BIOGRAPHICAL MEMOIRS

Donald Alfred Gurnett

April 11, 1940–January 13, 2022
Elected to the NAS, 1998

A Biographical Memoir by Stephen A. Fuselier

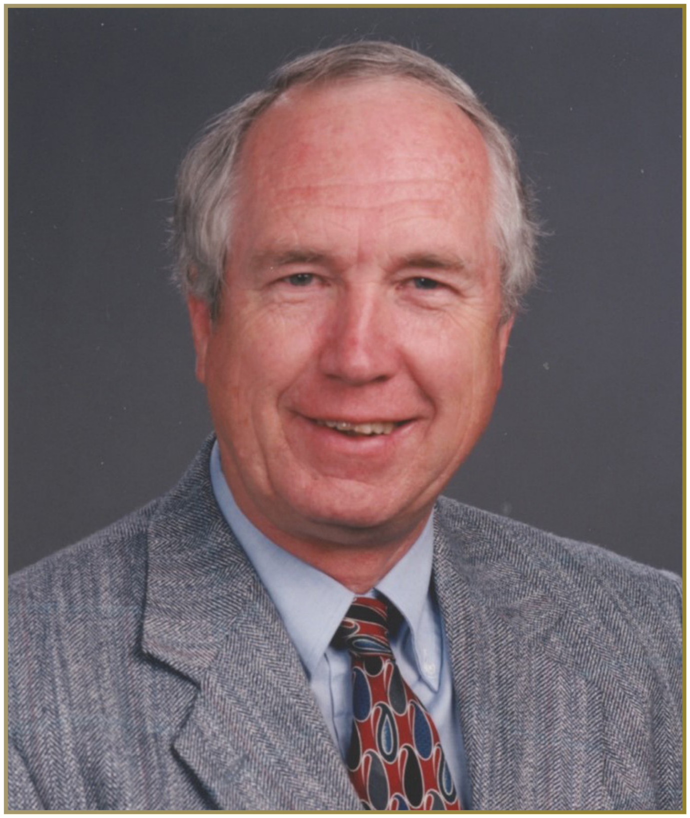

Figure 1 Department portrait from 1998. *Courtesy of the University of Iowa.*

Donald A. Gurnett was a space plasma physicist who pioneered the study of electromagnetic and electrostatic waves in space plasmas. He participated in more than thirty space missions, starting in the early 1960s. His instrumentation has orbited the Earth for decades, flown to the outer planets, and flown throughout the heliosphere (the magnetic bubble that surrounds the solar system) from very close to the Sun to beyond its boundaries and into interstellar space. He used plasma wave observations to make seminal discoveries about the Earth's magnetosphere and the magnetospheres of all the magnetized planets except Mercury and about the interaction within the solar wind and between the wind and the interstellar medium. He mentored more than sixty graduate students, authored two textbooks on plasma physics, and was an author on more than 750 scientific publications. He taught at the University of Iowa for more than sixty years and was a highly sought-after lecturer up until his retirement in 2019. His lifelong passion was aviation and, in addition to model aircraft, he had many thousands of hours in gliders and propeller aircraft.

Early Years

Donald A. Gurnett was born on April 11, 1940, in Fairfax, Iowa, and grew up on the outskirts. He was the only child of Velma and Alfred Gurnett, who owned a 160-acre corn and soybean farm very close to the Cedar Rapids Airport. When Don was about seven years old, his father took him to Cedar Rapids and bought him a rubber-band-powered model airplane. This event was the beginning of a lifelong passion for aviation. He joined a model airplane club at a Cedar Rapids hobby shop that included Alexander Lippisch, a German rocket scientist. Lippisch was the father of delta-wing aircraft, such as the future Concord and the Space Shuttles, and the first rocket-powered, flying-wing fighter, the Messerschmitt 163. Before and during World War II, Lippisch developed his aircraft by first building gliders; therefore, it was only natural that he was involved with the Cedar Rapids model airplane club after the war. He made a huge impression on Don, who decided he wanted to be an aeronautical engineer.

