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# Discovering Earth's Radiation Belts: Remembering Explorer 1 and 3

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On 31 January 1958, at 10:48 P.M. eastern standard time, the United States launched its first satellite, Explorer 1, on a modified Jupiter-C rocket.

Later, at about 1:30 A.M., after confirming that it was indeed in orbit, three men triumphantly held aloft a full-scale model of Explorer 1 at a crowded press conference in the Great Hall of the National Academy of Sciences (Figure 1). In the center stood James A. Van Allen, head of the physics department at the University of Iowa and the scientist responsible for the scientific experiment. Flanking him were Wernher von Braun, director of development operations for the Army Ballistic Missile Agency (ABMA), which was responsible for constructing the Jupiter-C, and William H. Pickering, director of the Jet Propulsion Laboratory (JPL), which provided the Explorer spacecraft, the solid-fueled upper stages, and the guidance and control system. The United States had just successfully entered the race to explore, understand, and utilize space.

It was not the first to do so. The launch of Sputnik 1 some 4 months earlier generated excitement around the world and shocked an American public unprepared for such a powerful demonstration of remarkable technical achievement by the USSR. Later, the orbiting of the 508-kilogram Sputnik 2 on 8 November 1957 with the dog Laika on board substantially enhanced this new USSR prestige, particularly because it revealed the Soviets' ability to launch heavy payloads into space and their intention to develop life-support systems for eventually launching humans into space. The subsequent failure of the first U.S. attempt to launch a satellite on the Vanguard rocket emphasized the magnitude of the Russian accomplishment. Not only had the United States failed to lead in the race to space, but it could not even follow.

Despite setbacks, the launch of Explorer 1 marked the beginning of the U.S. civilian space program, the onset of the modern era of space science, and the birth of space physics as a scientific field. Further, the data from Explorer 1, confirmed some 2 months later by payloads on Explorer 3, revealed the presence of vast regions of trapped particles surrounding the Earth. This unexpected discovery highlighted the great potential of going into space and increased the expectations of other scientific disciplines.

The University of Iowa, ABMA, and JPL, represented in Figure 1 by their directors, played vital roles in the success of Explorer 1. Now, 50 years after Explorer 1's successful launch, nearly 900 active spacecraft are in orbit above the Earth or at various locations throughout our solar system. These spacecraft support science as well as our increasingly technologically dependent lifestyles.

Scientists and engineers looking back owe a great deal to the pioneering efforts of the Explorer program's developers. In this article, we focus on the events that led to the selection of Jupiter-C as Explorer 1's launch vehicle, the University of Iowa's scientific involvement, and the discovery of Earth's radiation belts.

*A New Opportunity for Science*

Astronomers, astrophysicists, atmospheric physicists, and meteorologists had long recognized the magnificent opportunities for research offered by satellites operating for months and years above the atmosphere and outside the range of the Earth's magnetic field. Despite this awareness, scientists of the midtwentieth century could only reach altitudes of about 36 kilometers for a day or two, by using balloons. Those using sounding rockets could send their payloads up to 300–1000 kilometers, depending upon the type of rocket and the number of stages, but only for a few minutes.

Further, government officials and academic scientists recognized that placing a satellite in Earth orbit would stir the imagination of the world. On 1 October 1954, the special committee of the International

*Fig. 1. (left to right) William H. Pickering, James A. Van Allen, and Wernher von Braun proudly display a full-scale model of the Explorer 1 satellite. Photo courtesy of James A. Van Allen.*

By F. McDonald and J. E. Naugle

Council of Scientific Unions responsible for the 1957–1958 International Geophysical Year (IGY) recommended that “thought be given to the launching of small satellite vehicles.” In 1955, the United States began serious planning for placing a scientific satellite in orbit. The Upper Atmosphere Rocket Research Panel (UARRP, an unofficial group of scientists and engineers from universities, government laboratories, and industry that played a key role in planning and coordinating the American Sounding Rocket Research Program) began planning for such scientific satellites. In early October 1955, the U.S. National Committee for IGY established a technical panel on the Earth Satellite Program (TPESP). The joint efforts of UARRP and TPESP helped establish the U.S. IGY’s satellite goals.

In late January 1956, the chair of TPESP asked Van Allen to chair the Working Group on Internal Instrumentation (WGII), a subcommittee focused on satellite experiments. Meanwhile, Van Allen, as chairman of UARRP, organized a symposium entitled “Prospective Scientific Investigations With Satellite-Borne Experiments.” This meeting was held at the University of Michigan on 26–27 January 1956. The 33 published presentations (*Scientific Uses of Earth Satellites*, edited by J. A. Van Allen, University of Michigan Press, 1956) give an excellent overview of the scientific interest and potential capability of these experiments.

