Thomas M. Donahue

May 23, 1921–October 16, 2004
Elected to the NAS, 1983

A Biographical Memoir by Donald M. Hunten and James G. Anderson

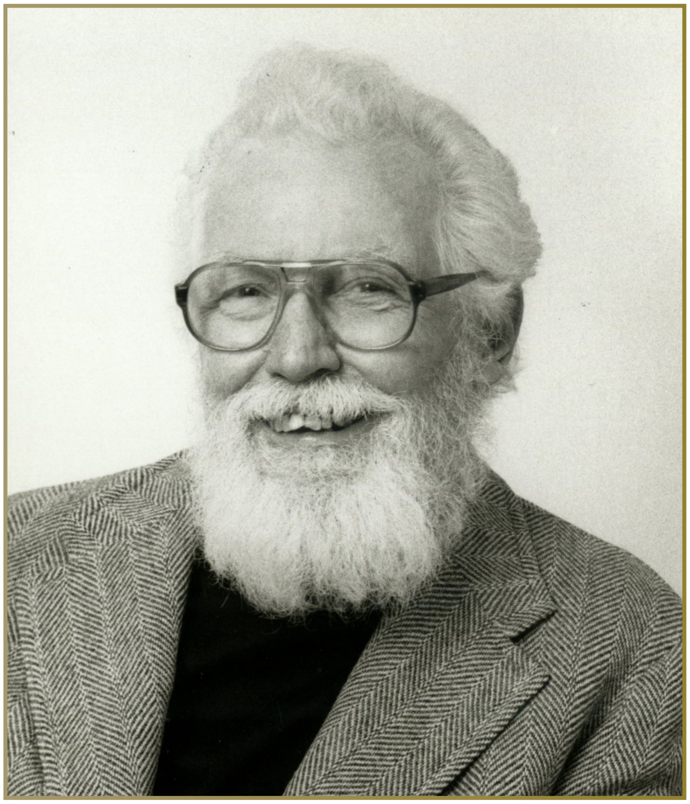

Figure 1 Thomas M. Donahue. *Photo by Don Goings, from photos, box 1, Thomas M. Donahue papers, Bentley Historical Library, University of Michigan.*

The explosion of scientific thought and innovation, propelled by the development of new experimental and computational strategies following World War II, expanded the frontiers of physics and chemistry to the outer reaches of the Earth's atmosphere and subsequently to the planets of our Solar System. Thomas M. Donahue was a central figure in this new scientific discipline of aeronomy, and he remained a potent, creative catalyst for innovation throughout his life. Donahue's scientific reach engaged three primary dimensions: fundamental research investigating the composition, physics, and chemistry of the atmospheres of Venus, Earth, Mars, and the outer planets; leadership in the U.S. space endeavor and associated program development during the genesis of NASA and modern space exploration; and an abiding role at the forefront of teaching and research that propelled higher education in the field to a position of international leadership. Yet all of this was accomplished within a context of spirited, collegial, joyful curiosity that drew students of all ages to his side—because pursuit of scientific progress was invariably far more exciting and rewarding when Tom Donahue was a partner. He was elected to the National Academy of Sciences (NAS) in 1983.

The complexity of the scientific endeavor today demands close collaboration among historically disparate disciplines within biology, physics, and chemistry to effectively address global problems in medicine, energy, climate, and materials, among others. But nearly six decades ago, Tom Donahue recognized the power of coupling the finest molecular-level chemical physics research with the mechanistic structures that controlled processes on the grand scale of the Earth system and its role in the larger planetary system within which we evolved and upon which our future depends. Donahue formed key collaborative links throughout his life that not only revolutionized the development of modern space physics, aeronomy, and atmospheric science, but also engendered a broad community built upon intellectual rigor and a through enjoyment of the broader aspects of human ingenuity: languages, music, conversation, wine, and culinary excellence.

