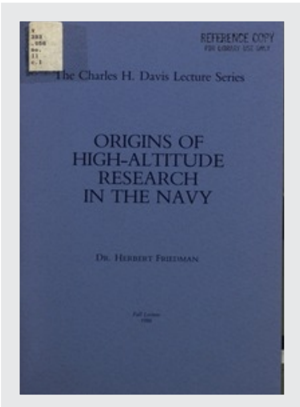

Origins of High-Altitude Research in the Navy

DETAILS

37 pages | 7 x 10 | PAPERBACK
ISBN 978-0-309-32041-2 | DOI 10.17226/19176

AUTHORS

Friedman, Herbert; Naval Studies Board; National Research Council

The Charles H. Davis Lecture Series

Eleventh Lecture

ORIGINS OF HIGH-ALTITUDE RESEARCH IN THE NAVY

by

Herbert Friedman
National Air and Space Museum

Presented Before the Students and Faculty of
The Naval Postgraduate School
November 24, 1986
and
The Naval War College
December 10, 1986

Organized by
The Naval Studies Board
of the
National Research Council

Sponsored by
The Office of Naval Research

NATIONAL ACADEMY PRESS
Washington, D.C. 1987

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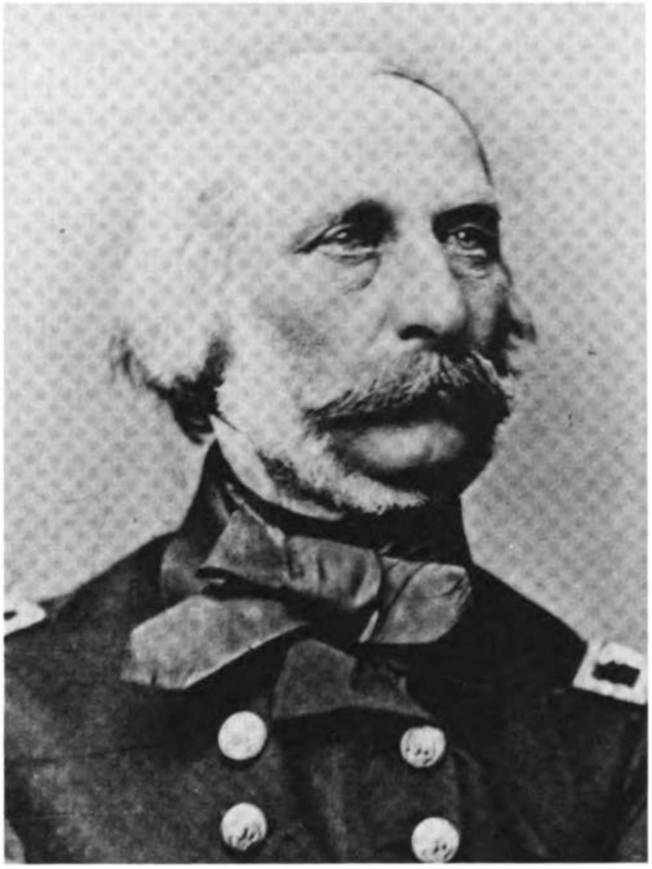
THE CHARLES H. DAVIS LECTURE SERIES

AT THE CLOSE of that greatest of all contests of men and machines, World War II, Theodore von Karman could say, with deep personal conviction, that ". . . scientific results cannot be used efficiently by soldiers and sailors who have no understanding of them, and scientists cannot produce results useful for warfare without an understanding of the operations." With such simple truths fresh on their minds, von Karman and his civilian and military colleagues proceeded to forge institutional links—such as the Office of Naval Research—through which they hoped to encourage an enduring partnership between the scientific and military communities. Though the intensity of the bond has fluctuated with the ebb and flow of international relations and internal affairs, the partnership has endured to produce a military capability but dimly perceived by those who established it. But the partnership is not self-sustaining; it requires the constant vigilance of those who have not forgotten the bitter lessons of the past, the outspoken dedication of those whose vision extends beyond the next procurement cycle, and, above all, it requires open communication between the partners. It is to this latter task that the Charles H. Davis Lecture Series is dedicated.

The lecture series is named in honor of Rear Admiral Charles Henry Davis (1807–1877) whose distinguished career as a naval officer and as a scientist so epitomizes the objectives of the series, and whose clear vision of the proper role of science in human affairs redounded to the betterment of all men. The topics and the speakers in the series are chosen by a Search Committee operating under the National Research Council of the National Academy of Sciences, and two lectures are presented each year before the students and faculty of both the Naval Postgraduate School in Monterey, California, and The Naval War College at Newport, Rhode Island. The series is sponsored by the Office of Naval Research.



Rear Admiral
Charles H. Davis
(1807–1877)

CHARLES HENRY DAVIS was born January 16, 1807, in Boston, Massachusetts. His education consisted of preparation at the Boston Latin School followed by two years at Harvard University (1821–1823). In 1823, Davis was appointed midshipman and sailed (1824) on the UNITED STATES to the West Coast of South America where he transferred to the DOLPHIN for a cruise of the Pacific. Returning to Harvard he continued to work on a degree in mathematics and is listed with the graduating class of 1825.

In 1829 Davis became passed midshipman and was ordered to the

ONTARIO (1829–1832) of the Mediterranean squadron. Later, while serving aboard the VINCENNES (1833–1835), he was promoted to lieutenant. Aboard the INDEPENDENCE (1837–1841) Davis made a cruise to Russia and then to Brazil. Throughout these early years at sea Davis continued to study mathematics, astronomy and hydrology. During this period one of his superiors would write of him, "C. H. Davis is devoted to the improvement of his mind; and his country may expect much from him."

From 1842 to 1856 Davis undertook a number of special tasks and served on several commissions and boards. Notable among these was his participation in a survey of the New England coastal waters (1846–1849) during which he discovered several shoals that may have been responsible for a number of unexplained wrecks in the area. It was during this period in his career that Davis published "A Memoir upon the Geological Action of the Tidal and Other Currents of the Ocean" (1849) and "The Law of Deposit of the Flood Tide" (1852). He was also a prime mover in establishing the "America Ephemeris and Nautical Almanac" (1849) and supervising its publication at Cambridge, Massachusetts until 1855 and again from 1859 to 1862.

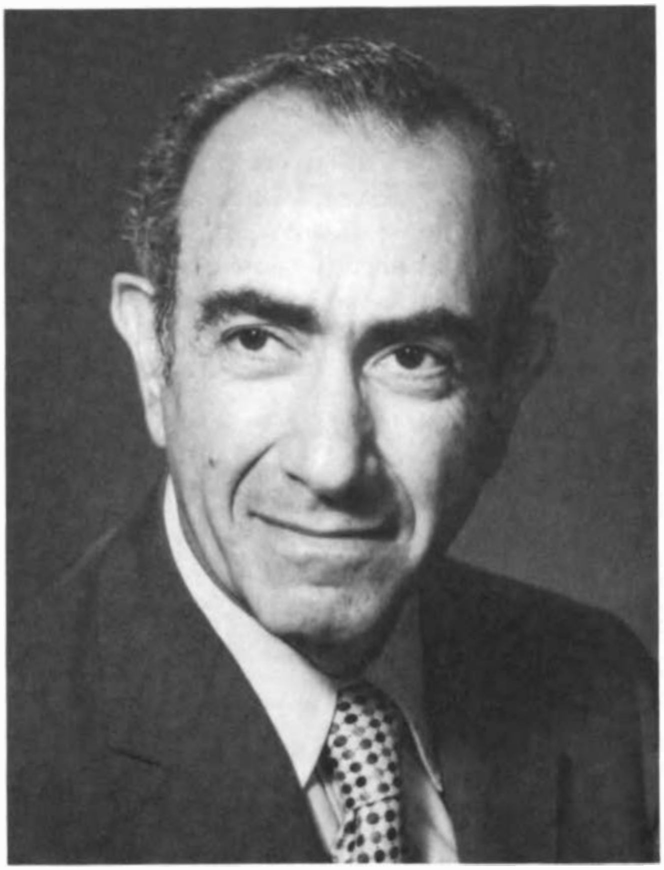
Promoted to commander in 1854, Davis resumed sea duty in command of the ST. MARYS in the Pacific (1856–1859). While he was captain of the ST. MARYS he was instrumental in securing the release of the adventurer William Walker and his followers who were beseiged at Rivas, Nicaragua.

With the outbreak of the Civil War Davis was immediately appointed to a number of important positions. He became the executive head of the new Bureau of Detail for selecting and assigning officers. He was one of three officers appointed by Secretary Gideon Welles to the Ironclad Board which passed judgment on the plans and specifications for the MONITOR and other ironclads. Promoted to captain in November 1861, Davis participated in the development of plans for blockading the Atlantic Coast, planning the operation against Hatteras Inlet and Port Royal Channel, and the early naval strategy of the war.

