NATIONAL ACADEMY OF SCIENCES

WILLIAM EDWIN GORDON
1918–2010

A Biographical Memoir by
MARSHALL H. COHEN AND NEAL F. LANE

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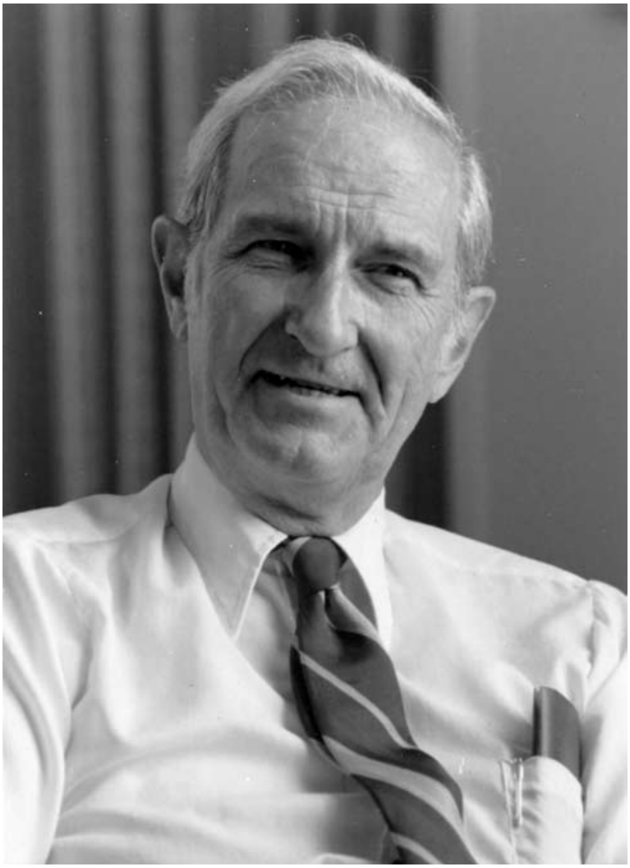
Biographical Memoir



W. E. Gordon

WILLIAM EDWIN GORDON

January 8, 1918–February 16, 2010

BY MARSHALL H. COHEN AND NEAL F. LANE

William Edwin Gordon was born in Patterson, New Jersey, on January 8, 1918. He studied meteorology at New York University while in the Army Air Corps during World War II, and then was engaged in radio wave propagation studies until the war ended. After the war, he continued these studies at the University of Texas in Austin, and in 1948 moved to Ithaca, New York, for graduate study in electrical engineering at Cornell. He stayed at Cornell after obtaining his Ph.D. degree in 1953. In 1958 he conceived of a large vertically directed radar to measure the electron density and temperature in the high ionosphere. This became the Arecibo project, whose study and construction in Puerto Rico he organized, and the giant system was dedicated in 1963. He became its first director. In 1965 he moved to Rice University as dean of science and engineering, later provost and vice president. He was active in ionospheric research into the 1990s. He died in Ithaca, New York, in February 2010; his survivors include two children, Nancy Ward and Larry Gordon; four grandchildren; three great-grandchildren; and his wife, Elizabeth Bolgiano Gordon of Ithaca. His first wife of 61 years, Elva Gordon, died in 2001.

THE EARLY YEARS

William Edwin Gordon ("Bill") was born in Patterson, New Jersey, on January 8, 1918. His father, James William Gordon, was born in England in 1878 and immigrated to the United States around 1905. His mother, Mary Scott Williamson, was born in Patterson in 1883; her parents had emigrated from Scotland. James Gordon worked as a sales representative for the Waterman pen company, whose office was in New York City, and his territory included areas in nearby New Jersey.

Bill studied mathematics at Montclair State Teachers College in New Jersey, obtained a B.A. in 1939 and an M.S. in 1942. He was a teacher in junior high schools in the northern New Jersey towns of Mendham and Oradell. At Montclair State, Bill met Elva Freile who had grown up in nearby Teaneck. They were sweethearts throughout college and were married in June 1941.

Bill enlisted in the Army Air Corps in 1942 and was assigned to study meteorology at New York University. He eventually earned an M.S. from NYU in 1946. At the end of the war he was a captain in the Air Corps in Austin, Texas. After the war, Bill and his family stayed in Austin, where he continued to work on radio wave propagation. In 1948 they moved to Ithaca, New York, and Bill became a graduate student in electrical engineering at Cornell University.

