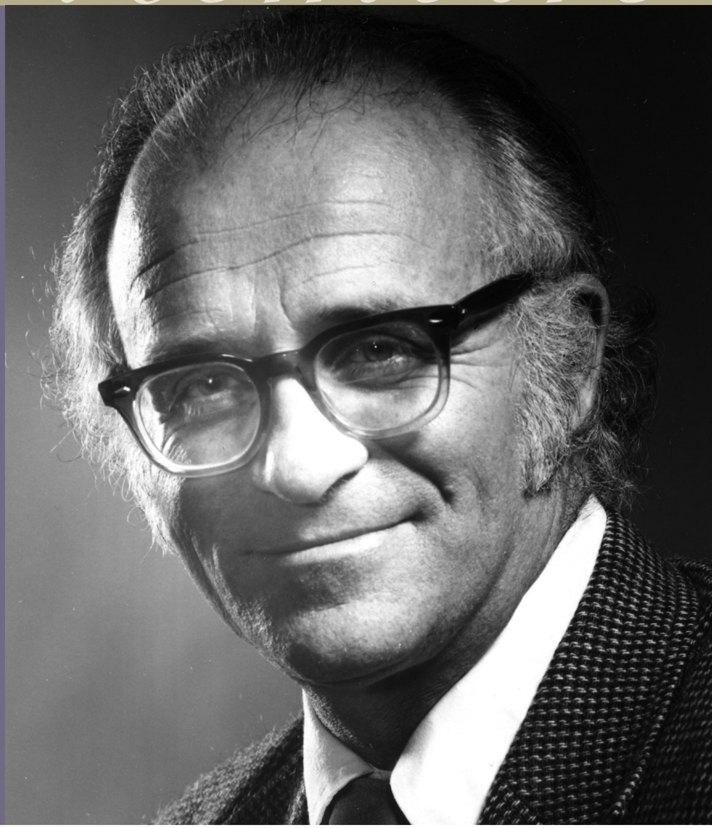
Bernard F. Burke

1928-2018

BIOGRAPHICAL *Memoirs*



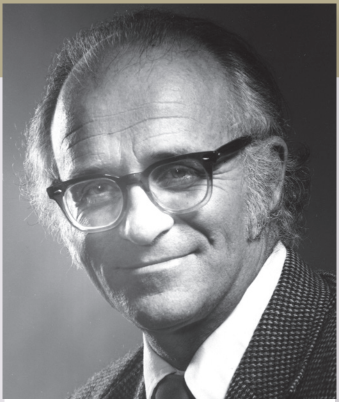
A Biographical Memoir by
J. M. Moran and
K. I. Kellermann

NATIONAL ACADEMY OF SCIENCES

BERNARD FLOOD **BURKE**

June 7, 1928–August 5, 2018

Elected to the NAS, 1970



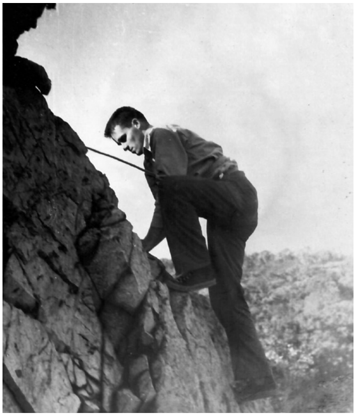
By J. M. Moran and K. I. Kellermann

Bernard "Bernie" Flood Burke was among the first generation of radio astronomers in the United States. He spent most of his career at the Massachusetts Institute of Technology (MIT), first as a student and then as a member of the Department of Physics faculty. Along with Alan Barrett, he founded the MIT radio astronomy research program and nurtured it for many decades. He trained thirty Ph.D. students and was an outspoken leader and consensus builder who made a great impact on the direction of the field. His half-century of research in radio astronomy extended from solar system investigations to cosmology and included electrical storms on Jupiter, interferometry, radio source surveys, gravitational lensing, interstellar masers, exoplanets, and the cosmic microwave background (CMB). As an elder statesman of U.S. radio astronomy, Burke was frequently called on to provide advice to the National Academy of Sciences (NAS), the National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF) as well as to many universities in the United States and around the world.