Thomas M. Donahue was born in Healdton, Oklahoma, the oldest of four children of plumber Robert Emmet and

Irish emigrant Mary Lyndon. The family settled in Kansas City, Missouri, where Tom went to school and then attended Rockhurst College (now Rockhurst University). He was awarded a bachelor of arts degree in classics and physics in 1942, spent 1944 and 1945 in the U.S. Army Signal Corps, and then pursued graduate work at Johns Hopkins University under the supervision of Gerhardt Dicke, receiving his Ph.D. in 1947. He remained there another four years and in 1950 married Esther McPherson, with whom he had three sons: Brian, Kevin, and Neil. His intense pride in his immediate family was a remarkable journey to watch. His wife and sons were always in the conversation, only to be nudged over slightly by the arrival of grandchildren.

In 1951, he was hired as a professor in the Department of Physics at the University of Pittsburgh and simultaneously became director of the Space Research Coordination Center and Laboratory for Atmospheric and Space Science. During his years in Pittsburgh, he spent sabbaticals at the University of Paris, Harvard University, and the Carnegie Institution of Washington. In 1974, he was attracted to move to University of Michigan by the opportunity to expand its small but excellent program in atmospheric science and space engineering as chair of the Department of Atmospheric and Oceanic Sciences. In 1990, Michigan lured him back from retirement to spend three years as director of the Project for the Integrated Study of Global Change.

The first half of Donahue's scientific career is described in a delightful autobiographical article, "The Aeronomical Pilgrim's Progress," in a 1996 special section, "Pioneers of Space Physics," in the *Journal of Geophysical Research*. Aeronomy is the study of the physics and chemistry of upper atmospheres, and its early practitioners were generally educated in atomic physics, chemistry, or astronomy and moved into aeronomy as opportunities were generated, especially by generous funding from the U.S. Air Force Cambridge Research Center and later by NASA. Shortly after Donahue moved to Pittsburgh, he formed a close relationship with a powerful young atomic- and molecular-physics group at the nearby Westinghouse Research Laboratory. He became interested in resonance scattering by a layer of sodium atoms that exists at a height of about 90 kilometers. He joined forces with Jaques Blamont of the University of Paris, applying his theoretical analysis to Blamont's observational program. Then in February 1957, as colorfully related by Donahue, Joseph Chamberlain assembled a "sodium summit conference" at the Yerkes Observatory in Wisconsin, where one of us (Hunten) and Donahue met for the first time; it would be the beginning of a lifelong friendship and a fruitful scientific collaboration.

Much of Donahue's work in this period had to do with resonance scattering, a phenomenon in which an atom absorbs a photon and quickly re-emits it in a different direction. Spectral lines for which this is important in the upper atmosphere and interplanetary medium are the familiar yellow doublet of sodium and, in the far ultraviolet, the Lyman-α line of atomic hydrogen and a triplet of atomic oxygen, all of which were objects of the attention of Donahue and his students. Astrophysical treatises on radiative transfer are devoted to related problems, and some of their methods have been applied to the sodium layer, but for the other cases it has been necessary to develop numerical methods.

A few years later yet, Donahue and Blamont flew a pair of photometers on the last of NASA's Orbiting Geophysical Observatories, OGO-6. These instruments, tuned to the yellow sodium doublet and the auroral green line, scanned a vertically narrow field of view up and down at the horizon. The most spectacular result was the discovery of polar mesospheric clouds in the summer hemisphere, curiously located at nearly the same 90-kilometer altitude as the sodium layer, and also the height of a deep temperature minimum that is especially cold in summer and is responsible for the condensation of the cloud. The fringes of this type of cloud had been observed in late twilight for more than a century and given the name "noctilucent clouds." Later, a different experiment was flown on the joint U.S.-Soviet Apollo-Soyuz mission, observing this time the absorption of the ultraviolet resonance triplet of atomic oxygen. The source and the detector were both aboard the Apollo spacecraft and the radiation was returned by retroreflectors mounted on the Soyuz.

Donahue's work and that of his students in the theory of resonance scattering in optically thick media is described in his 1996 autobiographical article. (A region is "optically thick" if a photon almost certainly cannot traverse it without being scattered at least once.)