The Gordon family consisted of Bill; his wife, Elva; and their two children, Larry and Nancy. They lived in Dryden, a small town 15 miles east of Ithaca. It was a rural area, and they spent a lot of time fixing up their house and working in the vegetable garden. In the winter they would frequently have been shoveling snow.

CORNELL AND ARECIBO

Bill went to Cornell to study with Edwin Hamlin, who had been his supervisor in Austin. Hamlin, however, died shortly after Bill's arrival, and Bill became associated with Henry Booker, an ionospheric physicist who also had moved to Cornell in 1948 from England. Booker was a particularly good teacher, and was generally described as brilliant. He and Bill remained close friends, and after Booker died in 1988, Bill wrote his biographical memoir for the National Academy of Sciences. Bill received the Ph.D. degree from Cornell in 1953, and became an associate professor in the School of Electrical Engineering there. In 1959 he was appointed to the rank of professor, and in 1965 to the position of Walter R. Read Professor of Engineering.

One of the current authors (MHC) arrived at the School of Electrical Engineering at Cornell as an assistant professor in 1954. He essentially took over the solar radio astronomy program that Gordon was supervising; the program was suffering because the researcher who had been doing most of the work had left Cornell. MHC worked closely with Gordon, and quickly learned to appreciate his scientific skills and organizational abilities. The school had considerable interest in radio wave propagation, and a lively group of students and professors participated in a weekly seminar on this subject. Charles R. Burrows, director of the School of Electrical Engineering, was a noted scientist and administrator who had worked on tropospheric radio propagation during World War II. But Bill Gordon was de facto the leader of the tropospheric research program, while Henry Booker was the leader of the ionospheric group. In April 1958 Gordon presented his ideas for what became the Arecibo radar to the seminar; this was the first public presentation of the concept of a large ionospheric scatter radar. The study and promotion of the idea kept Bill and others busy through 1958 and 1959. The project was approved by the Advanced Research Projects Agency, and construction started in November 1959.

In 1960 Bill moved with his family to Arecibo, Puerto Rico, to manage the construction of the large ionospheric radar that had begun at the site 12 miles south of the city. A few other families joined the Gordons, and the size of this group grew as construction proceeded. The group became and has remained very close. The development effort at the site was intense, and was balanced by swimming and shell collecting at nearby undeveloped beaches, along with trips to other parts of Puerto Rico and to other Caribbean islands. The Gordons and others developed friendships in the local Puerto Rican community, and most of the children, including Nancy and Larry Gordon, went to the American School at Ramey Air Force Base, about 30 miles away.

The radar was dedicated in November 1963 as the Arecibo Ionospheric Observatory, and Bill became its first director. In 1964 he ran afoul of university regulations concerning extended leave for faculty members and reluctantly moved back to Ithaca. In five years he had invented, promoted, and overseen the design and construction of the world's largest scientific radar and radio astronomy system. After the dedication he became the leader of the ionospheric research group. He later said that this was the best five years of his life.

The Arecibo Observatory has always been regarded as an engineering marvel. In 2003 it received a double award, when it was designated a Milestone in Electrical Engineering and Computing by the IEEE and a Historic Mechanical Engineering Landmark by the ASME. In 2008 it was listed on the National Register of Historic Places by the National Park Service.

RICE UNIVERSITY

In 1966 Bill joined Rice University, having been recruited as dean of science and engineering and professor of space science by Rice's third president, Kenneth Pitzer. Pitzer had a vision for Rice and under his leadership Rice had made the commitment to develop into a major research university of international stature, with strength in the arts and humanities as well as science and engineering, and with excellent graduate programs in parallel with its undergraduate programs. Bill was intrigued by the chance to be part of Rice's transformation, and the move eliminated the strains of dealing with Arecibo management issues at Cornell. But he had no way of knowing how challenging his new task would turn out to be, and how quickly he would be tested in his new job.

The ambitious research vision for Rice was not shared by all members of Rice's Board of Trustees, many of whom were concerned that Rice would lose its special focus on quality undergraduate education by diverting resources to graduate study and research. When Pitzer resigned to accept the presidency of Stanford University, the board appointed an executive committee to run the university while a search was conducted to find the new president. Bill was named the chair of that committee and essentially functioned as interim president. A faculty committee was formed to consider possible candidates and make recommendations to the board. Unfortunately, the board proceeded to choose and name a new president without consultation with the faculty committee, resulting in a major faculty protest, which received considerable media attention. Bill, having been at Rice only a short while, found himself in a very difficult position but never wavered in his judgment that indeed the board had acted improperly. It was a courageous decision on his part. In March 1969 the board dissolved the executive committee and appointed an acting president. Bill was appointed vice president (one of four) and remained dean of engineering and science. In the view of Rice faculty who were there at the time, Bill's steadfast determination to follow through on Pitzer's vision was a turning point for Rice.