In June 1956, WGII recommended four of the 25 experiments proposed at the January meeting as critical and feasible research objectives. These proposals were “Satellite Environmental Measurements” and “Solar Lyman-Alpha Intensity,” developed by the U.S. Naval Research Laboratory (NRL); “Proposal for Cosmic Ray Observations in Earth Satellites,” developed by the University of Iowa; and “Proposal for the Study of Interplanetary Matter From the Earth Satellites,” developed by the Air Force Cambridge Research Center. WGII gave these experiments “Flight Priority A” status, meaning that they were to be funded and flown on the early satellite missions.

### *Early Work to Develop a Suitable Rocket Launcher*

While science objectives were being discussed, the U.S. government was also searching for a launcher for this new venture. NRL proposed developing the Vanguard rockets, which would be upgraded Viking sounding rockets with modified Aerobee-Hi suborbital sounding rockets as a second stage (propulsion unit) and a new third stage that could place a 25-pound satellite into low-Earth orbit. ABMA and JPL proposed a Redstone (an intermediate-range ballistic missile), a direct descendant of the German V-2 rocket, as the first stage with an array of solid-propellant rockets for the upper stages with a 5-pound payload.

However, the U.S. Navy’s proposal to use Vanguard rockets was selected above the other contender because the Eisenhower administration wanted to use a nonmilitary rocket system to launch a scientific satellite and did not want the rocket’s production to interfere with the development of the Army’s intermediate-range ballistic missiles. The scientists who developed the proposals recommended by WGII were instructed to configure their payloads to be compatible with Vanguard.

Meanwhile, the Army started work on an expanded version of the ABMA/JPL proposal to study the effects of reentry heating on the nose cones of ballistic missiles. This launcher used a modified Redstone first stage with an enlarged tank, 11 JPL scaled sergeants as the second stage, and three for the third stage. JPL was also responsible for the guidance control and reentry system for these experiments. This configuration, called Jupiter-C, was flown three times, with the first and third flights being successful. The third flight was launched on 20 September 1956 with a dummy fourth stage, inactive on specific orders from the Pentagon to ensure that the roughly 9-kilogram payload could not be placed in orbit. Government officials did not want to risk orbiting a satellite on a classified military rocket because they feared the USSR would be averse to the passage of a military spacecraft over their territory and they believed there would be fewer objections if the United States’ first satellite was an unclassified scientific satellite launched by an unclassified rocket.

### *Von Braun’s Hunch*

After the success of the ABMA/JPL reentry studies, the U.S. Department of Defense canceled further Jupiter-C flights. However, von Braun carefully placed the remaining sets of first-stage hardware for this program in storage and quietly maintained it in a high stage of readiness. JPL did likewise for the remaining upper stage hardware.

From his long experience with rockets, von Braun was keenly aware of the difficulties in developing new systems such as Vanguard. He wanted to be ready to step in with the Jupiter-C if Vanguard encountered delays.

As a youth, von Braun had dreamed of sending rockets into space. As a young scientist, he had led the development of the V-2 at Peenemünde, a remote location in Germany, during World War II. The Allies regarded these missiles as a major threat—V-2s killed some 5000 people in England and Holland.

After Allied bombers destroyed a major portion of Peenemünde, Hitler transferred V-2 production from Army Ordnance to the Schutzstaffel (SS), which established a rocket production facility staffed with slave labor in a mine near Nordhausen, Germany. More than 10,000 political prisoners forced

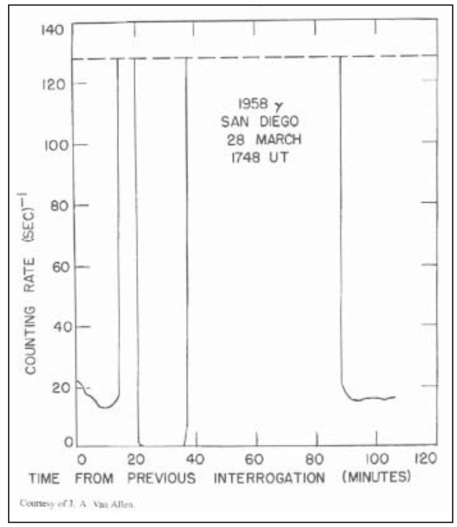


*Fig. 2. Data from first orbit. The repeatability of this pattern and the knowledge that intense radiation could drive the Geiger counter to saturation convinced the Iowa group that they were observing charged particles trapped in the magnetic field of the Earth. Image courtesy of James A. Van Allen.*

