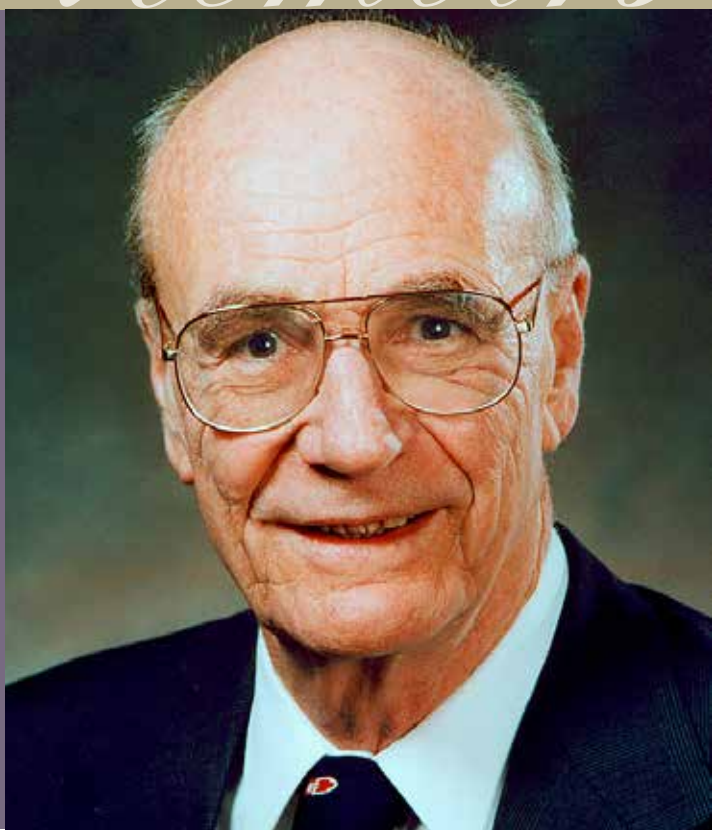
# Donald E. Osterbrock

1924–2007

BIOGRAPHICAL *Memoirs*



*A Biographical Memoir by*
*Gregory A. Shields*



NATIONAL ACADEMY OF SCIENCES

# DONALD EDWARD **OSTERBROCK**

*July 13, 1924–January 11, 2007*

Elected to the NAS, 1966

Donald E. Osterbrock was born in Ohio during the first quarter of the 20th century and died in California during the first quarter of the 21st. His astronomical research showed an exceptional mastery both of theory and observation. After important initial contributions to the understanding of the Milky Way and stellar structure, he did outstanding work on emission-line nebulae, on active galactic nuclei, and on the history of astronomy. He was an excellent teacher, and many of his doctoral students went on to distinguished careers in astronomy. He served as director of the Lick Observatory and as president of the American Astronomical Society. Those who worked with him appreciated his style of simplicity and directness, which were likely rooted in his Midwestern upbringing.

Donald Osterbrock

*By Gregory A. Shields*

## Early years

Donald E. Osterbrock (or "Don," as his friends and associates called him), was born on July 13, 1924, in Cincinnati, Ohio. His parents, William C. and Elsie Wettlin Osterbrock, had lived their entire lives in that city on the bank of the Ohio River. His father's parents and mother's grandparents had emigrated from Germany. Don's father, talented in physical sciences and mathematics, graduated from the University of Cincinnati in 1918 and was hired as an instructor in electrical engineering, ultimately becoming chair- man of the department. His parents enjoyed the outdoor life, and the family (including Don's younger brother, Carl) often went on Sunday outings to the countryside. Don gained more experience with nature at summer camp and as a Boy Scout. His boyhood hobbies included stamp collecting and envelopes postmarked on U.S. Navy ships.

Don was an avid reader, especially of books on astronomy borrowed from his high-school library. He participated in the local astronomy club, which met at the Cincinnati Observatory. There he observed with the 12-inch refractor and also heard lectures by such distinguished visitors as Harlow Shapley and Otto Struve.

In Okinawa as weather observer for U.S. Army. February 1946.