Models relating the rate of escape or hydrogen atoms to the abundance of water vapor in the stratosphere were just being developed around 1974. With his student Lie, Donahue found that only about half of this escape resulted from the classic thermal or "Jeans" mechanism, with the other half involving H^+ ions.

Donahue's work on the upper atmosphere of Venus began in the 1970s and led to his being recruited as a co-investigator for the mass spectrometer on the Pioneer Venus Multiprobe, and he was also selected as an interdisciplinary scientist for that mission. When the mission was fully organized, he was elected chair of the Project Science Group, and he led its triennial meetings that continued until the end of Orbiter operations in 1992. In his 1982 work on the data from the mass spectrometer, he established the huge enhancement of the deuterium abundance that is considered likely evidence that Venus started out with, and then lost, an amount of water equivalent to Earth's ocean.

From 1972 to 1976, Donahue was a member of a senior NASA advisory committee, the Physical Sciences Committee, and he sat on numerous committees of the National Research Council and from 1982 to 1988 was chair of its Space Science Board. As an aside, Donahue was fascinated by his Irish heritage (from both parents); his last Christmas card showed a photograph of him standing beside The O'Donoghue in front of the ancestral castle with a greeting in Gaelic. He was a fancier of fine wines, and his collaboration with Blamont allowed him to spend several periods in France.

Tom Donahue mentored many of the leaders in the space science and atmospheric chemistry communities, and one of his distinguishing characteristics was his completely unselfish approach to the support of science and the young members growing up in that scientific environment. For example, one of his flock (Anderson) arrived at the University of Pittsburgh Space Research Coordination Center in 1971 as a new postdoc under Donahue's support with the stated intention of measuring water vapor in the mesosphere and thermosphere of the Earth from a sounding rocket. Instead, within two weeks, that postdoc was working on OH kinetics with Fredrick Kaufman—a free radical chemist and subsequent member of the NAS, who Tom had recruited to Pittsburgh. That collaboration went on for more than three years, yet Donahue continued his support without a word. He was indeed generous in every human dimension.

This unselfish support for emerging scientific fields, often orthogonal to his rich legacy in aeronomy, resulted in the development of new fields of research that brought about the union of physics and chemistry to address the critical field of climate research, at least in part motivated by Tom's discovery that the early Venus ocean had been vaporized by runaway greenhouse warming. His support of Anderson's research on new spectroscopic approaches to free radical detection, which was first applied to laboratory studies of OH radical kinetics in Kaufman's laboratory, led directly to the development of myriad techniques for the in situ detection of the radicals $O(^3P)$, OH, HO_2, NO, NO_2, Cl, ClO, $ClONO_2$, Br, and BrO as well as with O_3 and H_2O in the stratosphere.

These observations first addressed the impact of the supersonic transport (SST) on stratospheric ozone using high altitude (to 45 kilometers) balloon platforms, then moved to the engagement of the NASA ER-2 (a modified U2) stratospheric observing platform. Together, these in situ observations provided direct proof in the determination of ozone loss processes over mid-latitudes of the northern hemisphere and then to the establishment of the cause of ozone loss over the Antarctic (aka the "Antarctic Ozone Hole"), which in turn established the scientific case for the Montreal Protocol banning chlorofluorocarbons (CFCs). Subsequent observations of halogen free radicals, along with observations of H_2O and O_3 in the stratosphere established the link between climate forcing via the extraction, distribution, and combustion of fossil fuels and stratospheric ozone loss.

Another of Tom Donahue's legacies is the uniquely creative contribution to the quantum mechanical understanding of free radical kinetics (specifically the fundamental mechanism controlling barrier heights in free radical reactions), as well as major advances in the complex photochemistry of atmospheric aerosols that dictate both the chemical processes of the troposphere and stratosphere and also the dominant factors at play associated with radiative forcing of the global climate structure. The international leader in these critically important fields is Tom Donahue's son Neil, Thomas Lord University Professor of Chemistry and Chemical Engineering at Carnegie Mellon University.