to build the V-2s died of illness, starvation, and maltreatment over the 18-month period. Although von Braun was an officer of the SS since May 1940, as the war progressed his role changed from being the overall leader of the development of the V-2 program to being a technical and administrative troubleshooter as it went into mass production. Though scholars are still assessing his role in SS activities, von Braun engineered the surrender of 500 of his scientists, along with V-2 rocket plans, to the Americans. As part of a military operation dubbed “Operation Paperclip,” he was bundled out of a defeated Germany in September 1945 and sent to Texas to assist the U.S. Army in launching the captured V-2s. He became the director of development operations for ABMA on 1 February 1956.

Von Braun’s familiarity with rockets allowed him to quickly see that Jupiter-C was better suited for launching a satellite into space, and he, along with JPL director Pickering, began petitioning the United States to use Jupiter-C rockets for their IGY launches.

### *Van Allen and the Search for Cosmic Rays*

In his quiet, affable way, Van Allen was as driven as Von Braun was, but his motivation was for science—he wanted to get his instruments above the atmosphere to study low-energy cosmic rays.

Van Allen had worked on proximity fuses during World War II and later flew experiments on V-2s at White Sands, N. M.; the Army had agreed to use the roughly 400-kilogram payload capability of the V-2 for science and engineering experiments. Van Allen was also a key figure in the development of the American high-performance sounding rocket, the Aerobee, first launched from

White Sands Proving Ground in late November 1947.

In 1946, during these experiments at White Sands, Van Allen met Ernst Stuhlinger, a German physicist who did his thesis work under Hans Geiger and had worked on guidance and control systems at Peenemünde. Stuhlinger was effectively the liaison between the American and German scientists. Van Allen's single Geiger counter experiment was on the first V-2 fired at White Sands. That rocket exploded shortly after launch, but in mid-1947, on the thirtieth launch, Van Allen's experiment had a completely successful flight.

On returning to Iowa in 1950, where he had received his Ph.D., Van Allen continued his cosmic ray studies and began to investigate ways to get above the shielding of Earth's atmosphere in a practical and inexpensive way. For the latter he developed a technique for launching rockets from high-altitude balloons. Nose cones and large tail fins for these "rockoons" were configured in the university machine shops to fit surplus military rockets, and students assembled and tested the payloads. Various payloads of single Geiger counters, ionization chambers, scintillation counters, and proton precession magnetometers were launched on four expeditions to Thule, Greenland, during the summers of 1952 to 1955 and during the IGY period. One significant finding, discovered while using the single, thin-walled Geiger counters, was a new "soft" charged-particle component of low-energy electrons in the auroral zone, the first direct confirmation of the particles producing auroral luminosity.

In May 1954, Ernst Stuhlinger met with Van Allen at his home in Princeton, N. J., where Van Allen was spending a sabbatical year working with Princeton Plasma Physics Laboratory founder Lyman Spitzer to design and build Stellerator A, which was intended as a demonstration for controlled thermonuclear fusion. At this informal meeting, Stuhlinger revealed ABMA's plans for developing a satellite launcher.

On 16 November 1956, Stuhlinger telephoned Van Allen to tell him the results of a successful ABMA/JPL reentry flight in September and their aspirations for Jupiter-C to assume a prominent role in IGY. Stuhlinger urged Van Allen to suggest a cosmic ray experiment for this venture. Van Allen agreed and immediately made plans to develop the Iowa Cosmic Ray Instrument so that it would be compatible with both the Vanguard and Jupiter-C launch vehicles.