Following a second presidential search, this time with faculty involvement, the board announced that chemist Norman Hackerman would become Rice's fourth president.

Bill continued as dean of science and engineering, and then dean of natural sciences (now the Wiess School of Natural Sciences) after engineering was split off as its own school. In 1980 President Hackerman named Bill as provost and vice president, a position he held until his retirement in 1986. Serving in Rice's administrations for two decades, Bill had been a major force in Rice's rise to a leading national research university.

As dean and provost Bill aggressively used his legendary powers of gentle persuasion, along with financial incentives where appropriate, to increase the faculty ranks of women and members of other underrepresented groups, especially in science and engineering. He enhanced interdisciplinary research, insisted on fair and balanced evaluation of faculty for promotion and tenure, ensured that faculty in nonscience and engineering fields were appropriately recognized for their scholarship and other creative endeavors, strengthened the undergraduate curriculum and teaching (he felt communications skills should receive greater emphasis across the curriculum), and eased Rice through the transition from expensive mainframe computers to personal computers. He stressed the importance of science and engineering majors studying the arts, humanities, and social sciences to better understand the proper role of technology in society. And in an effort to encourage dialogue across the intellectual boundaries of the campus and foster a true community of scholars, Bill created the Provost's Lecture series and encouraged members of the faculty to discuss their research and scholarly activity with scholars in other fields as well as the broader Rice community. To this end, he established the Rice faculty organization Scientia, the brainchild of mathematics professor, Salomon Bochner, for the purpose of broadening the conversation across traditional intellectual cultures; it remains a vital organization three decades later.

Bill thought about science beyond the boundaries of his own work. In a lecture to Rice alumni in 1977 he discussed the issue of scientific creativity. Creativity, he said, usually results from a confluence of circumstances.

- The problem is available and the time is right;
- Youthful spirit, a mix of logic and emotion;
- Preparation, hard work, insight, intuition;
- Combination of approaches;
- Realization that thinking is a lonely, individual process, but colleagues are essential;
- Joy of discovery; and
- Beauty of the product.

Speaking again to a popular audience, Bill explained the role of technology to the Society of Rice University Women in 1984.

> Technology is an art, an art of converting in a systematic way the work of scientists and engineers into products and processes that materially enrich civilization. The scientist's goal is knowledge, the engineer's goal is design, i.e., applying knowledge in a useful practical way, the technologists are the artists who efficiently and economically produce in the needed quantities, the products or processes.

Bill was one of the most highly principled people any of us are ever likely to meet. His honesty and integrity were legendary on matters large and small. And he was in all things a gentleman. Following a trip with a group of Rice alums to observe and talk about Halley's Comet, he received a letter penned by a member of the group with the heading "Tribute to Professor William Gordon from the Travel Group." The letter said it all:

> We could scarcely ask for a better companion, or a more qualified teacher. From my short experience here I am confident Bill is the kind of teacher Shakespeare had in mind when he wrote in Henry VIII: 'He was a scholar

and a good one; exceeding wise, fair-spoken, and persuading…(and) to those that sought him, sweet as summer.

Bill was well known and highly respected in federal policy circles, largely through his service on many advisory committees and as foreign secretary of the National Academy of Sciences. He had opportunities to hold high-level positions with the federal government but his heart was in academia. In a 1993 letter he wrote to National Science Foundation Director Ed Knapp, who had expressed an interest in recruiting Bill to an important position at NSF, Bill wrote back:

Were you to offer and I to accept a position…for a few years, I would find myself then ready to retire from academic life but having lost my already tenuous grip on an active career as a scientist… In contrast if I continue as professor and administrator, I don't lose my grip on a continuing career as an experimentalist and I find myself with something to retire to, not something to retire from.