Length constraints preclude discussion of the full depth and breadth of Tom Donahue's contributions to physics, chemistry, aeronomy, international collaboration, planetary sciences, satellite systems, stratospheric ozone photochemistry, free radical processes, and the coupling of atmospheric chemistry with climate change, his decades of scientific insights, his unique ability to foster cross-disciplinary scientific collaboration, and his unselfish support of multiple generations of emerging scientists, all of which stand as a powerful example for generations to come.

Selected Bibliography

1953 With A. Foderaro. Production of sodium airglow excitation by imprisonment of resonance radiation. *Phys. Rev.* 91:1561.

1963 With G. Thomas. Lyman-alpha scattering in the Earth's hydrogen corona: 2. *J. Geophys. Res.* 68:2661–2671.

1964 With J. R. McAfee. The influence of lateral flow on the diurnal variation in exospheric hydrogen. *Planet. Space Sci.* 12:1045–1054.

1965 Detection of high-altitude explosions by observation of air fluorescence. *Proc. IEEE* 53:2072–2078.

1966 On the ionospheric conditions in the D region and lower E region. *J. Geophys. Res.* 71:2237–2242.

Upper atmosphere and ionosphere of Mars. *Science* 152:763–764.

1967 With R. R. Meier. Distribution of sodium in the upper atmosphere as measured by a rocket experiment. *J. Geophys. Res.* 72:2803–2829.

1969 Deuterium in the upper atmospheres of Venus and Earth. *J. Geophys. Res.* 74:1128–1137.

1970 With D. J. Strickland. Excitation and radiative transport of OI 1304 Å resonance radiation–II: The aurora. *Planet. Space Sci.* 18:621–697.

With G. A. Doschek. Transport of resonance radiation in optically thick media. *Astrophys. J.* 161:737–750.

1971 Aeronomy of CO_2 atmospheres: a review. *J. Atmos. Sci.* 28:895 –900.

1972 With B. Guenther and J. E. Blamont. Noctilucent clouds in daytime: Circumpolar particulate layers near the summer mesopause. *J. Atmos. Sci.* 29:1205–1209.

With M. B. McElroy. Stability of the Martian atmosphere. *Science* 177:986–988.

1973 With B. Guenther and R. J. Thomas. The distribution of atomic oxygen in the upper atmosphere deduced from OGO-5 airglow observations. *J. Geophys. Res.* 78:6662–6689.

1974 With S. C. Liu. Realistic model of hydrogen constituents in the lower atmosphere and escape flux from the upper atmosphere. *J. Atmos. Sci.* 31:2238–2242.

1976 With D. M. Hunten. Hydrogen loss from the terrestrial planets. *Ann. Rev. Earth Planet. Sci*. 4:265–292.

1977 With S. K. Atreya and W. R. Kuhn. The distribution of ammonia and its photochemical products on Jupiter. *Icarus* 31:348–355.

1978 With S. K. Atreya and W. R. Kuhn. Evolution of N_2 atmosphere on Titan. *Science* 201:611–613.

1979 With H. A. Taylor et al. Ionosphere of Venus: First observations of the effects of dynamics on the dayside ion composition. *Science* 203:755–757.

With L. Brace et al. Electron temperatures and densities in the Venus ionosphere: Pioneer Venus Electron Temperature Probe results. *Science* 203:763–765.

With A. L. Broadfoot et al. Extreme ultraviolet observations from Voyager 1 encounter with Jupiter. *Science* 204:979–972.

1980 With J. H. Hoffman et al. Composition of the Venus lower atmosphere from the Pioneer Venus Mass Spectrometer. *J. Geophys. Res.* 85:3255–3263.

1981 With A. J. Watson and J. C. G. Walker. Gas dynamics of a rapidly expanding atmosphere: Applications to the evolution of Earth and Venus. *Icarus* 48:150–166.

1982 Venus was wet: A measurement of the ratio of deuterium to hydrogen. *Science* 216:630–633.

1996 The aeronomical pilgrim's progress. *J. Geophys. Res.* 101:10555–10566.