Don was in his senior year of high school when the Japanese attacked Pearl Harbor on December 7, 1941. After graduating and spending a few months at the University of Cincinnati, he volunteered for the U.S. Army in January 1943. He attended the Army Air Force pre-meteorology school at the University of Chicago, a move that would prove pivotal in shaping his early career path. The one-year course covered all the physics and mathematics required for a bachelor's degree. After completing the course, he went to Victorville Army Air Field in California for training as a weather observer. Then he spent a few months in Hawaii and went on to Okinawa. Following the end of World War II and three years' service in the Army, he resumed his college studies, financed by the G.I. Bill.

## Chicago and Yerkes

Osterbrock returned to the University of Chicago in the fall of 1946 to complete a bachelor's degree in physics, which he earned in 1948, having also attended graduate courses in physics and astronomy. Don often expressed his appreciation for the excellent teachers at Chicago, including Gregor Wentzel and Enrico Fermi, who he considered the best teacher he ever had; Don later emulated, in his own teaching, Fermi's style of emphasizing physical ideas. A number of astronomers came down from the university's Yerkes Observatory (Williams Bay, Wisconsin) to teach, and Don also took several reading courses with Thornton Page, the one resident astronomer at the Chicago campus. Don developed a special interest in gaseous nebulae and interstellar matter, subjects that would play a major role in his later research.

In 1949, Don moved to Yerkes, located in a rural enclave 70 miles from the bustling campus of the University of Chicago. Its famed 40-inch refracting telescope, the first major telescope built under the leadership of George Ellery Hale, was by then seriously outclassed by the large West Coast telescopes, including the Palomar 200-inch. Nonetheless, Yerkes for a time attracted some of the best minds in observational and theoretical astronomy. Don assisted W. W. Morgan in observing OB stars (hot and highly luminous stars concentrated in the spiral arms of our galaxy). By determining the luminosity of these stars from their spectral properties, Morgan, Don, and Don's fellow

graduate student Stewart Sharpless were able to map for the first time the structure of the nearby spiral arms. This was a major result that helped to launch Don's career as a promising research astronomer.

Don's thesis advisor was the theoretical astrophysicist Subrahmanyan Chandrasekhar, who would go on to win the 1983 Nobel Prize in Physics, with Don's thesis subject being the gravitational interactions between interstellar gas clouds and stars and the consequent alterations of stellar orbits and velocities. Also at Yerkes, Don met and married Irene Hansen, a native of Williams Bay who was Morgan's assistant.

## Princeton

After completing his doctoral work at Yerkes, Osterbrock began a postdoctoral fellowship at Princeton University in the summer of 1952. There he worked on a problem in the field of stellar structure, motivated by ideas he encountered in Bengt Stromgren's course on stellar interiors at Yerkes. Martin Schwarzschild, then immersed in pioneering theoretical studies of stellar evolution, served as Don's advisor at Princeton, and Don formed a high opinion of Schwarzschild both for his scientific and human qualities.

Don applied the numerical methods developed by Schwarzschild to investigating the structure of cool main sequence stars—called K and M dwarfs, or "red dwarfs"—having masses smaller than that of the sun. Existing models, with structures similar to the sun's, predicted values for the central temperature and luminosity of the stars that were too high to agree with observation. Don developed alternative models that achieved a good explanation of the observed properties of these stars—a key feature of his models was a deep convective envelope surrounding a core in radiative equilibrium. Toward the end of this work, he made use of the new electronic computer under development at the Institute for Advanced Study (Osterbrock 1953). At Princeton, Osterbrock gained his first teaching experience, giving a graduate course on stellar atmospheres.

It is striking to consider the number of disparate subjects that Don's early papers, written while at Princeton, involved. They covered observational galactic structure, galactic orbits and dynamics, red dwarf structure, convective envelopes, globular clusters, and the heating of the solar corona. And all this was only a prelude to his sustained efforts in the fields of emission-line physics and active galaxies. His breadth of topics, together with a mastery both of theory and observation, were truly exceptional.

## Caltech

In the spring of 1953, Don received an offer to join the astronomy faculty at Caltech; and he accepted. The Caltech astronomy department was formed in 1948, the year that the 200-inch Hale reflector went into service on Palomar Mountain, with Jesse Greenstein as head. When Don arrived later in 1953, Guido Munch and Fritz Zwicky were there, and Art Code followed in 1956. With guidance from Walter Baade and Rudolph Minkowski, Don undertook several observational projects on globular clusters and galaxies. Soon, however, he began a new kind of work that would define the central theme of his research career.