Early Life and Education

Bernard Burke was born on June 7, 1928, in Brighton, Massachusetts, and grew up in Lexington, Massachusetts, with two younger sisters, Sarah and Clare. His father, Vincent, was head of the math department at Rindge Technical School (now part of the Cambridge Rindge and Latin School) in Cambridge, and his mother was a technical typist. As a youth, Bernie loved hiking and camping in the White Mountains and rock climbing in the local granite quarries. While a student at Lexington High School, he played on the football team and also became an accomplished viola player. He turned down a full scholarship to study music at a major conservatory in order to go to MIT and study science. He did, however, maintain a lifelong love of music and organized many evenings of classical chamber music in his home.

Bernie met Jane Pann at a folk dancing event, and they were married in 1953. In high school, Jane was a gifted cellist and considered a career in music. After two years at

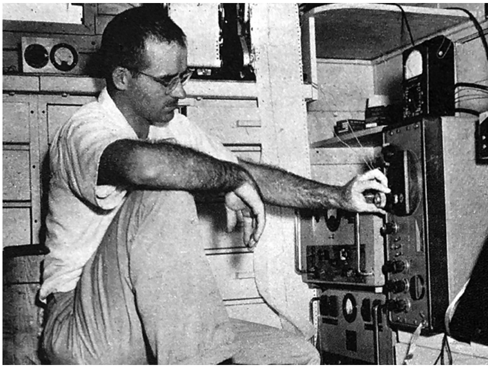

Burke rock-climbing with the MIT Outing Club, circa 1952. (Courtesy of Elizabeth Kahn.)

Syracuse University, she moved to Cambridge, where she worked as a laboratory assistant to Edwin Land at the Polaroid Corporation. Bernie and Jane would raise four children, Geoffrey (born in 1954), Elizabeth (1955), Mark (1958), and Matthew (1960), and would have eight grandchildren.

Bernie received his bachelor of science and Ph.D. degrees in physics from MIT in 1950 and 1953, respectively. As a graduate student, he worked on microwave spectroscopy under Malcolm "Woody" Strandberg and wrote a thesis on the Zeeman effect in asymmetric molecules. He continued his work in microwave spectroscopy on the nuclear moments of selenium in collaboration with the group at Columbia University headed by Charles Townes.[1]

While still a graduate student, Bernie heard a series of three talks on radio astronomy from Edward G. "Taffy" Bowen—a pioneer in British radar development in World War II and a founder of radio astronomy in Australia—that would lead to his lifelong career at the forefront of this rapidly developing new field. Before accepting an invitation from renowned ionospheric physicist Merle Tuve to join the Department of Terrestrial Magnetism (DTM) at the Carnegie Institution of Washington, Bernie interviewed at Bell Labs with Harold Friis, who had supervised Karl Jansky, the founder of radio astronomy. But Bernie got the message from Friis that Bell Labs was in the telephone, not the radio astronomy, business. He also applied for a Fulbright Fellowship to do radio astronomy with Martin Ryle at the Cavendish Laboratory at the University of Cambridge in the United Kingdom, but as he later reported, "That didn't work." Ryle had strong opinions about Americans and was not likely to hire a spectroscopist from the "colonies."

At DTM, Bernie was joined by Francis Graham-Smith, who was visiting from Ryle's group at Cavendish. Together, Burke and Graham-Smith built a 22-MHz Mills-Cross transit array that spanned ninety-six acres near Seneca, Maryland. It had the intended goal of observing the occultation of the Crab Nebula radio source by the Moon expected to occur in the spring of 1954. While making preliminary daily calibration observations of the Crab Nebula, Bernie and colleague Kenneth Franklin detected powerful sporadic bursts that they first assumed were caused by terrestrial interference. Further observations showed that the radio bursts were coming from a slowly changing direction in the sky. While working on their antenna, Burke noticed the planet Jupiter brightly shining in the evening twilight, and they quickly realized that Jupiter was the source of their mysterious bursts. This was a classic example of luck favoring the prepared. After Burke's and Franklin's discovery of Jupiter's radio bursts, Australian astronomers confirmed the discovery by reviewing their old telescope recordings. They found many detections in the old records, were able to localize the longitude of the emission regions on Jupiter, and accurately determined the period of rotation that was later adopted by the International Astronomical Union as the official rotation period of Jupiter.[2] The site of the Mills-cross array is commemorated by a roadside marker maintained by the Maryland Historical Trust.