During the operations against Port Royal, Davis served as captain of the fleet and Chief of Staff to Admiral Samuel F. Du Pont. He shares with Du Pont a great deal of the credit for the excellent plan of attack carried out on November 7, 1861. Later, as flag officer of the Mississippi Flotilla, Davis led successful engagements against the Confederate fleet which contributed to the abandonment of Fort Pillow and the surrender of Memphis. He was promoted to commodore in July 1862, and to rear admiral on February 7, 1863.

In late 1862 Davis returned to Washington to head the newly established Bureau of Navigation. From this position he worked closely with such distinguished scientists as Joseph Henry and Alexander Bache to establish a "Permanent Commission" to advise the government on inventions and other scientific proposals which were being stimulated by the war. The Permanent Commission was established by the Secretary of the Navy on February 11, 1863 with Davis, Bache and Henry as members. However, Davis and his colleagues saw a wider need for cooperation between science and government and worked diligently for the establishment of the National Academy of Sciences. Their efforts were successful; President Abraham Lincoln signed a bill authorizing the establishment of the Academy on March 3, 1863.

In 1865, Admiral Davis was appointed superintendent of the Naval Observatory in Washington. In 1867 he returned to sea in command of the South Atlantic Squadron. Back in Washington in 1869 he was made a member of the Lighthouse Board and commander of the Norfolk Navy Yard. He later resumed his post as superintendent of the Naval Observatory where he served until his death on February 18, 1877.



HERBERT FRIEDMAN

ORIGINS OF HIGH-ALTITUDE RESEARCH IN THE NAVY

HERBERT FRIEDMAN
Martin-Marietta Fellow in Space Science
National Air and Space Museum

EARLY STUDIES OF THE IONOSPHERE

During the 1920s and 1930s studies of the physics of the ionosphere were pursued most prominently in the United States at the Naval Research Laboratory (NRL), the Carnegie Institution, and the National Bureau of Standards (NBS). Much of the early research by Edward O. Hulburt and E. Hoyt Taylor at NRL was accomplished with the cooperation of radio amateurs ("hams") who truly pioneered round-the-world shortwave communication using vacuum tubes with power outputs of less than 50 watts and transmissions limited to very short waves—less than 200 meters. Working with as little as 5 watts of power, the amateurs could communicate from hemisphere to hemisphere. Their reports showed that shortwaves skipped over regions near the transmitter and were received at great distances with a zone of silence in between, extending 20 or 30 miles around the transmitter. Outside this zone, reception extended hundreds of miles.

These observations showed that the waves were reflected only when the angle of incidence exceeded a minimum value. At smaller angles the waves simply escaped the ionosphere into space. With the data collected from their amateur network, Hulburt and Taylor found skip distances of about 1,300, 700, 400, and 175 miles for wavelengths of 16, 21, 32, and 40 meters respectively, during daytime. At night, skip distances were greater than during the day, and greater in winter than in summer in mid-latitudes. From these primitive observations Hulburt calculated the height of reflection and the electron density of the ionosphere.

With charts of skip distances published by the Navy, communicators could select wavelengths for specific paths of communication. For his flight to the South Pole in 1929, Admiral Richard E. Byrd had very little power available for communication. He matched a special program of shortwaves to skip distances over the course of the flight; 69 meters over the first 200 miles, 45 meters for the next 200 miles, and 34 meters over the final 380 miles. In this way he could maintain continuous radio communication.

Pioneering research on the ionosphere was carried out in England by Edward Appleton and his student, Miles Barnett, and in the United States by Hulburt and Taylor at NRL and Gregory Breit and Merle Tuve of the Carnegie Institution. By 1927, Appleton had confirmed the existence of D, E, and F reflections from successively higher regions of the ionosphere. For this accomplishment Appleton received the Nobel Prize.

The possibility of pulse-reflection experiments appealed to the American scientists early in the 1920s, but it was extremely difficult to measure time delays of milliseconds between transmission and reflection when they had only string galvanometers of much longer restoring times to work with. In the winter of 1924–25, Breit and Tuve at the Carnegie collaborated with Hulburt and Taylor, who sent pulses at 4.2 MHz by means of a ten kilowatt shortwave transmitter at NRL to the Carnegie laboratory seven miles away in northwest Washington. The Carnegie scientists devised a multivibrator keying circuit to pulse at full power for 10 seconds at 80 cycles per second. The receiver was next moved to NRL and positioned close to the transmitter. With a range sensitivity of about 20 meters of path length, precise phase measurements were begun. This "ionosonde" was the forerunner of the instruments in common use today. In the course of their measurements interference was noted from approaching ships and planes. A young Navy lieutenant, William Parson (who later rose to the rank of admiral and became a key figure in the development and delivery of the atomic bombs that were dropped on Japan), suggested that the interference difficulties implied the possibility of detecting ships and planes. He sent a proposal labelled secret to Bureau of Ships; it led the Navy into the development of radar.

In 1928, Hulburt proposed that it was ultraviolet radiation shortward of a wavelength of 1230 A that was ionizing the upper atmosphere. By 1930, he was convinced of a connection between solar ultraviolet and sunspots and their link to magnetic storms and the disruption of radio communications. In 1935, J. H. Dellinger at the NBS reported on a series of sudden ionospheric disturbances (SID) over a period of six months. He stressed the importance of understanding the phenomenon and organized a joint effort of NBS, DTM (Director, Telecommunications Management), and the solar observatory on Mt. Wilson. His goal was to integrate ionospheric physics with solar astrophysics. During the same time frame, Robert H. Goddard was working on his rocket to carry instruments to high altitude for atmospheric research. Correspondence between Hulburt and John Fleming at the Carnegie in the early 1930s reveals that Hulburt contemplated the possibility of solar rocket astronomy to study the physics of solar control of the ionosphere.

These early glimmerings of high-altitude research with rockets were interrupted by the war, but the new technologies of warfare rapidly changed speculations to reality. In 1942, Ernst Krause in the Radio Division at NRL undertook to organize a program on guided missiles. Work began on a U.S. version of the German V-1 buzz bomb known as the JB-2 and a rocket propelled guided missile, the Lark, for ship to air. It was NRL's experience with guidance and telemetry for drones and target ships used in gunnery practice that paved the way for its future role in rocket research. Some remote controlled bombers saw combat in Europe and bomb-loaded assault drones were used against Japanese strongholds on Pacific islands. At the end of the war Krause urged NRL to commit to a substantial effort in rocket development and high-altitude research.

Debate about the difference between basic and applied research and which is appropriate to a mission-oriented laboratory has been going on continuously since the end of World War II. Hulburt was the primary influence in establishing the research character of NRL at the end of the war. NRL was distinguished for its accomplishments in radio science and for the development of radar, but Hulburt, several high-ranking naval officers, and prominent Navy advisers believed that a great future for NRL could be achieved only if there was a strong emphasis on basic research. Otherwise, NRL might easily become little more than an electronics test and development organization.

Hulburt, who was appointed director of research in 1949, was strongly oriented toward basic research but never lost sight of its potential connection with the needs of the fleet. The nature of the upper atmosphere and the ionosphere and the controlling influence of solar ultraviolet and X rays were subjects of great scientific interest, but also clearly important to future military needs in space, and capable of being studied with sounding rockets. It was natural that Hulburt led NRL into a great era of high-altitude research with the remarkable new rocket tools.