At Yerkes, Don had known Bengt Stromgren, the Danish astronomer who arrived there in 1951 to serve as director. Stromgren had made classic contributions to the understanding of the structure of photoionized nebulae, which are regions of interstellar gas that are heated and ionized by the ultraviolet radiation from hot stars. Such nebulae—which include planetary nebulae surrounding the dense hot cores of recently deceased stars and also H II regions ionized by one or more luminous young stars—have a rich spectrum of emission lines; for that reason they had been an important testing ground for the theory of atomic physics based on quantum mechanics. Some of the emission lines are produced by radiative recombination of electrons with ions, others by the collisional excitation of bound levels by electron impact. Don, who enjoyed atomic physics, took an interest in a 1954 paper, by the British atomic theorist Michael Seaton, that gave cross sections for excitation of low-lying levels of the $O^+$ ion—the process that produces the strong [O II] 3726, 3729 Angstrom emission doublet in nebulae. The intensity ratio of these two lines gives a measure of the electron density in the emitting gas. Don obtained spectra of these lines at many positions across the face of the Orion nebula, thereby mapping the decrease in density in the emitting gas outward from the center of the nebula. In a widely cited follow-up paper, Don and Edith Flather showed that the density in the nebula must be highly inhomogeneous, with most of the line emission coming from clumps of gas that occupy only a small fraction of the nebular volume. This was a crucial insight with implications for the mass of gas in the nebula and the dynamical state of the emitting gas. This concept of a small "filling factor" is found to apply in most ionized nebulae throughout the universe. Don went on to make similar measurements of a variety of other astronomical objects.

At Caltech, Don supervised his first two Ph.D. students, George Abell and John Mathis. The latter researcher's project involved Don's new specialty of nebular astrophysics, in

this case the emission spectrum of He I. Mathis computed the expected line emission resulting from radiative recombination of helium from the ionized to the neutral state, and he used the observed intensities in Orion to measure the abundance of helium relative to hydrogen.

Don remained at Caltech for five years. He appreciated the observing facilities and scientific environment, but he and his wife missed the natural environment of Wisconsin. When Art Code went to the University of Wisconsin in Madison in 1958 to head the astronomy department, Don—age 34 at the time—accompanied him.

## Wisconsin

At Wisconsin, Don helped to establish a graduate program in astronomy and he taught courses on stellar structure, nebulae, and galactic structure. He continued his nebular studies with the new 36-inch reflector at the Pine Bluff Observatory outside Madison, and he supervised a number of Ph.D. theses in this area. Significantly, he also began work on galaxies with emission-line nuclei, which would be his main research area for much of his career. Such objects include "Seyfert galaxies," first systematically studied in 1943 by Carl Seyfert at Mt. Wilson Observatory, which are a rare class of galaxies with bright emission lines from a compact and luminous nucleus.

While on leave at Yerkes in 1963–64, Don used the 82-inch telescope at the McDonald Observatory to observe two bright Seyfert galaxies. In 1965, with his postdoc, Bob Parker, Don published an influential analysis of the nature of the emission-line gas. They also noted the similarity of Seyfert galaxy spectra to those of quasars—the compact but extraordinarily powerful energy sources identified in 1963 by Maarten Schmidt and others at Caltech. This was an early step in the understanding of the relationship of the different types of active galactic nuclei (AGN)—a general term for galaxies with a compact energy source in their center.

In the "monastery" at the Mount Wilson Observatory. Spring 1955.

In his later years at Wisconsin, Don continued to advise Ph.D. students on observational and theoretical topics relating to nebulae and AGN. He also published the first edition of what became a widely used graduate-level book, *Astrophysics of Gaseous Nebulae*.

In 1960–61, early in the Wisconsin period, Don had a research leave at the Institute for Advanced Study in Princeton, New Jersey, supported by a Guggenheim Fellowship. He used this period to do some widely cited theoretical work on the solar corona and on the escape of resonance-line radiation from nebulae. Later, in 1968–69, he spent a year at University College London (UCL), where Seaton and a number of other atomic theorists were located. Under their tutelage, Don carried out new and widely used calculations of the excitation cross-sections for the $C^{+2}$ ion, which has important ultraviolet lines in the spectra of nebulae and AGN. After returning to the United States, Don and Harry Nussbaumer of UCL published cross-sections for multiply charged ions of iron, including $Fe^{+6}$. (This provided the author, several years later, with a basis for calculating the abundance of iron in planetary nebulae; the iron proved to be mostly in the form of dust particles, or "grains," rather than in the gaseous state.)