Burke at the controls of the receiver apparatus at the 60-foot telescope of the Carnegie Institute in Derwood, MD, circa 1963 (Courtesy of Elizabeth Kahn.)

For much of the next decade or so, Bernie primarily worked on 21-centimeter hydrogen line research using the DTM 60-foot steerable parabolic dish. In 1962, he began his long association with the National Radio Astronomy Observatory (NRAO) by bringing the DTM 64-channel spectrometer to the new 300-foot transit radio telescope in Green Bank, West Virginia. He and his colleagues surveyed the HI distribution and kinematics of regions such as the center and outer parts of our galaxy, M31 and M33.[3]

In 1962, he became chairman of the DTM Radio Astronomy Section, where, together with Ken Turner, he initiated a joint project to build a 100-foot dish in Argentina that led to the establishment of the Argentine Institute of Radio Astronomy under the direction of Carlos Varsavsky.

Back to MIT

In 1965, Bernie left DTM and returned to MIT as a professor of physics and member of the Research Laboratory of Electronics. In 1970, he began his thirteen-year role as the first chair of the department's astrophysics division, when the Department of Physics was administratively divided into four research areas. In that capacity, he advised junior professor Rainer Weiss, in regard to his tenure prospects, that "if you don't begin to have results on a topic that can be published in a scientific journal, you won't be around to do any of that grand stuff you have been working on." Weiss shifted his research focus from feasibility studies of the detection of gravitational radiation to measurements of the CMB. Burke's advice turned out well for Weiss, who showed that previous measurements indicating an infrared excess in the CMB made from rockets were incorrect in his 1973 article with Dirk Muehlner.[4] Only much later, Weiss returned to the challenging problem of building LIGO and detecting gravitational radiation, which led to his sharing the 2017 Nobel Prize for the detection of gravitational waves. In 1981, Bernie became the William A. M. Burden Professor of Astrophysics, a position he held until his retirement in 1994.

During his long tenure at MIT, Bernie worked in a variety of areas of radio astronomy with about thirty doctoral students, many of whom have gone on to distinguished careers in radio astronomy and related areas.[5] According to his former students, Bernie treated them with benign neglect. In nautical terminology, which he frequently invoked, he ran a loose ship. His self-described approach to supervising graduate students was somewhat Darwinian: Throw them in the water; the good ones will learn to swim. He did, however, make sure that his students understood his priorities and approach to astronomy, telling them, "You can't discover anything if you don't look at the sky," and "Theorists are important; the world needs five of them." As soon as he arrived at MIT, he enlisted two of Alan Barrett's graduate students, Alan Rogers and one of the present authors (Moran), to build a 684-meter interferometer by linking the Lincoln Laboratory's 85-foot Millstone Hill and the 120-foot Haystack antennas. They showed that several of the recently discovered sources of 18-centimeter OH (hydroxyl) emission, suspected to be caused by the maser process, were less than 25 arcseconds in size. Perhaps more importantly, they measured the positions of a number of these masers to an accuracy of 5 arcseconds and found that none were coincident with emission from the prominent HII regions with which they were associated.

Burke and two other students, Tom Wilson and Ted Reifenstein, joined with Peter Mezger and his colleagues in the discovery that these OH masers were coincident with compact HII regions of ionized gas surrounding newly formed high-mass stars.[6] Later, his MIT group extended the interferometer baseline using a radio link to connect the Millstone Hill antenna with the 60-foot antenna at the Harvard College Observatory's Agassiz Station, about ten miles away. But still, the OH sources were unresolved, so they further increased their resolution by extending their baseline to 850 kilometers between the NRAO 140-foot radio telescope in Green Bank, West Virginia, and Haystack, using the nascent very-long-baseline interferometry (VLBI) technique of separately recording the received signal streams at each telescope on high-speed tape recorders. They then played back the data and correlated it using a CDC-3200 mainframe computer with software written by Moran at the Haystack Observatory. Time synchronization and local oscillator stability were controlled by independent atomic frequency standards at the two sites. Baseline extensions to transcontinental and then intercontinental distances with improved angular resolution followed.