The V-2 Era

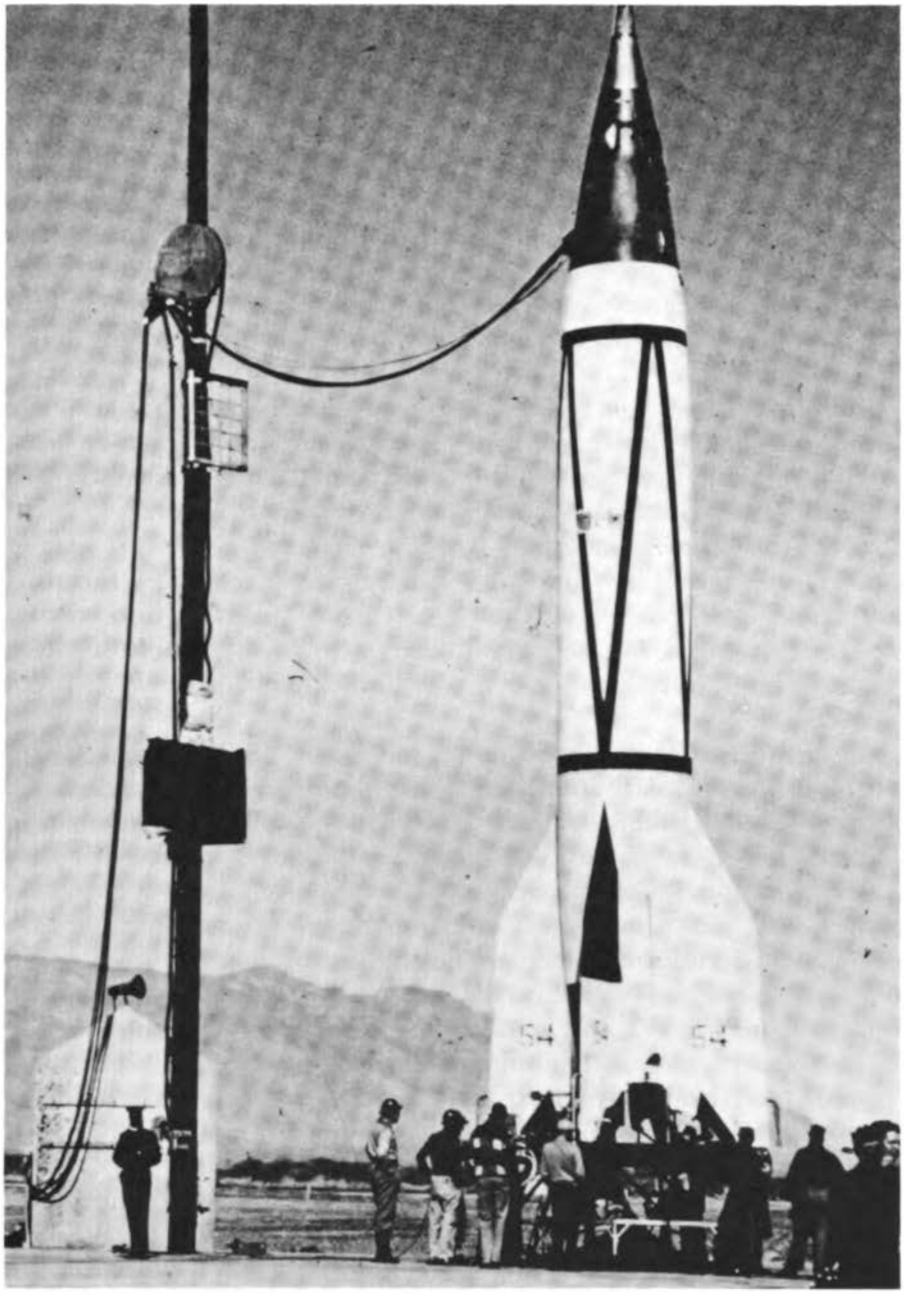
Peenemunde was established in 1936 by the German military as the center for rocket development. By 1939 Wernher von Braun and his team had perfected the V-1, and by the end of World War II the V-2 was also hitting England. When American forces entered Germany in 1945, the huge underground factory for V-2 production at Nordhausen was high on their priority list. Racing the Russians to Nordhausen, the Americans got there first and made off with about a hundred rockets. The rockets were shipped to the White Sands Missile Range in New Mexico where the Army set about studying the propulsion system. Fortunately for the scientific community, the warhead space was made available for scientific instrumentation. The first V-2 flew from White Sands on April 16, 1946. Some 60 launches were carried out up to the fall of 1952.

After the short-lived bursts and rapid acceleration that characterized the firing of small rockets, the slow majestic rise of the V-2 and the sudden vanishing of the roar of the rocket in the eerie quiet of burnout was a breathtaking experience. Silent snaking vapor trails marked the passage of the rocket through the stratosphere, and sound returned only near landing when shock waves reverberated from the mountains.

We expected the V-2 to become a great asset for solar astronomy, but it came with a variety of handicaps. About 45 feet tall and 5 feet in diameter, the motor was so large that a man could crawl through the nozzle. It had been designed as a weapon and not as a tool for high-altitude research, but the Army offered the space of the 2,000-pound warhead to the scientific community for instrumentation. In the early days at White Sands, one had to be something of an acrobat to mount his experiment in the nose of the V-2. To get to the top of the rocket meant climbing a long extension fire ladder. A little later a gantry was built, and from then on access to the rocket was much simpler and safer.

The rocket was fueled by 10 tons of alcohol and LOX. At takeoff it generated 28 tons of thrust and accelerated to 6 Gs. A successful flight could reach 170 km and last about 450 seconds, with about 270 seconds above 80 km. During powered flight, the rocket was guided by gyro-controlled graphite steering vanes that deflected the exhaust stream of hot gas. The landing speed in streamlined impact on the desert usually created a crater about 80 feet in diameter.

Rarely did the V-2 fly like an arrow straight into the sky. As often as not, the rockets tumbled and faltered. Some burned up furiously upon ignition. One took off in horizontal flight to land on the edge of Juarez across the Mexican border. On the day after the incident, street



One of the first V-2 rockets to be launched from the White Sands Missile Range in 1946.

urchins were hawking souvenir parts in the markets of the city. Another rocket fell near wandering tourists on the pristine sands of White Sands National Park that borders the rocket range.

The first five of the huge rockets all returned nose down in streamlined flight and buried their pulverized remains in craters about 30 feet deep and 80 feet in diameter. Not a trace could be found of the first spectrograph flown by NRL in June 1946. The scientific crew dug and dug until they found—water. In the few buckets of debris that were sifted from tons of overlying sand, there was no trace of the film cassettes. Subsequently, to reduce the impact speed, streamlining was destroyed by blowing off the warhead at 50 km on the down leg. The rocket then broke up, scattering parts over a large area of the desert. Smaller and lighter parts decelerated to landing speeds below 0.1 km/sec. The separated warheads tumbled down erratically with only minor impact damage.

Early participants in the V-2 upper air research program at White Sands included The Johns Hopkins Applied Physics Laboratory, Harvard, Princeton, Michigan, the Air Force, and the Signal Corps as well as NRL. The first NRL success in rocket astronomy came on October 10, 1946, when a team led by Richard Tousey flew a small grating spectrograph, only a foot and a half long, and captured the solar ultraviolet spectrum below the ozone cut-off at 3,000 A down to a short wavelength limit at about 2,200 A. Compared to modern instruments for spectroscopy, it was flea-weight and toylike, but it worked.

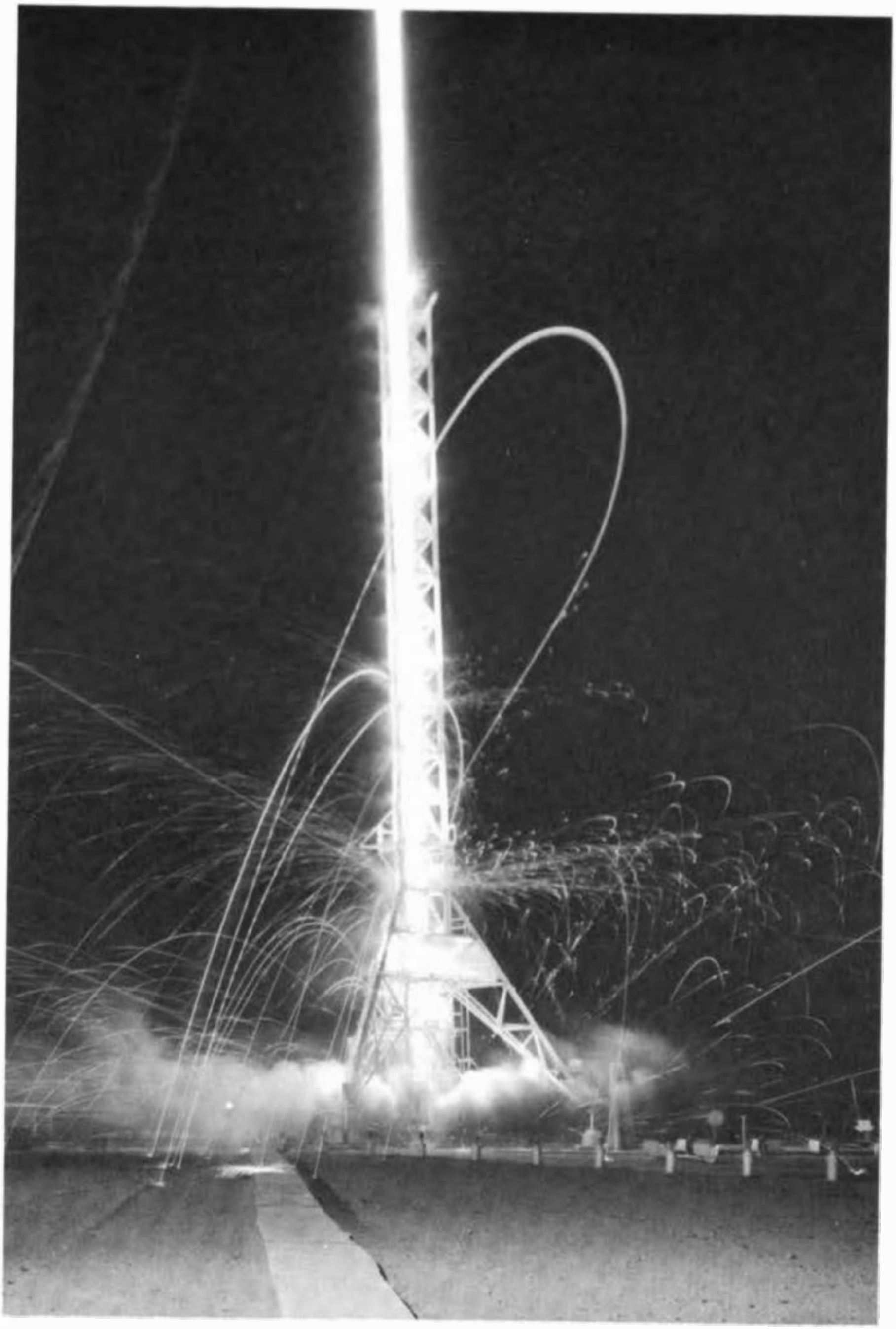
In the micromanaged environment of today's big rocketry, it is hard to recall the casual coordination between shared experiments in the early V-2s and Vikings and the emphasis on individual initiative. In the first few years of the V-2 program, experiment preparations were rushed and glitches in the operations were more common than not. There was great dismay and embarrassment, for example, when a sophisticated cloud chamber instrument for cosmic ray studies was flown with the lens cap left on the camera. Because there was so much space aboard the V-2, it was parcelled out to several experimenters on each flight plus some last minute bidders. Instruments were often placed in less than ideal juxtaposition. Packets of frogs' eggs or seedlings were frequently thrust upon the launch crews late in the preparations with pleas to tape them into any free space.