Don spent high school designing and flying model aircraft, working at and eventually running the model shop in Cedar Rapids, and devouring every technical book in the

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local library in Cedar Rapids. He started entering and winning model airplane competitions while in high school and was a U.S. national champion in 1955-56. He won in a category that was sponsored by Pan American World Airways for the person who flew the most weight in their model aircraft. The competition attracted many older and more experienced aeronautical engineers, and yet a high school student from Iowa won! These years taught Don about the need to have a deep understanding of the fundamentals of any technical challenge. It also taught him to be innovative and not be afraid of experimenting with a design. Working in the model shop taught him how to interact with and manage people. But the most important educational experience during Don's high school years, and the one that would propel him into a space research career, was his interest in electronics; in particular, his interest in building radio equipment for model aircraft.

At the time, complete radio controls for model aircraft were not available. Instead, the hobbyist had to put the radio together with purchased components. In his last year in high school, Don, seventeen at the time, started building and working with these model aircraft radio controls. This interest in electronics shifted his focus from aeronautical engineering to electrical engineering. That shift was an important reason why he chose to remain local and attend the University of Iowa (then called the State University of Iowa).

Indeed, except for year-long visits to Stanford University, the Max Planck Institute in Germany, and the University of California, Los Angeles, Don would spend his entire life in Iowa and his entire career at the University of Iowa. Although this life choice may appear limiting, when Don entered the University of Iowa as an undergraduate, the Department of Physics and Astronomy, led by James Van Allen, was on the verge of becoming the center of U.S. space research, and Don was destined to play a huge part in it. And, like his future space instrumentation, he also traveled extensively.

The University of Iowa

Don arrived at the University of Iowa campus as an engineering undergraduate in September 1957. That October, the Soviet Union shocked Don and the rest of the world by launching *Sputnik*. There was considerable speculation about when and how the United States would launch its own satellite. Then, in February 1958, five months into Don's college career, James Van Allen launched a Geiger tube in orbit on Explorer 1 and discovered the Earth's radiation belts, which are part of its magnetosphere and named for Van Allen. Don had no idea that literally right across the street from the engineering building was the United States's answer to the Soviet space program. Van Allen became an instant celebrity. In April 1958, Don, still a first-year engineering student, filled out an application for employment in Van Allen's research group. On it, he described his knowledge of electronics and especially radio-controlled systems.

Don started working on space projects at the University of Iowa in the fall of 1958. From 1958 to 1962, he would attend his classes during the day and work on spacecraft subsystems into the evenings, and sometimes well into the morning. He was often away at Cape Canaveral and missed exams and had to take makeups. One of the early projects he worked on was a satellite called *Injun 1*. Don and the *Injun 1* team designed a digital data system and digital transmitter for the satellite. The satellite was launched in June 1961 and returned radiation data through its digital system until March 1963. This early success almost didn't happen, because a harmonic frequency of the transmitter was the same as the destruct command frequency for the rocket's third stage. Had the team activated the transmitter on the launch pad, as originally requested by the Air Force, the rocket would have blown up. Instead, they turned on the transmitter in orbit after third stage separation and only learned about the third stage destruction when the North American Defense Command told the Iowa team that they were tracking about 200 objects in the *Injun 1* orbit.

By 1962, Don was working on another Iowa spacecraft, *Injun 3*. *Injun 2* never made it to orbit, as was the case for