Burke and his group also used the VLBI technique to study interstellar H_2O water masers at 22 GHz (1.3 centimeters) shortly after they were discovered in 1969, exploiting ever-increasing interferometer baselines to obtain angular resolutions as fine as 200 microarcseconds. This culminated in exciting expeditions to the Soviet Union, starting in 1971, to use its 22-meter precision dish in Crimea in conjunction with radio telescopes in the United States.

It was well known from the quantum mechanical description of Young's two-slit experiment that an interferometer will produce interference fringes even if the photons arrive at the aperture plane at a low rate. Bernie, with his ever-inquisitive mind, wondered whether VLBI might violate the uncertainty principle because individual photon arrival events were identifiable in the recordings at each aperture. After consultation with Victor "Viki" Weisskopf, his colleague in the physics department who had worked with both Niels Bohr and Werner Heisenberg in the 1930s, he showed that there was no violation because of the need to amplify the incoming signals before recording. Because the minimum system temperature in a coherent amplifier corresponds to one photon per polarization mode, it is impossible to identify at which antenna a specific photon arrived.[7]

Bernie was quick to recognize that with the new VLBI technique, there was essentially no fundamental limit to the length of radio interferometer baselines and that in principle, by using spacecraft, baselines could be extended beyond the diameter of the Earth. But it would be a long and difficult road before the first successful Earth-space VLBI program was developed. He first proposed a plan to place an antenna on the 1981–83 Space Lab mission that was approved by NASA before it withdrew from the European-led program. This was followed by an ambitious but unsuccessful proposal to have a Space Shuttle carry a 50-meter diameter antenna. He then led the U.S. effort to promote a project called QUASAT with NASA that failed to advance beyond the mission-definition phase. Other equally unsuccessful proposals followed. U.S. radio astronomers could not compete with the proposals from X-ray and infrared astronomers who depended on NASA for their research. Bernie did ultimately participate in three successful space VLBI projects: a JPL space-to-ground experiment using the NASA Tracking and Data Relay Satellite System (TDRSS), the Japanese led VSOP mission, and the Russian-led RadioAstron mission, which provided an order-of-magnitude increase in radio interferometer baselines.[8]

The long-sought discovery in 1979 of the first gravitational lens, 0957+561, startled the astronomical community. Bernie immediately shifted his focus from masers to this new field and pursued it vigorously for the rest of his career. Together with his students, Burke used the Very Large Array (VLA) observatory in New Mexico to produce the first detailed radio image of 0957+561 and concluded that the double image was more likely to be two independent quasars rather than a lensed single quasar. After a brief period of devil's advocacy, however, they endorsed the lens interpretation. It was quickly realized that because the lensed galaxy was not exactly along the line of sight to the lensing galaxy, the time shift between the temporal curves of intensity of the two images could be used to estimate the Hubble constant, H_0, in a manner independent of the usual distance ladder assumptions. At the time, the community was split between two camps, one advocating H_0 = 40–60 km/s/Mpc and the other 80–100 km/s/Mpc. This spurred a widespread effort to determine the time delay for 0957+561. After collecting a decade of data, Burke and colleagues reported one of the first delay measurements and interpreted it as indicative of a Hubble constant of 46 +/- 14 km/s/Mpc.[9] The MIT group continued observations for almost another decade. But this technique has not been useful in resolving the current discrepancy among different methods of determining H_0, which are in the range 68–74 km/s/Mpc (at the time of this writing), because of systematic errors caused by uncertainty in the mass distribution in the lensing galaxy.

With the principal objective of finding gravitational lens candidates, Bernie initiated a survey of radio sources at 5 GHz with the NRAO 300-foot telescope. The survey was conducted in four segments from 1979 to 1988, involved more than half a dozen graduate students (Charles Bennett, Charles Lawrence, Glenn Langston, Chris Carilli, Sam Connor, Michael Heflin, Joseph Lehár, James Mahoney, and Mark Griffith), covered 40 percent of the sky (5.0 steradians), and identified 17,500 radio sources down to a flux density limit of about 40 mJy.[10] Called the MIT-Green Bank (MG) survey, it was one of the most complete radio source surveys conducted at the time. He followed up the survey with imaging of individual sources on the VLA in search of gravitational lensing. One of the survey sources, MG 1131+0456, turned out to be an Einstein ring, caused by the nearly perfect alignment of a background quasar and lensing galaxy. This formed part of Jackie Hewitt's thesis.