I was guilty and yet innocent of ruining a colleague's experiment on my first V-2 flight. Unbeknownst to me, Herman Yagoda, a cosmic ray physicist from the Air Force Cambridge Research Laboratory, had sent a photographic emulsion package to White Sands with instructions to mount it in any available V-2 space. It was the practice of my group to do a final checkout of our Geiger counters and telemetry after the payload was buttoned up by exciting them from outside with a 5-milligram radium source. Unwittingly, we were also exposing Yagoda's emulsion. To his consternation after flight, his developed film exhibited an incredibly large number of electron tracks for the few minutes of exposure during the rocket flight. Yagoda was baffled while we were totally unaware of the damage we had wrought. It was some time before the connection was made and we all suddenly understood what had gone wrong with Yagoda's experiment.

To simplify the conduct of research with rockets, it was clearly desirable to trade the heavy payload lift capability of the large rockets for more modest payloads aboard smaller, less expensive rockets dedicated to a single experiment. The Navy supported the development of the Aerobee, a two-stage research rocket consisting of an acid-aniline sustainer atop a solid propellant booster. The combination was fired out of a tiltable tower, 140 feet tall.

The sealing wax and string approach to instrumentation of the Aerobee typified much of our effort in the 1950s. We often went into the field with three rockets to attempt a single experimental objective because they were relatively inexpensive. Mistakes experienced on the first attempt could be adjusted at the launch site by quickly preparing new detectors, for example, on a rudimentary vacuum system with liberal use of wax and Glyptal resin paint to cement new windows, seal leaks, and insulate the electronics against corona discharge. The first Aerobees barely reached 80 to 90 kilometers, but simple modifications soon doubled its height performance and the rocket became the workhorse of the research community.

My entry into the V-2 research program came indirectly from laboratory research into the design of photon counters and the fundamental properties of gas discharges in rare gases doctored with various quenching agents. As a graduate student I had developed very high efficiency soft X-ray counters for use with crystal spectrometers. I brought that expertise to NRL and found an early application in a goniometer for orientation of quartz crystals to determine the precise cuts to be made for oscillator plates that were used in controlling communication frequencies of radio sets aboard military aircraft. Very large numbers of crystals had to be cut to supply the wartime requirements, and photon counters of the required type had never been incorporated in industrial equipment. Commonly used hydrocarbon quenching agents were typically short-lived, making for tubes that were cranky enough in the laboratory and hardly suited to field use. NRL research with new quenching agents and tube materials quickly led to rugged and reliable detectors.



Night launch of an Aerobee rocket out of the launch tower at White Sands.

Another requirement for rugged radiation detectors came in the immediate aftermath of the Hiroshima and Nagasaki bombings. A Navy team was organized under the leadership of Dr. Shields Warren to evaluate the radiation pattern around the center of the explosion. To carry out its survey the Navy team needed portable detectors, but none were available in the "Metallurgy" project at Chicago nor at Los Alamos. At Chicago the Navy representatives were told that there were no Geiger counters that could be packaged in the United States and survive long enough to carry out the mission in Japan. NRL had developed halogen gas quenched counters that met the requirements of long life and ruggedness. These detectors were quickly built into portable radiacs for the Navy survey team and the Hiroshima and Nagasaki operations were carried out successfully.

Parenthetically, it is interesting to note that the Geiger counters flown by James Van Allen on Explorer I in 1958 were commercial versions of the Bureau of Ships halogen quenched tubes. In the intense radiation environment of the Van Allen Belts, they choked but recovered promptly when they exited the belts. Conventional tubes would have failed permanently.

Further studies of electronegative gas mixtures in discharge counters revealed interesting possibilities of combining long wavelength filters and selected gas mixtures to produce narrow bandwidth response characteristics in photon counters for the extreme ultraviolet. At the time the NRL solar spectroscopy team in the V-2 program was experiencing many frustrations in their efforts to achieve simultaneously high altitude, good pointing control, and successful recovery of instrumentation and film cassettes. It occurred to me then that photometric measurements could be carried out over the entire range of the ultraviolet and X-ray spectrum with our newly developed, very sensitive, narrow bandwidth detectors in combination with radio telemetry to avoid the need for complicated pointing controls and film recovery after impact.

The earliest opportunity to fly a set of photon counters came in 1949 and was entirely successful. Solar X rays were measured for the first time as a function of altitude and revealed the direct connection with production of the E-region of the ionosphere. The principal resonance radiation of the hydrogen atom is known as the Lyman alpha line at 1216 A. It penetrated to D-region where it could ionize the trace constituent, nitric oxide. In the broad span of the Schumann region, 1450 A to 1750 A, the flux of radiation was sufficient to dissociate the molecular oxygen in a way that explained the height dependence of recombination rates in the F-region ionosphere. Observations made with rockets over the next decade by the NRL team traced the full solar cycle control of the ionosphere and made it possible to model ionospheric processes in sophisticated detail.