Figure 2 Don Gurnett was the project engineer responsible for the encoder and digital telemetry system design for the *Injun 1* spacecraft, which was the first spacecraft to be designed and built entirely at a university. *Courtesy of the University of Iowa.*

approximately one in three satellites in the early 1960s. *Injun 3* was a seminal transition for Don. While working on the spacecraft design, he heard a talk by Roger Gallet from the National Bureau of Standards about whistlers (plasma waves that are detectable on the ground and that have a variety of generation mechanisms, one of which is lightning). Brian O'Brien, then an Iowa professor of physics, suggested that he and Don build a multichannel wave receiver for *Injun 3*. Don built the receiver, which had eight channels each filtered for a specific frequency. In addition to this fixed-frequency receiver, he built an analog receiver, his first of many wide-band receivers. He tested the receivers at his parents' farm (to avoid the high 60 Hz noise in Iowa City) and heard his first whistlers. He brought these working receivers to James Van Allen and asked if he could fly them on *Injun 3*. At the time, he was still an undergraduate in electrical engineering! *Injun 3* and the plasma wave receivers launched in December 1962, the same year Don graduated from the University of Iowa with a bachelor of science degree in electrical engineering.

Injun 3 and the Sounds of Space

The plasma wave receivers on *Injun 3* represent the beginnings of space plasma wave research for Don. He switched his major from electrical engineering to physics and completed a master's thesis entitled, "Very Low Frequency Electromagnetic Emissions Observed with …. *Injun 3*" in 1963 using data from the plasma wave receivers he designed, built, and operated. Quite often, the waves that he studied were in the audible frequency range; therefore, in his scientific talks, he often played recordings of the "sounds of space." In 1964, he entered Stanford University to study plasma physics with the group that included Peter Sturrock, Oscar Buneman, and Robert Helliwell. The Stanford group was investigating several plasma phenomena, including whistler waves detected on the ground. Don completed his Ph.D., with a thesis entitled "Ion Cyclotron Whistlers," under James Van Allen in 1965. As described by Don, to receive a Ph.D. in the Department of Physics and Astronomy, one had to show the committee something that they had never seen before. Because the *Injun 3* observations of plasma waves in space were completely new, Don met this requirement easily. In addition to receiving his Ph.D., Don married Marie Schmitz, the love of his life, whom he met on a blind date. They were married for fifty-seven years, until his death, and had two daughters. Finally, immediately after receiving his Ph.D., he was hired onto the faculty in the Department of Physics and Astronomy at the University of Iowa. With the exception of some sabbaticals, he never left.

Don pioneered research on space plasma waves. Plasma (a gas consisting of ions and electrons often with an imbedded magnetic field) is usually not in equilibrium and therefore has "free energy" to generate a wide variety of electromagnetic and electrostatic waves. Don was a master at identifying these waves and understanding their generation and propagation. In addition, he used this knowledge to quantify plasma properties not only at the source of the waves, but along their propagation path from the source to the observing spacecraft. His most cited paper exemplifies this path of research. In it,[1] Don used his plasma wave instruments on two Earth-orbiting satellites to demonstrate that the Earth is a strong radio source. Jupiter was already known as a strong source of radio emissions. Don showed that the Earth's total power output in kilohertz frequencies was comparable to that of Jupiter's emissions. He correctly identified the source of these emissions at low altitudes in the high-latitude auroral zones of Earth and argued that electrons were ultimately responsible for the emissions. Further, he showed that these were electromagnetic emissions that propagated outward from the relatively low-density auroral zone. An important property of plasmas is that electromagnetic waves are prevented from propagating through regions where their frequency is below that of the fundamental plasma frequency. This fundamental frequency is directly related to the plasma density. Don used this property to understand plasma properties along a path of propagation. For the terrestrial radio source, Don showed that the waves did not propagate to lower latitudes where the plasma density was higher. Don also realized that the source could be triangulated from a high-altitude, high-latitude vantage point. He called these radio emissions terrestrial kilometric radiation; however, because of the association with the auroral region, these emissions soon became known as auroral kilometric radiation (AKR).