Bill was a model civic scientist, not only because of his many services to the science and engineering community and federal agencies but also by virtue of his public outreach to community organizations, churches, and schools, where he was a frequent speaker. In addition to talking about his passion—space and atmospheric physics, and Arecibo, in particular—he often addressed pressing national concerns such as energy and climate change. In the 1970s he began to alert fellow scholars and especially business and community leaders to the potential impacts of climate change, warning that while the threat was long-term, it was time to start paying attention.

As the years passed with little policy progress Bill became convinced that the problem of global warming and climate change was indeed becoming urgent. In a lecture he gave to the Rice faculty in November 1986, shortly after his retirement, he posed the question:

> The world we live in, will it survive? Are we abusing it in ways that may not be reversible?…Man's economic and technical activity, even providing his food, fuel and housing, contributes to significant global changes. The enemy is us.

When Bill announced his retirement from Rice in 1985, President Hackerman said:

> William Gordon has been a great acquisition for Rice. He is the quintessential academic, a model of a good faculty member and academic officer, an administrator with a collegial nature. He's the only retiring professor I've qualified as Distinguished Professor Emeritus.

Bill's response was characteristic: "I'm not retiring from the administration, research, and teaching—just administration. I'll be involved in experiments at Arecibo, in Norway, and in Peru; however, I'll still be around Rice." He retired in 1986.

Bill and Elva were very pleased that two of their grandchildren attended Rice; Amanda Gordon graduated in 1998 and George Ward in 2001. Bill liked to raise tropical plants he discovered in Puerto Rico and enjoyed sailing his boat *Dulcinea* on Galveston Bay. The family spent many summers at their lakeside cottage on Cape Cod, where they enjoyed sailing and the visits of friends and relatives. In 2003 after the deaths of their respective spouses, Bill married Mary Elizabeth Bolgiano ("Liz"), a friend of long standing, and moved to Ithaca, where Liz had lived for over 50 years. Bill and Elva had been friends with Liz and her husband, Ralph, who was on the engineering faculty at Cornell. Liz was a wonderful partner for Bill in their adventures together and gave him loving care throughout the remainder of his life.

One of the authors (NL), who first met Bill when they both arrived at Rice in 1966 and served under him as dean and provost, offers the comment:

Over the three decades that I have had the good fortune to know Bill Gordon, my admiration for his achievements and respect and affection for the man grew steadily. In my years as his successor, as provost, followed by my time in government service, I frequently sought his wise counsel. All great universities can point to a few individuals who were critical to an institution's achievement of greatness. For Rice, Bill Gordon is very high on that list.

The Arecibo Observatory. Gordon called his time there the happiest years of his life.

SCIENTIFIC CAREER

Radio Wave Propagation (1942-1957)

William Gordon obtained a B.A. in 1939 and an M.S. in 1942, in mathematics, at Montclair State Teachers College in New Jersey. He entered the Army Air Corps in 1942 and was assigned to study meteorology at New York University. While in the army he investigated anomalous radio propagation due to vertical stratification, or ducting.

In 1945 Bill was stationed at the University of Texas in Austin, studying tropospheric radio wave propagation. He continued this work after World War II at the Electrical Engineering Research Laboratory. He developed the idea that atmospheric "blobs," or turbulence, with corresponding fluctuations in the refractive index of air were responsible for some of the peculiar radar echoes that he saw. He remained interested in turbulence and its effect on radio wave propagation for his entire career.

Bill moved to Ithaca, New York, in 1948 to work for a Ph.D. in electrical engineering at Cornell University. His adviser and mentor was Henry G. Booker, who was by turns an applied mathematician, ionospheric physicist, and electrical engineer. Booker was from England and had worked on ionospheric propagation before the war and on radar during the war.

At Cornell, Booker and Gordon investigated long-range anomalous radio wave propagation, and published their results in an important paper in April 1950. In the paper they developed the theory of scattering by atmospheric turbulence and used it to explain long-range propagation. This work provided the basis for understanding long-range radio communication, which has had important applications.

Bill received the Ph.D. degree in 1953; his thesis was on atmospheric turbulence and the resulting scatter propagation of radio waves. This work was restricted to the troposphere, the part of the atmosphere below about 10 km, where water vapor is important and the maximum range for scatter communications is about 700 km. Longer-range propagation existed, however, and was due to scattering in the stratosphere, the dry region above about 10 km. But few direct measurements of the dielectric constant in the stratosphere existed, and theoretical reasoning was used in another paper by Booker and Gordon to estimate the fluctuations and the scattered power. This successfully explained scatter propagation from the troposphere, to distances of about 1000 km, at frequencies from 100 to a few thousand MHz.