Burke with some of his students gathered for a Festschrift in honor of his 60th birthday in June 1988 at MIT. (front row): Alan Rogers, Martin Ewing, Bernard Burke, Jacqueline Hewitt, Thomas Wilson, Fred Lo. (back row): Hans Hinteregger, Keith Tuscon, Michael Heflin, José Antonio García-Barreto, Charles Lawrence, Samuel Connor, Joseph Lehár, James Moran, Glen Langston, and Vivek Dhawan. (From Gravitational Lenses, Lecture Notes in Physics, vol. 330. Berlin: Springer-Verlag, 1989.)

Late in his career, Bernie began exploring new areas. With students Max Avruch and Jonathan Weintroub, he searched for neutral hydrogen in the early Universe at a red shift of $z \sim 6$ on the telescope at the Arecibo Observatory in Puerto Rico, an early start in the burgeoning field called the epoch of reionization.[11] He also became interested in the search for Earth-like planets and extraterrestrial life. He joined the Palomar High Precision Astrometric Search for Exoplanet Systems using the Palomar Testbed Interferometer in California at a wavelength of 2 microns.[12]

Not all of Bernie's initiatives led to success, and a few of his projects did not come to fruition despite substantial effort. These included a pulsar array in Mansfield, Massachusetts, and a three-element, short-baseline millimeter-wavelength interferometer at the Haystack Observatory, an effort that occupied many students over a number of years.[13]

Bernie's students organized a festschrift at MIT in honor of his sixtieth birthday in 1988. It included a conference on gravitational lenses attended by many of the pundits in the field from around the world. George Clark introduced the conference by describing Bernie thusly:[14]

> *Bernie is a science politician in the best sense of the word—a scientist with a dedication to steering public science policy in the most fruitful direction and with a sure instinct of where the levers of power reside and*

how to pull them. … He is a person of many parts. He is a classical scholar who can read Virgil in Latin with pleasure. He is a violinist and enthusiastic chamber player. He is a yachtsman able to hold his own in the fierce competition of Marblehead races, which he sometimes wins. He is a teacher who can convey to students a sense of how one thinks creatively in science. And he is a master of the sophisticated back-of-the-envelope calculation that can set a great scientific enterprise in motion.

Burke (left) at the Amundsen-Scott South Pole Station as part of a visit by the National Science Board, 1996. (Courtesy NRAO/AUI Archives.)

Bernie was well known as an engaging conversationalist who might read up on some obscure topic that he would then manage to introduce in a subsequent discussion. He relished the art of one-upsmanship. A typical example is the time a colleague proudly described his trip to the Atacama Large Millimeter Array site in Chile's Atacama Desert in 1994, when it was only a shack and a stick in the ground, as well as to the Le Paige Archeological Museum in the nearby town of San Pedro de Atacama. Bernie responded with a story of his own first visit to San Pedro in 1957, when he was a member of a cosmic ray team making measurements during the International Geophysical Year. He spoke to the legendary resident archeologist, Fr. Gustavo Le Paige, at the town well, where he was washing pottery shards from his daily excavations. Bernie also enjoyed telling colleagues about his visit to the South Pole as part of a National Science Board trip in 1996.

Community Service and Leadership

Throughout his career, Burke served in many important national and international leadership and advisory roles. He was a member of the NRAO Visiting Committee during its formative years from 1958 to 1962. From 1972 until 1990, he served as a trustee of Associated Universities Inc., which operates NRAO, first as a trustee-at-large and then as the scientific representative from MIT. During this period, he provided not only wise counsel to NRAO but also worked behind the scenes to support the NRAO programs.

Closer to home, for more than forty years, he was a member of the North-East Radio Astronomy Corporation board, which operates the Haystack Observatory, and for many years was its chair.