Figure 3 Don Gurnett, *Injun 3* project engineer, was responsible for the spacecraft engineering system design and development of a very-low-frequency (VLF) radio receiver. *Courtesy of the University of Iowa.*

AKR is just one of many planetary radio emissions that Don investigated using plasma wave instruments on multiple Earth-orbiting spacecraft. It is safe to say that Don, his colleagues, and his students have investigated essentially all plasma wave phenomena in near-Earth space. His instruments[2] were used to investigate the plasma wave environment around Jupiter, Saturn, Uranus, and Neptune—all the magnetized planets in the solar system except Mercury.[3–6] His plasma wave instruments on the *Voyager* spacecraft made flybys of the four outer planets, and he followed up the flybys of Jupiter and Saturn with plasma-wave instruments on the *Galileo*[7] and *Cassini*[8] missions that orbited these gas giants. His many investigations include the identification of lightning on Jupiter[9] and Neptune[10] and the detection of micron-size dust in a passage through Saturn's ring plane.[11] Later in his career, he used ground-penetrating radar on a European satellite mission to "sound" the Martian ionosphere and investigate the crustal magnetic field.[12] These are just a few examples of the very large body of work that Don, his students, and collaborators produced using his plasma wave instruments.

Interplanetary Space

Don also published extensively on plasma waves in interplanetary space. In the inner heliosphere (inside of 1 AU, the distance from Earth to the Sun), Don and his colleagues studied extensively electron plasma oscillations (electrostatic waves at the electron plasma frequency) associated with type-III radio bursts (a type of electromagnetic radio emission).[13] They developed a model whereby "runaway" electrons from a solar flare or other impulsive event generate electrostatic plasma waves that undergo a non-linear mode conversion to an electromagnetic type III radio emission. The type III radio emission frequency decreases with time because the plasma density and the plasma wave frequency decreases with distance from the Sun. Using observations from the *Helios* spacecraft, Don was able to show that the intensity of the plasma waves increases dramatically inside of 1 AU, which facilitates the non-linear mode conversion.[14]

The research on type-III radio bursts in the inner heliosphere was important because Don applied the basics of this same model to observations from the *Voyager* spacecraft in the outer heliosphere (the magnetic bubble that surrounds the solar system) and ultimately in interplanetary space. The *Voyager 1* and *2* plasma wave instruments made and continue to make extraordinary contributions to the understanding of the heliosphere, its boundaries, and interplanetary space.

Surprisingly, these instruments were not included in the original *Voyager* mission scientific payload. In the early 1970s, as part of the selection process for this payload, NASA convened a meeting at which the principal investigators of competing instruments presented to one another. Don and Fred Scarf from TRW got into a heated argument about the

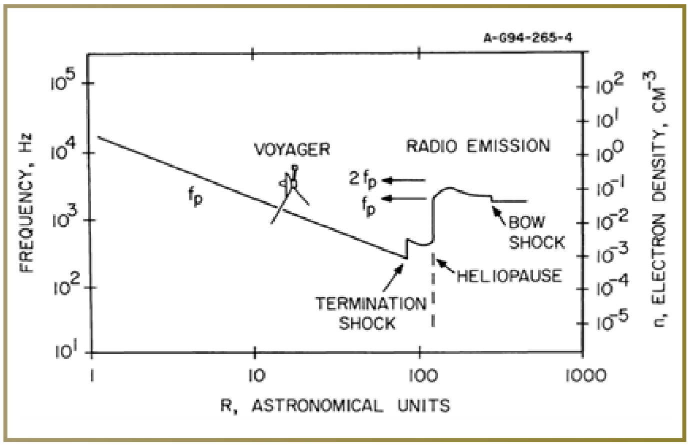

Figure 4 Don had access to a world-class drafting department. In those days, illustrative figures like this one were done entirely by hand. Don was a master at developing a simple figure that contained a large amount of information. In this figure, the location of the *Voyager* spacecraft in the heliosphere is shown along with the solar wind and interstellar medium density profile. Radio emissions at the plasma frequency (fp) from the interstellar medium propagate back into the heliosphere, but, owing to the solar wind density profile, spacecraft need to be ~20 AU from the Sun before these emissions are observed. *From: Gurnett, D. A., and W. S. Kurth. 1996. Radio emissions from the outer heliosphere.* Space Sci. Rev. *78:53–66, used with permission from Springer Nature.*

measurement of plasma waves in space. As a result of this confrontation, NASA decided not to include a plasma wave investigation on *Voyager 1* and *2*. After that exchange, Don and Fred met, settled their differences, agreed to collaborate in the future, and agreed that they should work together to convince NASA to fly a plasma wave instrument on the *Voyager* spacecraft.