Scatter propagation via the ionosphere was also of interest. In this case the medium is partially ionized, and the magnetic field can have a strong effect. Scattering on field-aligned irregularities in electron density was shown to be important for a number of phenomena, including echoes from the aurora, and for radio wave propagation to 2000 km. The ionospheric region responsible for these effects was from about 70 to 300 km. Gordon considered the possibility of getting sufficient scatter from yet higher levels, but concluded that the signals would be too weak to allow long-range communication. At that point apparently he had the idea to stop thinking in terms of eddies or irregularities established by turbulence, and to think instead of scattering from the individual electrons acting incoherently. He calculated the strength of the forward-scattered signal to be expected with this mechanism, and found that the signal would be much too weak for communications. But then he took the crucial step of estimating the signal to be expected if the antenna were directed vertically, rather than horizontally, as in applications to over-the-horizon communications. The signal was still weak but strong enough to detect with sufficient averaging, and this could give the electron density in the scattering region. This was the birth of incoherent scatter radar, ISR.

Incoherent Scatter Radar and Arecibo (1958-1965)

Gordon's first estimate of the signal to be expected from the incoherent scattering of radio waves on electrons in the ionosphere was made early in 1958. He worked out the required properties of a radar that could measure the density and temperature of the electrons in the ionosphere to a height of 1000 km. Using readily available components at a frequency of a few hundred MHz, the antenna would need a diameter of about 1000 ft (305 m). The main assumption was that the electrons scattered the incoming radiation according to the Tompson formula, and the elementary scattered waves added independently to form the total echo. The density was obtained from the strength of the echo, and the temperature from the width of the spectrum of the echo, as each elementary echo contained a frequency (Doppler) shift according to the vertical component of the electron's velocity. Bill published an article in October 1958 that described the radar and its capabilities. His ideas were largely confirmed by Kenneth L. Bowles, who in October 1958 did an ionosphere experiment at 41 MHz, which showed that Gordon's calculation gave roughly the correct back-scattered power. However, it also showed that the width of the spectrum was narrower than expected. The narrow spectrum turned out to be important, as it later allowed for a much greater range of experimentation than was originally realized.

During the summer of 1958, Bill assembled a group to study the radar. In December 1958 they published a report giving design parameters, and a brief discussion of experiments and observations that the 1000 ft radar could support. The report also contained a discussion of sinkholes in karst regions that might serve as a natural bowl to support a large reflector. They ultimately settled on a site 12 miles south of the city of Arecibo in Puerto Rico, where the observatory has now stood for more than 50 years.

Gordon led the design team in 1958, and while doing that he also promoted the dish in Washington. The Advanced Research Projects Agency (ARPA) had just been formed, and its mission included the support of studies of the ionosphere. In late 1959 ARPA provided funds for an engineering study of the radar, and funds for construction were awarded in June 1960. Excavation at the site started in September 1960, and the construction lasted about three years. The project proceeded in an extremely rapid manner, with less than six years from conception through funding and construction. Bill had been intimately involved in all phases of the program, from its inception through design and construction. He became its first director after the system was dedicated in November 1963 as the Arecibo Ionospheric Observatory.

Ionosphere Experiments (1966-1997)

The radar was designed to measure density and temperature up to 1000 km, and Bill Gordon and his students quickly began to exploit the system. They verified the theoretical calculations that showed that for a certain range of the ratio of the radio frequency wavelength to the Debye length (the "screening distance" around a charged particle), the echo was concentrated in a narrow "ion line" controlled by the ion mass and not the electron mass. This meant that in this range the system was two orders of magnitude more sensitive than had originally been thought, and this opened up many avenues of research into the ionospheric plasma. The time-dependence of the ionosphere was monitored, and strong sunrise and sunset effects were studied. Beam motions provided by the Arecibo feed structure showed that north- to south-traveling waves existed; they were interpreted as gravity waves excited by the aurora.

The radar had new capabilities previously not available with sounders, including its use as a mass spectrometer measuring the ionic composition of the ionosphere as a function of height and time. This works because the width of the spectrum is determined by the ratio of the ion mass to the temperature, and the temperature can be independently determined. The result is that H^+ is the dominant ion at high altitudes; O^+ is dominant at a few hundred km in the F region, and there is a transition region containing about 30 percent He^+ at 300 to 1000 km, depending on the time of day. Below the F region heavier ions, O_2^+ and NO^+, are found.