Burke was a member of the 1972 NAS/NRC Decade Review (Greenstein) Committee. The committee's radio panel considered three major new proposed radio telescope projects: the NRAO Very Large Array, the Caltech Owens Valley Array, and an MIT-Harvard/Smithsonian radome-enclosed 440-foot fully steerable parabolic antenna. They were all expensive projects, and it was clear the NSF would fund only one of them. The radio panel, chaired by NRAO director David Heeschen, was charged by the NRC with recommending a single project for funding. Bernie was expected to support the MIT-Harvard/Smithsonian interests on the panel, which he did with his characteristic vigor. He later described the discussions as intense and rancorous, with blood on the floor, but it soon became obvious that the majority view was in favor of one of the arrays. To the chagrin of his MIT and Harvard/Smithsonian colleagues, Bernie abandoned the MIT-Harvard/Smithsonian project and convinced the rest of the committee to support the VLA. Together with a few other committee members, Bernie met with Ed David, President Richard Nixon's science advisor, to secure his support for the VLA. Construction of the VLA appeared in Nixon's 1973 budget request, was soon funded, and began operation in 1980. For the past forty years, the VLA has been the most powerful radio telescope in the world, and Bernie and his students were among its major users.[15]

In 1965, Bernie learned from former DTM colleague Ken Turner of the planned Princeton University experiment to detect the CMB remnant of the original Big Bang. Bernie was probably the first person to recognize the cosmological implications of the apparent excess sky temperature that he heard about from his Bell Labs colleagues Arno Penzias and Robert Wilson. Following Burke's recognition of the connection, only after the Bell Labs and Princeton groups got together, did they understand that Penzias and Wilson had discovered the CMB, starting a new era that has revolutionized the field of cosmology.[16] Later, Burke and graduate student Martin Ewing, along with David Staelin, built a high-precision radiometer operating at 3.2 GHz and made one of the early confirmations of the thermal nature of the CMB from White Mountain in California.[17]

Burke was a member of the Astronomy Advisory Panel of the NSF from 1958 to 1963 and in 1990 was appointed by President George H. W. Bush to a six-year term on the National Science Board. At the NAS/NRC, he served on the Space Studies Board and the Naval Studies Board. He was also chair of the U.S. National Committee for the International Astronomical Union and an active member of the NAS Committee on Radio Frequencies, which he chaired from 1974 to 1978; the NRC Assembly of Physical and Mathematical Sciences; and the Commission on Physical Sciences, Mathematics, and Resources. He was a member of the NASA Planetary Systems Working Group, the Astronomy Missions Board, the Physical Sciences Committee, and the Space Science Advisory Committee and the chair of the Towards Other Planetary Systems Science Working Group. He also served on the editorial boards of the *Astronomical Journal,* the *Annual Review of Astronomy and Astrophysics, Science* magazine, *Comments on Astrophysics,* and the MIT Press. He was active for many years in the American Astronomical Society, where he served as a counselor and as president from 1986 to 1988. He was also a member of the Harvard College Observatory's Visiting Committee.

Bernie spent a great deal of time traveling to telescopes and meetings. Traveling with Bernie was always an adventure. His mantra (in those pre-TSA days) was, "If you have never missed a flight, you are spending too much time in airports." Upon visiting a new city, he eschewed taxis and relished mastering local subway and bus systems so he could get to know the locals. When he and one of us (Kellermann) managed to upgrade tickets to fly home from Paris on an Air France Concorde for an additional $50 each, Bernie insisted they sit apart so he could meet some real jet-setters. His schedules between trips were often so tight that on more than one occasion, he would plan a short layover at Boston's Logan Airport, where his wife would meet him to receive his laundry and supply him with clean clothes.

Awards and Recognition

In 1963, Burke received the American Astronomical Society's Helen B. Warner Prize, given each year to a scientist under the age of thirty-five for outstanding contributions to astronomy, and in 1970, he became the first radio astronomer to be elected to NAS membership. In 1971, Bernie, along with twenty other scientists from the three groups involved in the development of VLBI (Canadian, NRAO-Cornell, and MIT) received the Rumford Medal of the American Academy of Arts and Sciences "in recognition of his work in long-baseline interferometry."

He was a Fellow of the American Physical Society, the American Academy of Arts and Sciences, and the American Association for the Advancement of Science. He was active as a member of the International Astronomical Union, especially the IAU Commission 40 on Radio Astronomy, and the U.S. National Committee of the International Scientific Radio

Burke (at the helm) with sailing crew aboard his J33, circa 1990. (Courtesy, Elizabeth Kahn.)

Union, Commission J. At various times during his long tenure at MIT, Burke was a visiting professor at the University of Leiden, a Regents Fellow at the Smithsonian Institution, and a Sherman Fairchild Distinguished Scholar at the California Institute of Technology.