After securing a mounting location on the spacecraft and an agreement to share the antennas for the radio astronomy experiment, NASA gave the plasma wave experiment 1 kilogram of mass and 1 watt of power. With these meager resources, Don developed a fixed frequency receiver and a wideband receiver, similar to the receivers that he had been flying for more than a decade. NASA also told the plasma wave team that, because of limited telemetry resources, they would receive exactly one wideband wave spectrum for the entire mission! In response, Don and his team formatted the wideband receiver data to match that of the camera format. Then, instead of transmitting fill data to ground when the camera was not operating, the spacecraft transmitted Don's wideband data. Among the amazing discoveries from these instruments, arguably the most significant one was the detection of radio emissions from the boundaries of the Sun's heliosphere. This 1984 discovery was not fully confirmed until *Voyager 1* crossed into the local interstellar medium in 2012.

In 1984, William Kurth, a former graduate student of Don's and a colleague at the university, discovered radio emissions[15] that appeared to come from a distant source. *Voyager 1* and *2,* at 19 and 13 AU from the Sun at the time were past their encounters with Saturn, and *Voyager 1* was out of the ecliptic plane—the plane that contains most of the planets in the solar system—heading for interstellar space. When the radio emissions re-appeared in July 1992, Don and his team realized that these electromagnetic emissions were coming from near the heliopause, the boundary that separates the heliosphere, where the Sun's solar wind dominates, from the interstellar medium.[16] Furthermore, they realized that the emissions were generated in much the same way that shock waves close to the Sun produce type-III radio bursts. These emissions from beyond the heliosphere were coming from shock waves that propagated outward from the Sun. They identified a time of intense solar activity and shock waves in the solar wind the year before the emissions re-appeared, and, by using the time delay between the arrival of the shock waves at *Voyager 1* and *2* and the arrival of the emissions at the spacecraft, they measured the size of the heliosphere in a way that was independent of all other measures at the time. Their estimate of the heliopause distance between 116 and 177 AU from the Sun implied that the heliosphere was considerably larger than other estimates at the time. Finally, from the frequency range of the emissions, they measured the plasma density and its variation in the interplanetary medium just outside the heliopause.

Over the next two decades, Don and his team refined their model but never changed their original estimate of the size of the heliosphere.[17] The *Voyager* spacecraft continued their journey out of the solar system, and other estimates of the size of the heliosphere always seemed to be 10 AU more distant than the location of the *Voyager* spacecraft. *Voyager 1* finally crossed the heliopause in 2012 at 121.8 AU and *Voyager 2* did the same in 2018 at 119 AU, consistent with the distance that Don and his team determined two decades earlier. More importantly, over the years in interplanetary space, the *Voyager 1* plasma wave receiver observed a plasma density profile that was as predicted from the radio wave emissions observed in 1984 and observed the shock waves propagating in interplanetary space that were generating the emissions.[18]

Professor, Educator, and Mentor

In addition to authoring two textbooks and more than 750 publications, Don was a gifted teacher and mentor. Through his career, he mentored more than sixty graduate students. He was a source of unending ideas and had data from more than thirty space research missions to pursue these ideas. His only limitation to the number of graduate students he could mentor was the number of hours in a day, week, month, or year. He delighted in working with his students to find connections between seemingly disparate physical realms. One of his favorite connections was the mathematical link between the ducting of whistler waves in the Earth's magnetic field and the angle that a boat wake makes as it is moving through water.[19] He even wrote a scientific publication describing the similarities of airplane contrail interactions and a process in plasmas called magnetic reconnection.[20] His plasma physics course for upper-level undergraduates, which was centered around plasma waves, was very popular and ultimately became one of his textbooks. In addition to plasma physics, he taught courses in fluid mechanics over a period of thirty years, ending in 2016, just three years before his retirement. He retired in 2019, sixty-two years after he entered the university as an engineering student.