Rockets at Sea

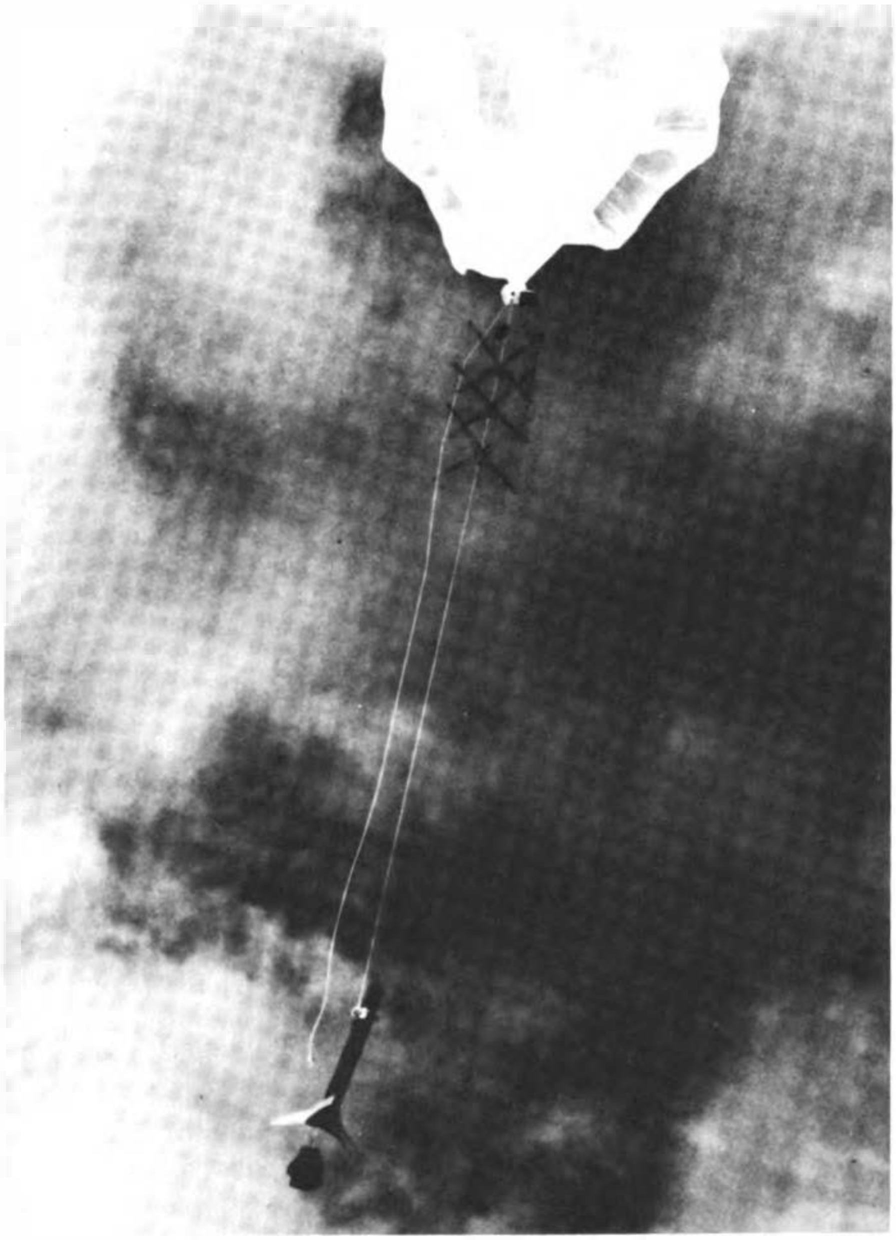
Of all the forms of solar activity, flares are the most spectacular and create the strongest impact on the terrestrial environment. A large solar flare produces prompt shortwave radio blackout that may last for two to three hours followed by great auroral displays and ionospheric and geomagnetic storms for one or two days that seriously degrade radio communications.

The Aerobee was ill-suited to the study of solar flare radiations because there is little capability for predicting the onset of a flare even within minutes of its outburst. It was impractical to tie up the launching tower for days with a rocket in place while awaiting a solar flare. Furthermore, the fuel system had to be pressurized with helium and, once ready, the launch could not be delayed for more than an hour.

In the early 1950s, Lieutenant Lee Lewis, assigned to the Office of Naval Research (ONR), conceived of launching a rocket suspended from a balloon at stratospheric altitude. Van Allen began to experiment with the "Rockoon," a solid propellant Deacon rocket hung on a Skyhook balloon and floated at 25 km, from where it could be fired by radio command. Here was an inexpensive system that could be kept in the air all day and fired at the moment that evidence of a flare was obtained. The Rockoon was truly a poor man's rocket. The cost breakdown was as follows:

Deacon rocket	$ 900
Tail fins	100
Firing box	50
Skyhook balloon	200
Helium	79
Total	$1,329

Without recourse to an expensive orientation system on the balloon, the rocket's impact point could not be predicted within a circular area of about 100 miles radius, and winds contributed further uncertainty. Launch from shipboard far at sea offered range safety and facilitated the balloon launching operation. When the Skyhook balloon was being inflated, surface winds had to be less than 5 to 10 knots. By sailing downwind the ship could achieve nearly zero relative wind conditions for inflation and release of the balloon and its suspended payload.



The Rockoon used in Project San Diego-Hi, 1956, consisted of a helium filled plastic balloon, a collection of corner reflectors for radar tracking, a Deacon solid propellant rocket suspended on a nylon rope and a firing box beneath the rocket. The balloon carried the rocket to 80,000 feet. From that altitude, the rocket was fired by radio command and rose to about 400,000 feet.

The Rockoon seemed to be ideal for studying solar flares. An NRL proposal for a naval expedition as part of the International Geophysical Year (IGY) was strongly endorsed by the National Academy of Sciences, and ONR obtained the use of the USS *Colonial*, an LSD, and the destroyer USS *Perkins* to support the experiment. However, in working with Rockoons there was precious little experience to guide us. Igniters, for example, that had been designed for a ground-launched Deacon were unreliable at 80,000 feet. It must have appeared very amateurish for one of the NRL scientists to play the part of an explosives expert under the watchful eyes of a gunner's mate and to fiddle with new formulations of the igniter on the deck of the ship.

In 1956, the USS *Colonial* embarked on Project San Diego-Hi. We sailed to a launch area about 400 miles southwest of San Diego and released a Rockoon each morning on successive days. While the ships chased the drifting balloon, communications were monitored for information about flare occurrence. One flare was caught in the act and gave convincing evidence that X rays were responsible for the ionospheric disturbance.

A year later Rockoons were out of style. In place of the balloon, a Nike solid rocket booster lifted the Deacon to the stratosphere. The two-stage rocket was fired from a simple rail launcher that the NRL team set up on San Nicholas Island off Point Mugu. In 1958 and 1959, a series of these rockets were launched at times of flares, giving quantitative confirmation of the dependence of SIDs on the intensity and wavelength of flare X-ray emission.

NRL's marriage of rocketry with naval vessels in those years also involved launchings of the Aerobee and Viking from the deck of the USS *Norton Sound*, but certainly the most exciting and glamorous outing was the IGY eclipses expedition to the Danger Islands aboard the LSD USS *Point Defiance*.

Eclipse at Puka Puka

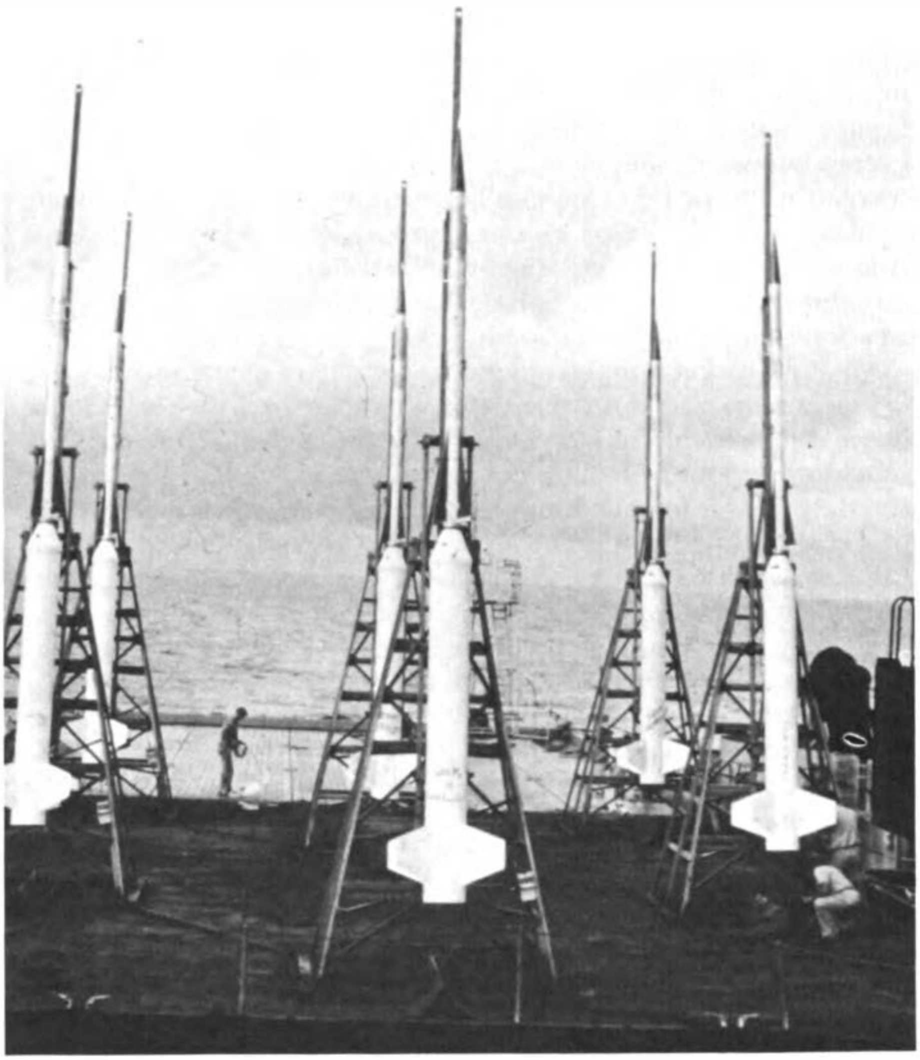
Before the direct measurements of X rays from the sun, theorists had surmised that the corona would be a source of thermal X rays at a temperature of millions of degrees. They reasoned that the great extent of the corona required such high temperature to overcome the very strong pull of gravity at the surface of the sun. This simple reasoning assumed that the corona was a great bag of gas almost without structure, but the corona seen at solar eclipse showed a great variety of structure that connected with sunspot regions. Although no X-ray images of the sun had been obtained up to the time of the IGY, the evidence from NRL rocket measurements over a decade indicated a close link of X-ray emission to active sunspot regions on the face of the sun. In 1958, a true X-ray reflecting telescope had not yet been built, but the eclipse of October 10 offered an opportunity to observe the X-ray distribution by making a series of measurements as the sun was being occulted by the passage of the moon across its face. In its path across the Pacific Ocean, the eclipse crossed only one piece of land, a group of coral atolls, the Danger Islands, about 400 miles southwest of Samoa.

