II. Science

The Van Allen Belts and the Genesis of the Space Age

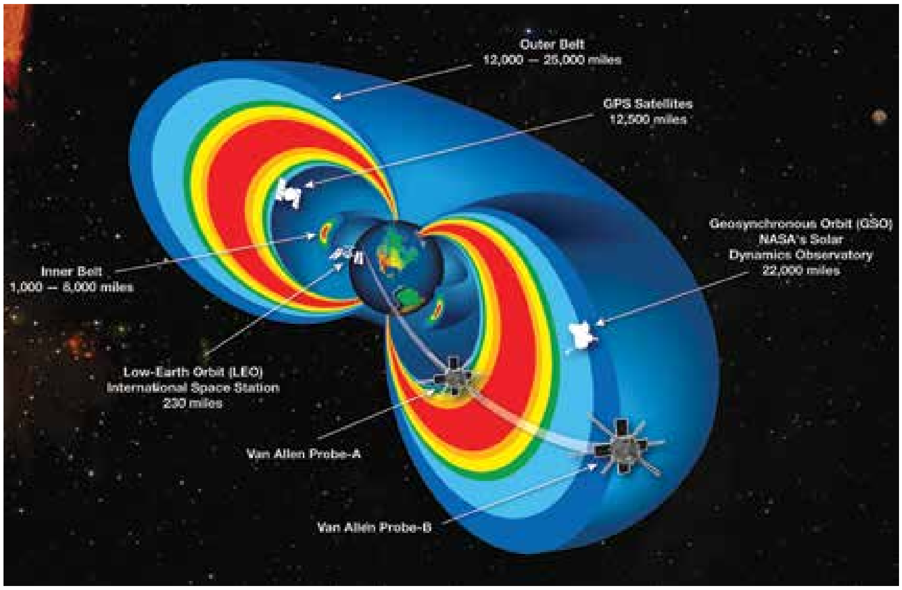
by Janet G. West

"Science is a collaborative effort, and we are all part of a larger community of explorers."
—Dr. James A. Van Allen

December 2023—The successful launch by the Soviet Union on October 4, 1957 of the first artificial satellite into orbit around the Earth, *Sputnik* ("fellow traveler"), opened the Space Age; 2023 was the 65th anniversary of the launching of the first rocket into orbit by the United States, *Explorer 1*, in 1958. But it was in the years immediately after World War II that mankind began to experiment with various types of rocketry.

It is important to bear in mind the historical context of these experiments—the aftermath of the bombings of Hiroshima and Nagasaki, demonstrating the power and danger of nuclear bombs and radiation; and increasing tensions between the U.S. and the Soviet Union, as well as other world conflicts.

FIGURE 1



NASA

A conceptual sketch of the Van Allen Belts. It also depicts the orbits chosen for various spacecraft, including the two Van Allen Probes.

What Are the Van Allen Belts?

The Van Allen Belts, named after their discoverer, James Van Allen, are zones of energetic charged particles, most of which originate from the solar wind, which have been captured by and are held in place by the Earth's magnetic field (the magnetosphere), taking the form of a torus (a donut or tire shape) around the Earth. These belts extend from about 965 km to over 21,100 km above the Earth. One can get a sense of Earth's magnetic fields by looking at the Aurora Borealis, which is the result of collisions of electrically charged particles (hereafter "particles") released from the Sun with gases in Earth's atmosphere, and which travel along the field lines of the magnetic poles.

Similarly, the Belts are oriented along the lines to Earth's magnetic field—broader at the equatorial level and bending in at a low angle around the polar regions. (**Figures 1** and **3**) All planets with magnetic fields have such radiation belts, which necessitates any spacecraft travelling to them to be properly shielded. Mars has no magnetic field (except sporadic surface fields), and therefore no radiation belts.

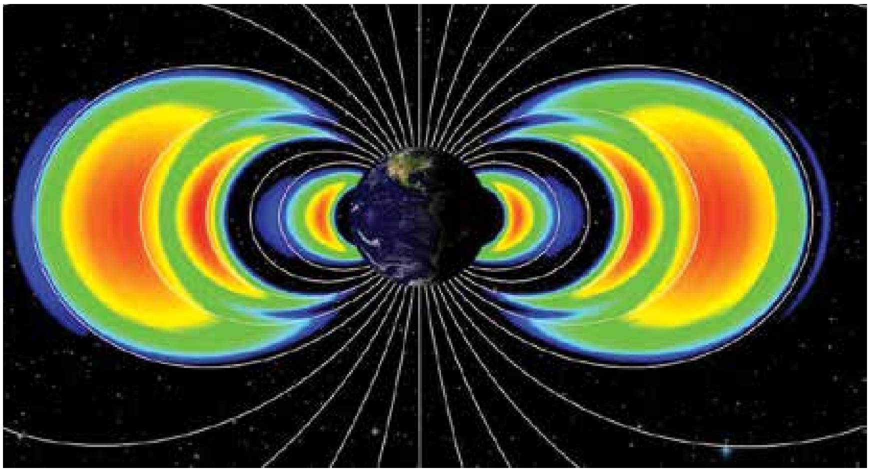
Earth actually has two Van Allen Belts. The smaller (inner) belt, with more intense radiation, is roughly

FIGURE 2

NASA, JHU/APL

Photograph of the two identical Van Allen Probes in orbit around Earth.