Other Activities

Bernie maintained a lifelong interest in playing the viola. He often played with his family and, with his wife Jane's help, frequently organized evenings of chamber music with friends and colleagues at his home. He also loved to sing. He sang the lead in his high school operettas and sang in his church choir, always giving priority to enthusiastic delivery over artistic precision. He enjoyed woodworking and playing chess. His favorite outdoor activity was sailing, which he loved as a pastime as well as an intellectual challenge. He owned many generations of sailboats, mostly named *Io*, which he moored in Marblehead Harbor in Massachusetts. He also kept a dinghy named *Zeus* in Sippewissett Harbor in Falmouth near the family summer home. He was one of the first owners of a J33 boat, a 33-foot masthead sloop with a racing crew of six introduced in 1989. He won numerous racing trophies and enjoyed taking students on sailing trips, where they were drafted to act as crew, often getting very wet. His admonition was, "If you don't capsize once in a while, you aren't trying hard enough."

Bernie was very interested in supporting the intellectual pursuits of his children and his grandchildren, whether in scientific or non-technical fields. After Jane died in 1993, he met Elizabeth (Betsy) Platt at an NAS meeting. They were married in 1998 and enjoyed more than twenty years together. Jane and Betsy each accompanied Bernie in his global travels, providing much-appreciated and much-needed logistical support, both at home and on the road.

Bernie retired from MIT in 1994. In his later years, he relished writing extended essays on a wide variety of subjects. *Uncertainty* is his historical play based on activities related to the putative development of the atomic bomb in Germany during World War II.

The cast of characters included Viki Weisskopf, Isadore Rabi, Werner Heisenberg, Otto Hahn, Albert Speer, and Moe Berg. Bernie relied on his close friendship with Weisskopf to inform some of the dialogue. The play was read to audiences in Cambridge, Massachusetts, and Los Alamos, New Mexico. *How England became England: The Thousand Year Journey* provides his own idiosyncratic view of the island nation. *Stars, Galaxies, and Dark Energy: A Brief History of the Universe* is a collection of twenty-five essays that explain physics and astrophysics to the layperson, starting with Newton's laws and progressing through the modern issues of cosmology, including inflation and dark energy. A companion effort, *A Dozen Brief Essays on Physics and Our World*, which is a sweeping tour of the field, was inspired by Carlo Rovelli's *Seven Brief Lessons of Physics* and Martin Rees' *Just Six Numbers*. Both of these books underscore Bernie's enthusiasm for physics and his desire to help people understand how the world works. His final effort, *Evolution, Astronomy, and Genesis*, touches on the perennially contentious topic of creation versus evolution. He encourages wonder at how closely the stepwise sequence of creation in the ancient Genesis myth matches the scientifically informed sequence. He uses the six-day framework of the myth to give a short history of the development of the Universe, Sun, and Earth teeming with life, without suggesting that the ancients had God-given foreknowledge. Impressed by the unlikely coincidence of many just-right physical constants, Burke expressed his own belief in a God who, "In the beginning," ordained elegant physical laws that allowed the Universe to create itself, without need for remote tinkering.

After his formal retirement from MIT, Bernie remained active in astronomy and science policy as an emeritus professor. One of his last professional activities was to coauthor, along with Peter N. Wilkinson and Francis Graham-Smith, the popular textbook *Introduction to Radio Astronomy,* now in its fourth edition.[18]

The papers of B. F. Burke can be found in the NRAO Archives.[19]

ACKNOWLEDGMENTS

We thank Bernie Burke's daughter, Elizabeth Kahn, for sharing family stories and photographs and Bernie's sister, Sara (Sally) Berenson, for sharing stories of their childhood. We also received helpful comments and suggestions from Carolann Barrett, Charles Bennett, Chris Carilli, Vivek Dhawan, Antonio García -Baretto, Jacqueline Hewitt, Colin Lonsdale, Alan Rogers, Barbara Smith Moran, Paul Vanden Bout, and Craig Walker.