With Joy Seaton, Irene Osterbrock, and Mike Seaton at a Baltimore symposium. May 1994.

A tragic incident on the university campus affected Don during his time at Wisconsin. Following a series of confrontational protests against the Vietnam War, a bombing occurred in September 1970 at Sterling Hall, where the astronomy department was located. A physics postdoc, with whom Don was acquainted, was killed in the blast. A lifelong liberal Democrat, Don was very much against the war, but he was dismayed at the escalating violence of the demonstrations. He felt that the University of Wisconsin and the city of Madison did not pursue the perpetrators with sufficient vigor.

## Lick Observatory

After several years of courtship, Don agreed to become director of the Lick Observatory, and so he moved to California in 1973, with some reluctance, at the age of 49. He, his

wife, and children loved Wisconsin and their friends and colleagues there. Don felt at home in Wisconsin with its progressive politics. However, he was drawn by the 120-inch telescope on Mt. Hamilton near San Jose, with the new Wampler-Robinson electronic spectrograph, ideal for the AGN work that Don wanted to pursue. The Lick astronomers were by then situated on the campus of the University of California, Santa Cruz, forming a strong research environment.

Despite Don's managerial responsibilities as director, he maintained a high scientific profile; colleagues often noted his ability to switch his thoughts and energies rapidly between administrative matters and science. He kept a separate office for work on research and to meet with students, while the director's office was largely reserved for administrative duties, although a lot of science was done there as well. He pursued an active observing program at Mt. Hamilton, and he made it a point, in his capacity as director, to regularly visit the Observatory, some 60 miles distant from the Santa Cruz campus. Don's administrative director, Joe Calmes, remarked that Don wanted to know what sort of people would live on a relatively remote mountain top and provide the services so crucial to making observational astronomy possible.

Even before taking the reins at Lick, Don began observing a radio galaxy with nuclear emission lines, Cygnus A, with his former Wisconsin Ph.D. student Joe Miller. Their analysis supported the idea that the emitting gas was photoionized by ultraviolet radiation from the central energy source, by then suspected to involve a supermassive black hole in the galactic nucleus. Working at Lick with several graduate students, Don carried out spectroscopic studies of many AGN, with an emphasis on "radio galaxies"—which are similar to Seyfert galaxies but have strong radio emission. Don's work helped to clarify the nature of the line emitting regions in AGN. In particular, the spectra typically show broad emission lines attributed to dense gas moving at high speeds near the center of the nucleus ("broad line region," or BLR), and narrow emission lines from slow moving gas hundreds of light years from the center ("narrow line region," or NLR). Don's work showed a continuous range in the strength of the broad lines among AGN, from highly conspicuous to invisible.

During a 1977–78 leave at the University of Minnesota, Don refined the geometrical picture of the broad line region, proposing a disk-shaped arrangement of gas rotating about the central object, with ionizing radiation able to escape most easily along the rotation axis. This picture is widely accepted today, and it underlies the subsequent use of the broad emission lines to estimate the mass of the central black hole. The disk model

also underlies the now-popular "unified model," in which AGN of widely different appearance can be understood in terms of the same basic object seen from different directions.

An important and controversial topic to this day is the relationship of the broad line region to the "accretion disk" believed to feed matter to the central black hole and to provide the ultimate power source of AGN. Work by Don's graduate student Rick Pogge directly detected "ionization cones" of line emitting gas corresponding to the predicted escape of ionizing radiation along the disk axis. Don and his student Joel Tohline were among the first to show convincingly large variations from year to year in the strength of the broad lines in one Seyfert galaxy. Such variations have since become a powerful tool for exploring the size and kinematics of the broad line region. With his last Ph.D. student, Sylvain Veilleux, Don developed widely used diagrams involving the narrow line intensities that distinguish between various types of emission-line nuclei in galaxies.

When Don arrived as director, the Lick astronomers were clamoring for "more glass"—that is, a larger telescope. The new instrument needed to be located at a site darker than Mt. Hamilton, which was increasingly affected by light pollution from nearby population centers. Lick astronomer Merle Walker had completed extensive surveys of potential observing sites in the United States and around the world. One of those sites, Junipero Serra (also called Santa Lucia) Peak in southern Monterey County, was within 100 miles of the Santa Cruz campus. Under Don's leadership, a new Dark Sky Observatory (DSO) was envisioned. However, after extensive environmental studies and fund-raising efforts, the project ground to a standstill.