There was close interaction between the experimenters at Arecibo and plasma physicists. One new phenomenon that had been predicted was the "plasma line," an echo offset from the radio frequency by the plasma frequency and due to scattering on longitudinal plasma waves. This line was predicted to be weak but was sometimes observed orders of magnitude stronger than expected. This was interpreted as a nonequilibrium effect, with hot photoelectrons perturbing the velocity distribution function of the electrons.

Heating Experiments

An upward radio wave in the ionosphere, at a frequency below the critical (penetration) frequency, will be partially absorbed near the level where the wave frequency equals the local plasma frequency. If the wave is strong enough, substantial heating can occur, and parametric instabilities will induce large fluctuations in the densities of both ions and electrons. To study these effects a 100 kW transmitter at 5.6 MHz was added to the Arecibo system in 1967. Larger and more versatile transmitters were later added, and in 1980 a new heating facility consisting of a powerful transmitter and an array of log-periodic antennas was built at Islote, Puerto Rico, 17 km northeast of the observatory. The high-frequency wave (HF, 3-30 MHz) heats the plasma, while the 430 MHz radar is used as a probe to study the heated region. Gordon, with students and collaborators, did research on heating experiments using this equipment for much of the rest of his scientific career, publishing papers spanning the years 1971 to 1991.

When the plasma is heated by an HF wave, parametric instabilities can greatly enhance the thermal plasma waves (by a factor up to 10^5), and generate various other waves with combination frequencies from the HF, the plasma, and the ion acoustic waves. The resulting spectrum of waves can be analyzed by the 430 MHz radar. Gordon with his graduate students studied these enhancements both for their intrinsic connection to ionosphere composition and dynamics, and for the new insights they gave to plasma physics. This work aroused substantial interest in the plasma physics community, as it allowed controlled experiments that otherwise were unavailable. For example, the experiments showed that HF heating can excite instabilities that generate large-scale irregularities and striations along the magnetic field. This was interpreted as due to a self-focusing instability.

During the 1980s at a time when Bill was a senior administrator at Rice University, he continued to pursue research at Arecibo and to counsel graduate students. He retired in 1986 and continued to do research at Arecibo and with other facilities. In 1994 he collaborated with a group studying radar reflections from clear-air cells in the troposphere and lower stratosphere. The echoes apparently were due to reflections from corrugated surfaces set up by gravity waves. At the end of his career Bill returned to where he had started, radar echoes from the neutral atmosphere.

HONORS

In recognition of his engineering and scientific accomplishments, and for his numerous public services, Bill was elected to and received awards from many organizations. He was elected to the National Academy of Sciences in 1968 and served as foreign secretary during 1986-1990; he was elected to the National Academy of Engineering in 1975. He was a foreign associate of the Engineering Academy of Japan; a fellow of the American Academy of Arts and Sciences, the American Association for the Advancement of Science, the American Geophysical Union, and the IEEE. He received the Balthazar van der Pol Gold Medal from the International Union of Radio Science (URSI) in 1966, the Medal of the American Meteorological Society in 1969, the Arctowski Gold Medal of the National Academy of Sciences in 1984, a Medal from the U.S.S.R. Academy of Sciences in 1985 for distinguished contributions in international geophysical programs, and the Centennial Medal of the University of Sofia in 1988.

PROFESSIONAL SERVICE ACTIVITIES

Throughout his career Bill consulted with industry, and served as an adviser to federal agencies and national and international scientific organizations, and in other ways served the professional community and public. His many professional service activities included work with URSI (international vice president, honorary president); the Institute of Radio Engineers (chair of the Professional Group on Antennas and Propagation); the Upper Atmosphere Research Corporation (chair 1971-1972, 1973-1978); University Corporation for Atmospheric Research (chair, Board of Trustees 1979-1981); Cornell University Board of Trustees; and more than 60 advisory and review committees for the National Science

Foundation, Stanford Research Institute, U.S. Information Agency, National Academy of Sciences, National Academy of Engineering, and the National Research Council.

WE WOULD LIKE TO THANK Kenneth Bowles, Dale Corson, and Donald Farley for reading portions of this manuscript; Nancy Ward for sharing information about Bill's family life; Paul Cloutier for commenting on Bill's scientific work while at Rice, and the Woodson Research Center of the Fondren Library at Rice for providing access to many of Bill's papers.

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