Following our experience with Project San Diego-Hi, I proposed to the IGY Satellite Committee of the National Academy of Sciences that support be provided to NRL to carry out a series of rocket firings from shipboard at the time of the 1958 eclipse in the vicinity of the Danger Islands. The proposal was given high marks for scientific interest but was rejected because the committee thought the technology was too risky. In 1957, Sputnik began to play its tune overhead and suddenly research money became much easier to find. I approached Admiral Rawson Bennett, Chief of Naval Research (CNR), directly and obtained his promise of $70,000 and the use of a Navy vessel for an eclipse expedition to the South Seas.

My NRL rocket team was joined by a group of optical astronomers to conduct the traditional types of ground-based eclipse observations under the leadership of Jack Evans, Director of the Sacramento Peak Observatory. Our base of operations was the LSD USS *Point Defiance* and the plan was for Jack Evans to set up his instruments on the island of Puka Puka and my group to erect six Nike-Asp rockets on the helicopter deck on simple rail launchers. This complex operation was carried out with the remarkable resources of the Navy. A marine demolition team had to work for weeks to blast a channel through the coral reef to the island in order to get the heavy astronomical instruments ashore. Aboard ship we had to jury rig arrangements to keep our instrumentation dry and functional. Never before had a barrage of six rockets been fired from such close spacing aboard ship in the course of an hour.

On eclipse day it rained precisely at totality and the astronomers on Puka Puka were washed out. Just 20 nautical miles away, we had clear skies and a perfect view of the eclipse from the deck of the *Point Defiance* although it was immaterial to the rockets that rode high above the weather. The rocket observations were excellent and revealed clearly that X-ray emission came from localized condensations of the corona that were tightly bound to sunspot groups by magnetic fields.

In 1960 we flew the simplest kind of X-ray pinhole camera on an Aerobee rocket from White Sands and obtained the first X-ray



Nike-Asp rockets mounted on the helicopter deck of the USS *Point Defiance* for the 1958 IGY solar eclipse project off the Danger Islands.

photograph of the sun. It showed all the detail we had deduced from the eclipse experiment with almost trivial effort but without the high adventure of a Polynesian trip. Within a few years, reflecting X-ray telescopes were perfected and an entirely new invisible universe of high-energy celestial sources was discovered.

The Ultraviolet Background

Interest in sky background radiation at short wavelengths was a natural extension of aeronomical and astronomical studies. Before the advent of research rockets, ground-based observations had revealed visible airglow radiations associated with photochemical processes at ionospheric altitudes. Yellow emission lines from sodium atoms, green and red emissions from oxygen atoms, ultraviolet radiations from molecular nitrogen, near-infrared from hydroxyl radicals, and characteristic colors of potassium and lithium originate at individual heights from 45 to 225 miles. The excitation of airglow is connected with solar ultraviolet radiation and atomic collision processes, often involving complex chains of interactions that can quench or store the excitation energy and delay its release. The total airglow is about one tenth as bright as the combined light of all the stars. In the infrared, the glow is much more intense; if it were visible, it would be as bright as twilight.

The most dramatic contributions to the airglow come in the aftermath of great solar flares that excite auroral processes and suffuse the sky with red light that sometimes carries the energy equivalent of dozens of hydrogen bombs. Atomic weapons tests in the atmosphere in the late 1950s and early 1960s produced bright auroral displays. Artificial radiation belts were created that were intense for months and took almost ten years to fade away to a normal level, as well as lithium airglow that has since then exceeded the former natural background.

In 1955, the NRL group began exploratory observations of the extreme ultraviolet light of the night sky with Aerobee rockets. These efforts immediately produced a great surprise. Space around the earth was dominated by a great cloud of hydrogen, a geocorona, radiating Lyman alpha (1216 A). In those years work was also initiated to search for the far ultraviolet Lyman bands of molecular hydrogen from interstellar clouds in the galaxy. Successive improvements in sensor technology for ultraviolet imaging have led to important astronomical observations and applications of military interest.

For the Apollo-16 mission, George Carruthers of NRL built an ultraviolet imaging camera that was emplaced on the moon to photograph the geocoronal environment of the earth. In addition to the great cloud of radiating hydrogen extending to 50,000 miles, it revealed spectacular airglow arcs girdling the earth in the equatorial region. Improved Carruthers cameras have since been applied to studies of missile-related phenomena.

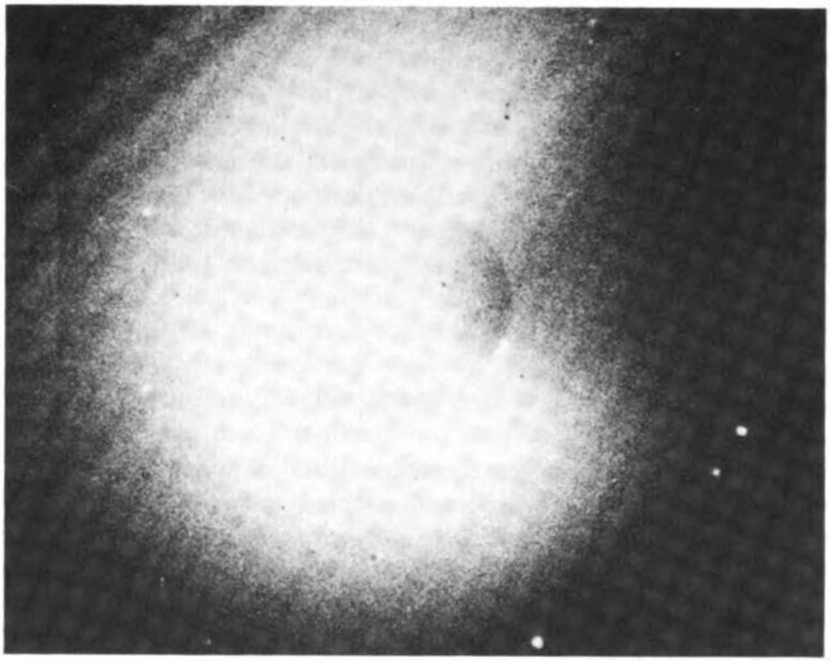
Up to the time of the IGY, auroral studies were conducted primarily from the ground in visible light with all-sky cameras. The Van Allen Belts had not been discovered and the name magnetosphere had not been coined. Observations from balloons had shown auroral X-ray emission and occasional rocket flights from the Fort Churchill range had picked up extreme ultraviolet wavelengths. In more recent years there has been great success in imaging the aurora from spacecraft in X rays and ultraviolet in ways that reveal fine details of morphology and dynamics.

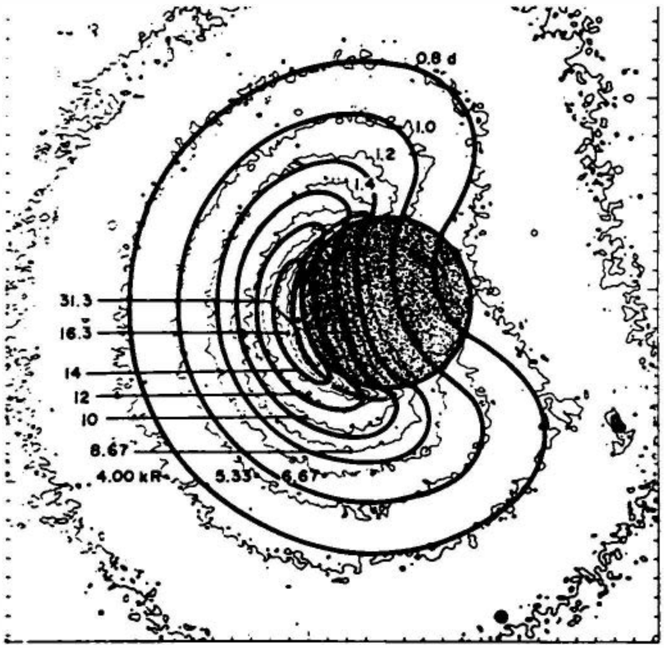
The Air Force Space Test Program (STP) has provided NRL with valuable space research opportunities for remote ultraviolet sensing of the space environment. STP 72-1 carried an NRL instrument to scan in several extreme ultraviolet wavelengths, including the resonance line of singly ionized helium at 304 A. Earlier rocket experiments had discovered that solar He 304 A was scattered from the helium ion in the daylit sky in much the same manner as hydrogen Lyman alpha is scattered from the hydrogen geocorona. The satellite data showed a 304 A glow from helium ions in the plasmasphere. NRL scientists named it "magnetoglow."