Lick astronomer Joe Wampler suggested that what was needed to generate excitement was not another 3- to 4-meter class telescope but something really big in the 8- to 10-meter class. This would be substantially larger than the reigning Palomar 200-inch (5-meter) telescope. With Don's active support, the University of California system formed a Ten-Meter Telescope Committee, which Don chaired from 1978 to 1980. Two innovative ideas were put forward for the design of this telescope. Lick astronomers Wampler and Dave Rank proposed a single-mirror design, or "monolith," which necessarily would be thin to avoid excessive weight. This would involve substantial challenges to avoid breakage and maintain the precise shape needed for the reflecting surface. An alternate concept, developed by Jerry Nelson at the Lawrence Berkeley Laboratory, involved a "segmented" mirror, the final design having 36 hexagonal sections kept in precise alignment by sensors and computer-controlled actuators.

With Al Whitford and Bob Kraft, former directors of the Lick Observatory.

The debate between these two factions was spirited, as each presented studies in support of their design. Don realized the need for a high-level "Graybeards Committee" to make the decision. At a meeting on the Berkeley campus in November 1979, the committee voted to adopt the segmented mirror approach. Participants in this process commented that Don was outstanding in the fair-minded way he conducted the selection process.

In 1981, Don stepped down as director after eight years at the helm, and he was succeeded by Robert Kraft. During Kraft's term, funding was ultimately achieved through a partnership: Caltech provided the capitalization through the W. M. Keck Foundation; and the University of California provided the operating budget for the first 25 years. The resulting Keck telescopes on Mauna Kea in Hawaii stand as testimonials to the successful outcome of this undertaking.

One reason for Don's effectiveness as director of Lick may have been the mix of theorists and observers that was in place there when he arrived. Lick had historically been staunchly observational, but earlier directors had moved in the direction of this "Yerkes model," which fit well with Don's background and temperament.

In the years after his directorship, Don twice returned to the Institute for Advanced Study, in 1982–83 and 1989–90. In addition to maintaining his vigorous research program on AGN, Don revised his book on nebulae. Published in 1984 as *Astrophysics of Gaseous Nebulae and Active Galactic Nuclei* (nicknamed AGN2), the revision contained additional chapters on active galactic nuclei and, like its predecessor, was widely used. A later edition, coauthored with Gary Ferland of the University of Kentucky, appeared in 2006; it contained still more new material on modern topics, in particular infrared and X-ray astronomy.

After his official retirement in 1992, Don continued to pursue an active program of research. One of his interests in later years was the study of the emission-line spectrum of

the earth's atmosphere, which involved the use of spectra from the Lick telescopes originally determined by other astronomers for different purposes.

## Administrative contributions

Don's administrative services to the astronomical community went well beyond his successful term as director of the Lick Observatory. From 1971 to 1973, while at Wisconsin, he served as letters editor of *The Astrophysical Journal*. From 1988 to 1990 he was president of the American Astronomical Society; Don held other positions with the AAS as well, including chairman of the Historical Astronomy Division from 1987 to 1989. The list of other committee assignments and chairmanships, including a number for the National Academy of Sciences, is long.

## Historian of astronomy

A major interest in Don's later years was the history of astronomy. Known for his famous statement, "History is too important to be left to historians," his resume lists 79 historical publications and 55 historical abstracts. Don wrote five excellent books on the history of astronomy. The first, published in 1984, was on James E. Keeler, an early Lick director and pioneer astrophysicist, and the next book was *Eye on the Sky*, which chronicled the first century of the Lick Observatory. Then came a book on George Ritchey and George Ellery Hale. Ritchey was a visionary designer of large reflecting telescopes; Hale was the prime mover behind the Yerkes, Mt. Wilson, and Palomar Observatories. The last two books were on the Yerkes Observatory (1997) and the great Mount Wilson astronomer Walter Baade (2001), who had influenced Don early in his career. These five books, together with Don's other highly readable historical writings, are characterized by a professional astronomer's understanding of the scientific issues together with insights into the personalities and institutional issues at play.