NOTES

1. Burke's PhD thesis was published as Burke, B. F. and M. W. P. Strandberg. 1953. Zeeman effect in rotational spectra of asymmetric-rotor molecules. *Phys. Rev.* 90:303–308; See Hardy, W. A., G. Silvey, C. H. Townes, B. F. Burke, M. W. P. Strandberg, G. W. Parker, and V. W. Cohen. 1953. The nuclear moments of Se^{79}. *Phys. Rev.* 92:1532–1537; Burke, B. F., M. W. P. Strandberg, V. W. Cohen, and W. S. Koski. 1954. The nuclear magnetic moment of S^{35} by microwave spectroscopy. *Phys. Rev.* 93:193–195.

2. See Burke, B. F. and K. L. Franklin. 1955. Observations of a variable radio source associated with the planet Jupiter. *J. Geophys. Res.* 60:213–217; Franklin, K. L. and B. F. Burke. 1958. Radio observations of the planet Jupiter. *J. Geophys. Res.* 63:807–824; and Shain, C.A. 1955. Location on Jupiter of a source of radio noise. *Nature* 176:836–837.

3. See, e.g., Burke, B. F. and M. A. Tuve. 1964. Hydrogen motions in the central region of the Galaxy. In *The Galaxy and the Magellanic Clouds*. F. J. Kerr, ed. Pp. 183-186. IAU Symposium 20. Canberra, Australia: Australian Academy of Sciences.

4. Rainer Weiss. 2018. In *A Note about Bernie Burke for the Celebration of his Life on November 10, 2018.*Unpublished memo dated Nov. 4, 2018. Burke's advice turned out well for Weiss, who showed that previous measurements indicating an infrared excess in the CMB made from rockets were incorrect. Muehlner, D. and R. Weiss. 1973. Balloon measurements of the far-infrared background radiation. *Phys. Rev. D.* 7:326–344.

5. Burke's 30 PhD students and their areas of research (in order of graduation) were: Alan Rogers* (OH Excitation and Interferometry), James Moran* (VLBI of OH masers), Thomas Wilson (Radio Recombination Lines, Southern Hemisphere), Ted Reifenstein (Radio Recombination Lines, Northern Hemisphere), Martin Ewing (CMB and Pulsars), Hans Hinteregger ** (VLBI astrometry), George Papadopoulos (Ku-Band Interferometer and H_2O Masers), John Spencer (Interferometric Observations of M31 and M33), K. Y. (Fred) Lo (H_2O Masers and Compact HII Regions), Patrick Crane (Radio Emission from Spiral and Irregular Galaxies), Aubrey Haschick (HI Absorption), R. Craig Walker (H_2O masers), Thomas Giuffrida (H_2O masers), Perry Greenfield (Gravitational Lenses), José Antonio García-Barreto (OH Masers), Charles Lawrence (MIT–Green Bank Survey), Barry Allen (SiO Masers), Charles Bennett (MIT–Green Bank Survey), Jacqueline Hewitt (Gravitational Lenses), Glen Langston (Gravitational Lenses), Vivek Dhawan (Millimeter-Wavelength VLBI), James Mahoney (The Antenna Galaxy Pair), Chris Carilli (Radio Imaging of Cygnus A), Michael Heflin (Gravitational Lenses), Joseph Lehár (Gravitational Lenses), Mark Griffith (Parkes–MIT–NRAO Survey), Lori Herold-Jackobson (Gravitational Lenses), Deborah Haarsma (Gravitational Lenses), Andre Fletcher*** (Evolution of Galaxies and Young Stellar Clusters) and Ian Max Avruch (HI in Early Universe). Footnotes: *Shared with Alan Barrett. ** Shared with Irwin Shapiro. *** Shared with Steve Stahler.

6. Mezger, P. G., W. Altenhoff, J. Schraml, B. F. Burke, E. C. Reifenstein III, and T. L. Wilson. 1967. A new class of compact HII regions associated with OH emission sources. *Ap. J.* 150:L157–L166.

7. Burke, B. F. 1969. Quantum interference paradox. *Nature* 223:389–390; See also Thompson, A. R., J. M. Moran, and G. W. Swenson. 2017. *Interferometry and Synthesis in Radio Astronomy*, 3rd ed. Pp. 44-45. Cham, Switzerland: Springer.

8. Burke, B. F. 2009. The early days of VLBI in space. ASP Conference Series 402, In *Approaching Micro-Arcsecond Resolution with VSOP-2*. Y. Hagiwara, E. Fomalont, M. Tsuboi, and Y. Murata, eds. Pp. 10-14. ASP Conference Series 402.

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