Until now the entry and circulation of plasma in the magnetosphere has been studied by occasional direct satellite probes, but it would require seeding the magnetosphere with large numbers of satellites to unravel a synoptic picture of the complex plasma convection processes. In the future it is proposed to use remote ultraviolet sensing of the magnetoglow from the distance of the Lagrangian Points, the moon, or highly elliptical polar orbits to image the dynamic behavior of the magnetosphere in real time.

Early on, military interest focused on the far untraviolet environment of the earth for the possibilities of identifying missile signatures such as plume radiation before burnout, shock excited emission around the nose cones of supersonic missiles and high-altitude aircraft, scars in the atmosphere left in the tracks of ballistic missiles, and, most generally, the detectability of such signatures against the natural space background and radiation from the surface of the earth. From above the ozone layer the earth appears black in the far ultraviolet, affording an ideal backdrop for detection of any manmade radiation.

With the current interest in SDI, an NRL development of a microchannel plate-intensified electronographic Schmidt camera for astronomical purposes is now being applied to studies of rocket plumes





The hydrogen geocorona photographed from the moon with the NRL ultraviolet camera during the Apollo-16 mission.

below 2,000 A in the solar blind range. Although infrared radiation from the plume is relatively intense and easy to detect, it is difficult to point at and track accurately. The far ultraviolet signature is smaller and lends itself better to precision tracking even though the intensity is lower. In these current applied studies, all the technology of ultraviolet sensing and spectral discrimination developed for astronomy is being profitably transferred, including CCD cameras with million pixel images, such as are incorporated in instruments for the Hubble Space Telescope.

VANGUARD

It is surprising how often the wise elders of science and technology fail to appreciate the prospects for opening new frontiers. Theodore von Karman, an aeronautical engineering genius and chief adviser to the Air Force in World War II, favored rocket research in the upper atmosphere after the war but did not believe in the possibility of artificial satellites in the near future. Neither did Vannevar Bush, chairman of the Joint Army and Navy Research and Development Board in 1946, express any optimism for the launching of satellites or even the possibility of intercontinental ballistic missiles.

Many other scientists and engineers, however, envisioned an era of earth-orbiting artificial satellites. Konstantin Tsiolkovsky in Russia and Hermann Oberth in Germany wrote about astronomical telescopes in earth orbit, and Lyman Spitzer in the United States seriously urged development of a large space telescope. Arthur Clark and John Pierce proposed communications satellites. But it was Fritz Zwicky of the California Institute of Technology who took the first step to place an artificial body in orbit.

As soon as V-2 rockets began to fly at White Sands, Zwicky proposed to use the rocket as a first stage from which to launch small metal slugs weighing no more than an ounce. The slugs were to be shot out by shaped charges that could propel projectiles to the highest ballistic velocities then known. Zwicky estimated that some of the slugs would attain escape velocity, 7 miles per second, and others at somewhat lesser velocities would enter into earth orbit. In either case there would be little to learn scientifically because the projectiles would remain invisible. At somewhat lower velocities, however, the slugs would attain suborbital trajectories and leave luminous ionization trails mimicking meteorites that burn up upon entering the earth's atmosphere.

It is estimated that about a billion meteorites enter the atmosphere each day and, at the time, there was considerable interest in studies of meteorite trails both for what they could reveal of the physics of the upper atmosphere and the possibilities for radio communication via reflections from the ionized meteorite trails. Zwicky's experiment was carried out on a successful V-2 launch in December 1946 with the collaboration of NRL and The Johns Hopkins University Applied Physics Laboratory. The results were inconclusive and the experiment was not tried again. It is interesting to note the current interest in radio communication over the polar regions via meteorite trails and the resurrection of Zwicky's early ideas.

Early in 1946, NRL scientists decided that a satellite project was still premature, but shortly afterward Navy and Air Force representatives agreed that "advantages to be derived from pursuing the satellite development appear to be sufficient to justify a major program, in spite of the fact that the obvious military, or purely naval applications in themselves may not appear at this time to warrant the expenditure." A study by Project Rand for the Air Force concluded that technology equal to the task of launching a satellite already existed and estimated that it could be accomplished in 5 years, about mid-1951. Louis Ridenour of Project Rand pointed out that "the development of a satellite would be directly applicable to the development of an inter-continental rocket missile," since the velocity required for the ballistic trajectory was only "4.4 miles per second, while a satellite requires 5.4."

The Navy response was to prepare a contract with the Glenn L. Martin Company to develop a sounding rocket that could exceed a height of 400 miles with a hydrogen propulsion system. Although proposed for high-altitude atmospheric research, Navy scientists felt that such a rocket would encourage support for a satellite program. When the report of the Secretary of Defense appeared at the end of 1948, it carried the information that all three services were studying the possibility of an Earth Satellite Vehicle (ESV). There followed a widespread outcry against the squandering of public money on such an unnecessary effort. The Navy had to drop its hydrogen rocket project, which we know with hindsight was at a development concept stage several years ahead of Soviet designs for propulsion and structural engineering.

In 1949, NRL moved ahead with the Martin Company to build the Viking rocket on the scale of the V-2 but with a gimballed motor for steering it. Successive Viking flights reached higher and higher altitudes while carrying experiments that provided valuable new scientific information. In spite of its promise for future military applications such as the study of ballistic missile reentry as well as research in the upper atmosphere, the Viking work was constantly hampered by inadequate funding. The outbreak of the Korean War produced healthier funding for missile development, but throughout most of the 1950s the Department of Defense remained very tight on funds for research that seemed to have only a remote connection to fighting equipment.

The formal endorsement of the IGY by the International Council of Scientific Unions in 1954 urged preparations for the launching of artificial satellites by 1958 for the conduct of space research. More effective than any arguments about practical benefits to come from commercial applications or contributions to national security, the most persuasive element in the national decision process was the strong motivation of many of the country's best scientists to conduct studies in astronomy and space physics from a long-lived orbiting platform. The announcement that President Eisenhower approved of the launching of an IGY satellite carried only a scientific justification: "The atmosphere . . . deprives man of the opportunity to observe many of the things that could contribute to a better understanding of the universe. . . . Only by the use of a satellite can sustained observations in both space and time be achieved. Such observations will also indicate the conditions that would have to be met and the difficulties that would have to be overcome, if the day comes when man goes beyond the earth's atmosphere in his travels." It is interesting in retrospect, that even so early on, the writers of the statement felt it was important to generate public support by talking about man in space while failing to mention communications via satellite and surveillance.

In the competition for the Vanguard project NRL won out, to the great surprise of von Braun's Redstone group and many others. Important elements in NRL's favor were its sophisticated plan, Minitrack, for tracking the satellite by radio, and the respect that the scientific community had for the talent at NRL to devise a high-quality space research program. The schedule for the IGY called for the launch of a successful orbiter in less than three years, starting with little more than NRL's experience with the slim 40-foot Viking booster and a partially designed upper stage, compared to the Army's powerful 69-foot Redstone into which four years of development work had already been invested. The challenge to the NRL team must have created some nervousness, but they executed their task with great professional skill and achieved success in their basic commitments.

For those of us at NRL who had set our goals on launching the Vanguard satellites in connection with the IGY, the anticipation of getting the first astronomical observations from a space observatory was quickly dispelled by the surprise of Sputnik and the initial Vanguard launch disasters that followed. Sputnik was orbited on October 4, 1957. Public reaction was initially mild, reflecting President Eisenhower's comment that "It does not raise my apprehensions one iota about national security." The numbness wore off quickly and public figures began to decry the shameful situation with the usual litany of accusations of administration penny pinching, short-sightedness, and general stupidity. White House pressure forced Vanguard project director, John Hagen, to advance the date of the first launch of a 6-inch diameter test sphere with a radio transmitter from February 1958 to December 1957.