## Interests and honors

Don and Irene's very happy marriage was blessed with three children: Carol, William, and Laura. Don had a strong interest in bird watching and an appreciation of art. He took pleasure in symphonic music, jazz, musicals, and traditional theatre, in particular plays by Ibsen and Strindberg. He and Irene did much theatre-going, both in Wisconsin and California. Don was fascinated by history, even as a boy, and he enjoyed reading biographies along with the works of some English novelists, especially Thackeray.

Don won many of the top awards given to astronomers. They included the Henry Norris Russell Lectureship of the American Astronomical Society, the Gold Medal of the Royal Astronomical Society, and the Bruce Medal of the Astronomical Society of the Pacific.

He was elected to the National Academy of Sciences in 1966. Don served the Academy as head of the Astronomy Section and for many years was coordinator of the biographical memoirs for the Astronomy Section. He was a member of the American Academy of Arts and Sciences and the American Philosophical Society (a rare distinction for an astronomer). Don received honorary doctoral degrees from Ohio State University (1986), the University of Chicago (1992), the University of Wisconsin (1997), Ohio University (2003), and the University of Cincinnati (2004). He served on many advisory committees at the campus, state, and national levels.

At the Yerkes Observatory archives. October 2001.

Don died suddenly on January 11, 2007, while walking from his office to the UC Santa Cruz campus library where the historical archives are kept. He was 82 years old. In keeping with his legendary work ethic, Don was doing the work he loved right up to his very last moment. He will be warmly remembered by those privileged to have known him and to have drawn inspiration from his broad interests, high standards, and human qualities.

## Personal reminiscences

The author first became aware of Don's work during my graduate work at Caltech, where I did a Ph.D. thesis on Seyfert galaxies. I read the study of NGC 1068 by Osterbrock and Parker (1965) with great interest. Thus I was delighted to meet Don at the 1972 meeting in Seattle of the American Astronomical Society. He chaired the morning session in which I spoke and afterward invited me to lunch, along with Kris Davidson, another young astrophysicist interested in emis-

sion-line nebulae and AGN. I recall a cordial discussion of the interpretation of emission-line spectra, during which I quickly sensed Don's high standards.

Back in Pasadena, I wrote to Don to ask how I could get a copy of the Ph.D. thesis that Gordon MacAlpine had recently completed at Wisconsin under Don's supervision. I was amazed when a large envelope soon arrived containing a copy of the thesis, with a note explaining that it was Don's personal copy, which I should return when I was finished with it. I was touched that he would entrust his only copy to a far-away student whom he had only met once. From that moment on, I thought of Don as an ally and friend.

Over the years we corresponded often, and I would see him during my frequent summer visits to the Lick Observatory. We would regularly have lunch together, often joined by Bob Kraft, either in Don's office or Kraft's. We often talked science and occasionally scientific politics. Don's work ethic was in evidence during my visits. I would sometimes go to the office on Saturday mornings and he would usually be there, often the only faculty member around. Typically, he left at noon to meet Irene for lunch at their home near campus. Ironically, he would stick his head in my office on the way out and say, "Greg, don't work too hard!"

Increasingly in later years, I loved to draw him out on his impressions of the institutions and scientists he had dealt with over the course of his career. He seemed never to tire of sharing these reminiscences! Don was always correct, cordial, and supportive, especially of aspiring young astronomers. Although there was a certain formality and reserve to his personal style, I found that his letters, usually handwritten until he adopted e-mail, had a special warmth that went beyond his normal bearing in conversation. While one was fully confident of Don's loyalty, one might wish for a deeper look into his inner thoughts and feelings. Still, Don would not hesitate to let you know if he was unconvinced of your ideas or arguments. Many have been treated to his trademark skeptical rejoinder, "I hear you talking!"

The author is grateful to Irene Osterbrock, Robert Kraft, Sandy Faber, Michael Bolte, Joe Calmes, Sylvain Veilleux, and Ken Kellermann for their valuable assistance, reminiscences, photographs, and comments on the manuscript.

## HONORS AND FELLOWSHIPS

Member, National Academy of Sciences (1966)

Henry Norris Russell Lectureship, American Astronomical Society (1991)

Catherine Wolfe Bruce Gold Medal, Astronomical Society of the Pacific (1991)

Antoinette DeVaucoulers Memorial Lectureship and Medal, University of Texas at Austin (1994)

Gold Medal, Royal Astronomical Society (1997)

University of Chicago Alumni Medal (2000)

Leroy E. Doggett Prize for Historical Astronomy, American Astronomical Society (2002)

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