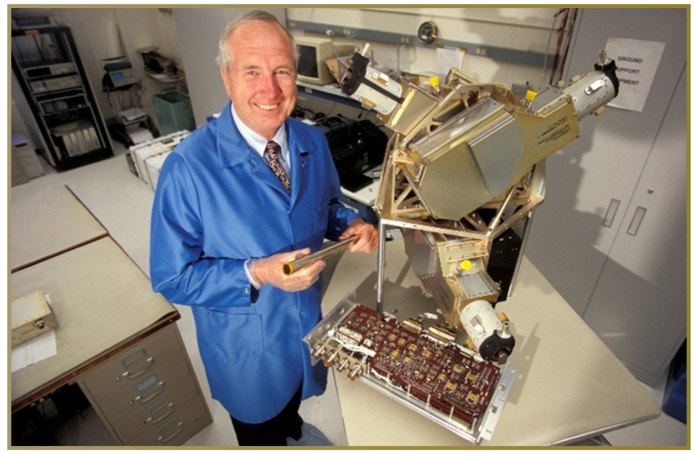

Figure 5 Don Gurnett, principal investigator responsible for the Radio and Plasma Wave Science Investigation (1990-2015); co-investigator (2015-2017). *Courtesy of the University of Iowa.*

Don Gurnett and Aviation

Don maintained his love for aviation and aeronautical engineering throughout his life, and his gliders got bigger as he grew older. He flew several sailplanes, including a high-performance glider that he flew in competitions. In an interview in 1994, he said he had 2,000 hours of flying in many types of aircraft, including a P-51 Mustang. When asked what his idea of a great time was, he said "soaring with an eagle over eastern Iowa on a beautiful fall day." Ultimately, in addition to his gliders, he owned a Stearman Biplane and a WWII T-6 trainer, which he delighted in taking to air shows. His lifelong passion for model aircraft never left him. He still flew them in his retirement.

Awards and Honors

Don received many awards over his storied career. These include the 1986 NASA Space Act Award for his instrumentation development and for his significant advancements and discoveries in space plasma wave and radio wave physics. Don applied the monetary award ($10,000) to the purchase of a high-performance glider. He also received the Union Radio-Scientifique Internationale's John Howard Dellinger Gold Medal, the American Physical Society's John Dawson Award for Excellence in Plasma Physics Research, the John Adam Fleming Medal from the American Geophysical Union (AGU), the NASA Exceptional Scientific Achievement Medal, the Hannes Alfvén Medal from the European Geosciences Union, and the University of Iowa Distinguished Alumni Award. He was elected a member of the National Academy of Sciences in 1998 and named a fellow of the AGU.

ACKNOWLEDGMENTS

Kathy Kurth, Don's long-time administrative assistant, provided considerable input to this memoir. William Kurth, Don's long-time colleague also provided input. In addition to personal recollections, I was aided by transcripts of interviews with Don from Shirley Reudy at the *Cedar Rapids Gazette* in 1994 and with Kris Denton Lighting in 2003. The latter interview was never published. Don Gurnett was an inspiration to me and to all his graduate students. Don taught his students how to do research, which was a lesson that remained with his students throughout their careers. One of my fondest memories of Don, and one that illustrates that he was a wellspring of ideas was when I was looking for an idea for my Ph.D. research, is when I visited his office and asked him for help. He took out a blank sheet of paper and his pencil and in ten minutes wrote down about seven topics. He suggested I research these topics and pick one. Unfortunately, I no longer have that piece of paper because I'm sure that at least five Ph.D.s, including my own, came from that ten-minute exercise.

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