On December 6, the first Vanguard test vehicle rose only a little over a meter and faltered. As it fell back, the fuel tanks exploded and the rocket crumpled to the ground engulfed in hellish flames and billowing smoke. From the top of the three-stage rocket, the silvery 6-inch test satellite plummeted 25 meters through the flames and bounced on the concrete deck. There the wounded bird with badly bent antenna radiated a futile signal at 108 MHz.

The NRL solar radiation payload had been assigned first scientific position in the Vanguard series and Jim Van Allen's cosmic ray experiment had second place. The Redstone group was now given approval to attempt a satellite launch and Van Allen's payload was moved over from Vanguard to the Army effort. Explorer I was launched successfully on January 30, 1958, and discovered the Van Allen radiation belts in the magnetosphere.

The Vanguard group persisted and finally succeeded in orbiting the grapefruit-sized test sphere in March 1958, a remarkable achievement, having started from scratch only 2½ years earlier. My long-awaited scientific opportunity to launch the solar radiation satellite came on April 28, 1958, but our first scientifically instrumented Vanguard turned out to be submersible instead of orbital. In September 1958 Vanguard III was successfully orbited with X ray and Lyman alpha detectors aboard, but it was swamped by Van Allen belt radiation. My colleagues and I had to wait for the first Navy Solar Radiation satellite (Solrad) launched in June 1960 before we succeeded in monitoring solar X rays and ultraviolet light. The Navy Solrad program was conducted with ten launches over a period of a decade and provided a complete history of the behavior of solar ionizing radiation over a full sunspot cycle. The nature of solar control of the ionosphere began to be understood in sophisticated detail.

The history of the Vanguard program still fills the NRL survivors with a sense of frustration and anguish, but in objective analysis its achievements were quite remarkable. Although the serendipitous discovery of the radiation belts is generally regarded as the most outstanding discovery of the first years of space science from a satellite, the combination of the NRL 6-inch satellite and the Minitrack system provided the first demonstration of geodesy from space. Minitrack itself was a highly sophisticated proof of the remarkable capability of radio interferometry for precision tracking. It should also be noted that the NRL engineers who built Minitrack subsequently had important roles in developing the Transit navigation satellites and the new Global Positioning System (GPS). Vanguard I showed the diurnal breathing of the thermosphere and the solar cycle variation of temperature and density. From years of tracking, Vanguard I revealed the plasticity of the lithosphere and the "pear" shape of the geoid. Since then the geological sciences community has been awaiting a new generation capability for geodesy, to carry forward the research pioneered by Vanguard. Hopefully, the NASA Geopotential Research Mission will fly in the mid 1990s to map the deviations of the geoid from sphericity with higher precision. In the interim, the radar altimeter aboard the short-lived SEASAT mission gave fascinating evidence of the new power to map the contours of the ocean bottom from space. A still more powerful radar altimetry mission, TOPEX, for topography of the ocean, should rejuvenate the study of the oceanic lithosphere in the 1990s.

During the year of Solrad I, concern was building about Soviet adherence to an atmospheric test ban. Was it possible to conduct atomic weapons tests in deep space and escape detection? The signature of an atomic explosion was known to contain strong emission in much the same X-ray range as was being studied by Solrad. NRL was requested to scrub its year-long Solrad data for any evidence of a nonsolar X-ray flash. Although there was much evidence of noisy signal in the NRL data, it was not possible to ascribe any real signal significance to it. The Air Force then implemented its Vela Hotel project that placed several satellites with omnidirectional viewing in orbit simultaneously. Coincidental signals in more than one satellite could be accepted as real. The Vela program did not come up with any evidence of a weapon flash in space but did make a seminal discovery in gamma-ray astronomy. Gamma-ray bursts were detected from deep space that delivered the power of a million suns for a few seconds from random directions in the galaxy. We now believe these bursts to be nuclear flashes that result from the accretion of gas onto invisible neutron stars until the buildup of density at hundred million degree temperatures satisfies the condition for thermonuclear ignition over the entire surface of the star—a natural helium bomb of fantastic power.

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The account that I have given here is a small sampling of Navy-supported efforts in the early years of space research. In every instance, the basic research provided a resource of scientific information and instrumentation techniques that were quickly linked to applied military research in the laboratory and developments in the fleet. Scientists involved in the rocket programs had one leg in the space research camp and the other leg in applied laboratory research and space applications. The combination was an effective stimulus to all areas of R&D.

The 6.1 support that NRL obtained from ONR and the Bureau of Ships for space research, with almost no strings attached, gave us remarkable freedom to exercise our scientific judgment and guaranteed longevity to our programs. NRL continues today to be one of the strongest participants in the national space program. When we sought to increase support for infrared astronomy by finding 6.2 sponsors, their interest disappeared in a few years. In retrospect, the cryogenic technology that we were developing for astronomy was judged in the Pentagon to be too remote from possible military application to merit their continuing support. They were soon proved wrong, but NRL found that having moved away from its 6.1 funding it could not easily regain it. Our lesson is that basic research should not be sold to the 6.2 elements or disguised under "directed research." It deserves to be supported in its own right.

CURRICULUM VITAE

Herbert Friedman was born in New York, New York. He received his BS degree from Brooklyn College in 1936, and his PhD in physics from The Johns Hopkins University in 1940. Subsequently, he received honorary DSc degrees from the University of Tubingen (1977) and the University of Michigan (1979).

Having served as an instructor at The Johns Hopkins University in 1939, he went to the Naval Research Laboratory in 1940 as a physicist in the Metallurgy Division. In 1941, he became Head of the Electron Optics Branch, then in 1958, Superintendent of the Astronomy and Astrophysics Division, and in 1963, Superintendent of the Space Science Division. On his retirement from the Naval Research Laboratory in 1980, he became Chief Scientist Emeritus, E. O. Hulburt Center for Space Research. In addition, from 1961–1980 he was Adjunct Professor, University of Maryland, and beginning in 1974, Adjunct Professor, University of Pennsylvania. He was a Visiting Professor at Yale University in the late 1960s, and served on the Visiting Committee, Division of Physical Sciences, University of Chicago (1974–1980) and the Visiting Committee for Astronomy, Board of Overseers, Harvard University (1976–1981). From 1981–1986, he was Chairman of the latter Board.

Following his retirement from the Naval Research Laboratory, Dr. Friedman first chaired the National Research Council's former Assembly of Mathematical and Physical Sciences, then its successor organization, the Commission on Physical Sciences, Mathematics, and Resources (1983–1986). Most recently, he became Martin-Marietta Fellow in Space Science, National Air and Space Museum (1986—).

Dr. Friedman is the holder of 50 patents, and is the author of some 300 publications in scientific journals. In addition, his books include, *The Amazing Universe* (National Geographic Society, 1975) and *Sun and Earth* (W. H. Freeman and Company, 1985).

Since 1960, Dr. Friedman has served on the editorial boards of many scientific journals, such as *The Astrophysical Journal* and *Solar Physics*, and has been editor or associate editor of such publications as the *Journal of Geophysical Research, ICARUS, Planetary and Space Science,* and *Astronautics and Aeronautics*.

Dr. Friedman is the recipient of many honors and awards, among which was the President's Distinguished Federal Civilian Service Award (1964). The citation noted "his leadership in the new science of rocket astronomy, and his achievements in advancing the nation's progress in space and the extension of man's knowledge of the universe." In 1968, he received the National Medal of Science for "pioneering work in rocket and satellite astronomy and in particular for his contributions to x-ray astronomy." Among his other awards were the Navy Distinguished Civilian Service Medal (1945 and 1980), the AIAA Space Science Award (1963), the Eddington Medal of the Royal Astronomical Society (1964), the Rockefeller Public Service Award (1967), the NASA Medal for Exceptional Scientific Achievement (1970 and 1978), the Dryden Research Award of the American Institute of Aeronautics and Astronautics (1973), and the W. Randolph Lovelace (1973) and Henry Norris Russell (1983) Awards of the American Astronautical Society.

In 1960, Dr. Friedman was elected to the National Academy of Sciences; in 1962, he became a member of the International Academy of Astronautics; and in 1964, he was elected to the American Philosophical Society and became a Fellow of the American Academy of Arts and Sciences.

Throughout his career Dr. Friedman has served on or chaired some 60 national and international committees and advisory groups. Among these were many organizations of the International Council of Scientific Unions, such as the Committee on Space Research and the Special Committee on Solar-Terrestrial Physics, and of the National Research Council, such as the Space Science Board and Geophysics Research Board. He was also a member of the President's Science Advisory Committee (1971–1972) and of its Rocket Panel (1964–1968) and Panel on Atmospheric Science (1965–1967).