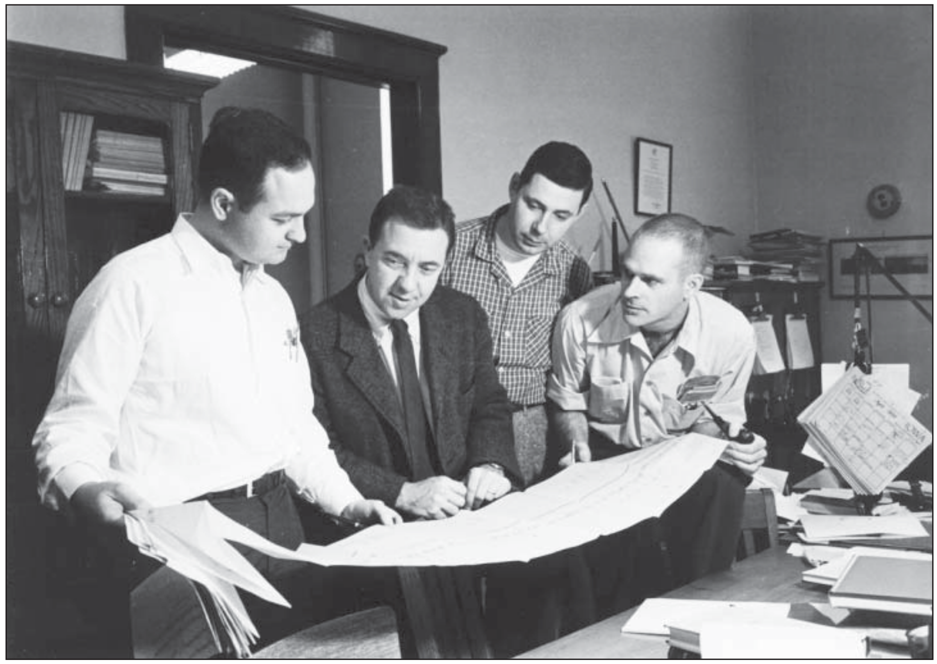

*Fig. 3. (left to right) Carl McIlwain, James A. Van Allen, George Ludwig, and Ernest Ray examine the strip charts from Explorer 1 and 3. Photo courtesy of George Ludwig.*

### *Explorer 1: Finalizing the Rocket and the Science Payload*

Following Stuhlinger's telephone call, ABMA sent a technical team to Iowa to brief Van Allen and George Ludwig, the graduate student designing and building the Iowa Cosmic Ray Instrument. Van Allen, convinced of Jupiter-C's utility, hedged his bets and decided that the new instrument would be compatible with both the Vanguard and Jupiter-C rockets. Van Allen advocated at the 1957 meeting of TPESP for the use of Jupiter-C rockets along with Vanguard for IGY. However, his petition was unsuccessful and TPESP stayed committed to using only the Vanguard.

By September 1957, George Ludwig had completed the design, construction, and testing of the Iowa instrument for the Vanguard along with plans to adapt it for the Jupiter-C. He taught himself how to design electronic circuits using transistors and developed a miniature magnetic tape recorder with a metallic tape. It could record the data from a complete orbit and then, on command from a ground receiving station, play back the entire tape in a few seconds as it passed over the station. Ludwig did most of this work himself, assisted by the skilled machinists in the University of Iowa's physics department shop and a few undergraduate assistants.

Following Sputnik 1, Pickering and von Braun began planning their strategy for getting approval from the U.S. government to use the Jupiter-C for an IGY launch. When they discussed which scientific experiments to use as payloads, Pickering pointed out that the Iowa instrument was the only one approved for Vanguard that had also been adapted for Jupiter-C. Von Braun is reputed to have innocently replied, "Isn't that interesting?"

Pickering and von Braun again pressured the Army for permission to proceed with one of the Jupiter-Cs in storage, promising they could be ready within 90 days after being given a go-ahead. Finally, on 28 October 1957 and after clearance from the Eisenhower administration, Jupiter-C was approved for use as a backup launcher. Up to this point, von Braun and Van Allen assumed that ABMA would also be responsible for developing the spacecraft. On 9 November, however, Pickering persuaded Army officials to assign the spacecraft task to JPL, heralding JPL's transformation from a developer of military rockets to a producer of space hardware.

In October and early November 1957, around the time Sputnik 1 was launched and the decision to use Jupiter-C as a backup was made, Van Allen and graduate student Larry Cahill were launching rockoons near Antarctica as part of the Iowa IGY program, and neither JPL nor Iowa could reach him until 10 November, when the USS *Glacier* arrived in Christchurch, New Zealand. Two days later, Van Allen approved the transfer of the Iowa experiment from Vanguard to the Jupiter-C, thereby giving up his Flight Priority A status in the Vanguard program. On 15 November, Ludwig loaded up the family car with his pregnant wife, Ros, their two children, and the Iowa satellite equipment and was off to Pasadena to integrate the instrument into the JPL spacecraft. To get a satellite into orbit in the shortest time possible, and with the greatest assurance of success, a greatly simplified version of the Vanguard design, without the tape recorder, was prepared for the first launch.

By then, the first U.S. attempted launch of the Vanguard system with a satellite payload had failed to gain sufficient thrust and toppled over on the launchpad. With Jupiter-C ready to take Vanguard's place and already configured with the Iowa Cosmic Ray Instrument, the United States had the hardware and science payload it needed to begin to compete in the space race. Explorer 1 was indeed successfully launched on 31 January 1958.

### *Discovery of the Radiation Belts*

Without the tape recorder, which was not modified in time for the first Jupiter-C mission, the telemetry coverage and the data from Explorer 1 were very sparse and very puzzling, sometimes showing normal counting rates, sometimes showing no counts at all.

A complete Iowa Cosmic Ray Instrument that included the tape recorder was set to be launched on Explorer 2, but on 5 March 1958, the failure of the fourth stage to ignite prevented Explorer 2 from reaching orbit. However, on 26 March, Explorer 3, identical to Explorer 2, was successfully launched. The instrument worked as designed. The data from a complete orbit are shown in Figure 2.

The telemetry data from Explorer 3 were printed out on a strip recorder and a ruler, and scientists used a slide rule to get the Geiger counter's counting rates, which were then plotted by hand. Van Allen received an orbit of data from NRL on 2 April 1958 and reduced it in his Washington hotel room. Ernest Ray, an assistant professor in physics at the University of Iowa who had done his thesis under Van Allen, and Carl McIlwain, another of Van Allen's students, also plotted out a complete orbit back at Iowa. The pattern was immediately clear (Figure 2). After hovering around the expected counting rate, the rate increased to 128 counts, the maximum permitted by the scaling circuits and the Geiger counter dead time. This was followed by a rapid decrease to zero counts, a rapid increase back to 128, and then a return to the lower expected counting rate.

McIlwain immediately began calibrating the spare payload at very high counting rates using an X-ray machine. He knew that intense radiation could drive the Geiger counter rate to zero when it no longer had a chance to recover from the previous count—this saturation condition was reached at a true rate of about 25,000 counts per second. The rapid changes with altitude, the latitude variations, and the repeatability of the pattern convinced the group of four that they were seeing an entirely new phenomenon: vast regions of particles trapped in the magnetic field of the Earth (see Figure 3).

Van Allen presented the results at a joint meeting of the National Academy of Sciences and the American Physical Society on 1 May 1958. This remarkable discovery excited both the scientific community and the public. The regions of trapped particles immediately became known as the "Van Allen radiation belts."

In 1958, Van Allen, Ludwig, and McIlwain also supplied the instrument package for Explorer 4, which was launched on 26 July 1958 with the primary mission of monitoring electron densities during and after the U.S. Defense Nuclear Agency's Argus experiment, in which a series of nuclear blasts were discharged at various high altitudes. Additionally, the Pioneer 1 mission, launched on 11 October 1958 with a mission of studying the near-Earth space environment, carried an ion chamber developed by McIlwain. It reached a maximum altitude of 17 Earth radii. Both missions led to the identification of a separate outer radiation belt and improved the spatial definition of the inner region. Over the next several years, Iowa was the center of the space science world.

### *Legacy of the First Satellites*

Explorer 1 and 3 and the follow-on missions exhibited the strength of American science and engineering programs and their commitment to exploring the unknown. In 1960, Van Allen himself went on to share *Time* magazine's "Man of the Year" award with several other pioneering U.S. scientists, and a generation of Americans were galvanized by the possibilities inherent in space exploration.

These early satellites also demonstrated that members of a university physics department could design, build, and deliver instruments for scientific experiments in space, and then analyze their data and publish significant new results in scientific journals. The Iowa group established a precedent for the involvement of academic scientists and their students in space science that has been fruitful for the past five decades.

The advent of satellite and space-based data and imagery has ushered in a new era of observations that are critical to many disciplines within the Earth and space sciences. Fifty years after the United States' first successful satellite launch, scientists and engineers continue to answer the call to learn more and reach farther out into space.

### *Acknowledgments*

In preparing this article, we used Van Allen's memoir (*Origins of Magnetospheric Physics*, Smithsonian Institution Press, 1983), his biography (*James Van Allen: The First Eight Billion Miles*, Abigail Foerstner, University of Iowa Press, 2007), information from the Marshall Space Flight Center's historical files (http://history.msfc.nasa.gov/), and private communications from George Ludwig and Carl McIlwain. Those interested in additional information can consult *Beyond the Atmosphere: Early Years of Space Science* (Homer E. Newell, NASA Special Publication SP-4211, Washington, D. C., 1980), *William H. Pickering: America's Deep Space Pioneer* (Douglas J. Mudgway, NASA Special Publication SP-2007-4113, Washington, D. C., 2007), and *Von Braun: Dreamer of Space, Engineer of War* (Michael J. Neufeld, Alfred A. Knopf, 2007).

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