FIGURE 3



NASA/Goddard Space Flight Center

Computer-enhanced satellite image of the third Van Allen Belt (the red crescent in between the inner and outer red crescents). Red = high-intensity radiation. Blue = lower intensity.

965–5,900 km, and the larger (outer) belt 14,800–25,100 km above Earth, that can sometimes extend out more than 25,100 km. Particles in the Van Allen Belts can accelerate to nearly the speed of light, producing ionizing radiation as they strike objects in their paths.

Many satellites travel through the inner belt during their orbits around Earth, and can be turned off when a coronal mass ejection (CME) is expected to impact the Belts. The International Space Station (ISS) is situated well below the inner belt, and GPS satellites usually operate in the gap between the two Belts. During manned space travel outside of Earth's environs, such as to the Moon, spacecraft have followed a trajectory with the least amount of magnetic and radiative activity, such as toward the poles; *Apollo 11* traveled this trajectory at about 25,000 km/h and spent less than an hour in the Belts, with minimal exposure for the astronauts inside.

Remarkable Discoveries of the Van Allen Probes

The Van Allen Probes ("Probes") were launched in 2012 as part of a mission to further explore the Van Allen Belts; the mission was intended to last two years, but was extended to October 2019, at which time the Probes were decommissioned. The Probes were powered primarily by their solar arrays, but used onboard fuel for maneuvers. At a certain point the mission team decided to start operations to begin changing their orbits (while they still had power), so they will eventually come close to Earth and burn up in the atmosphere sometime over the next ten years. As they descend, they will continue to collect and transmit data.

Two characteristics of this mission made it stand out from all previous missions to study the Belts. First, relying on two identical spacecraft instead of one—the probes weren't in exactly the same orbit, so they would tail or lap each other—meant that when the Probes took simultaneous measurements, from different locations, of the same event, they could determine whether an event occurred at the same time throughout the Belts, or instead traveled across the Belts, changing over space and time. Second, the instrument suite was unusually comprehensive, able to measure an enormous range of energies, particles, and waves. (**Figure 2**)

The two Probes flew in highly elliptical orbits, carrying identical instruments, sometimes coming as close as 600 km and going as far away as 32,000 km from Earth. This brought them through the greater portion of the Belts repeatedly, including the areas with the most intense radiation.

The instruments onboard included the Radiation Belt Storm Probes Ion Composition Experiment (RBSPICE), which focused on analysis of the ring current, which is an electric current circling Earth at the equator; and several other instruments which measured the types of particles in the lower, middle and higher ranges of energies and speed, and the causes of electromagnetic waves and particle acceleration and behavior. Descriptions may be found here.

What the Probes discovered about the Belts was nothing short of astonishing. Far from being "welldefined" and static, the Belts can disappear, only to replenish a few hours later. The dynamics within the Belts change throughout the 11-year solar cycle; it was previously thought that these dynamics were a result of interactions of three or four physical mechanisms, but now, they've discovered new physical processes that produce radiation and particles on the time scale of minutes and even seconds, rather than hours and days.

The dynamics of the Belts have opened new questions regarding fundamental scientific principles. Dr. Sasha Ukhorskiy, Van Allen Probes project scientist at Johns Hopkins University Applied Physics Laboratory (JHU APL), which also designed and built the spacecraft, described these:

> The Van Allen Probes rewrote the textbook on radiation belt physics. The spacecraft used uniquely capable instruments to unveil radiation belt features that were all but invisible to previous sensors, and discovered many new physical mechanisms of radiation belt acceleration and loss.

The radiation detectors were turned on a month before launch; this allowed them to overlap what they were detecting on Earth with what they detected in space.

In 2013, a major coronal mass ejection (CME) occurred, barreling towards Earth at around 1,609,000 km/h. It crashed into our magnetosphere like a solar tsunami; the magnetosphere was deformed as it was buffeted by the pressure, and the Van Allen Belts also responded—by forming a third belt! (**Figure 3**)

This confounded the scientists—it had never been observed before, and was not predicted by any computer model. Not only did it form—researchers thought it would merge with one of the other belts—but, remarkably, it remained stable for around four weeks. This represented a fundamental, new discovery; an event demonstrating new physical principles. Since the dynamics of the Belts have been so volatile, the research team doesn't yet know why the third belt was able to remain stable and distinct for so long.

Then, after another CME event, the third belt began to dissipate, and finally disappeared. Why, then, do similar events from the Sun create such radically different behavior in the Belts? Sometimes solar activity produces increased activity within them, and sometimes it decreases such activity.

Particles within the Belts can become highly energized, and the inner Belt seems to function as an accelerator, but the mechanisms by which this happens are not yet understood. The outer belt is constantly changing shape—it enlarges and diminishes with the effects from the Sun, and as it interacts with the magnetosphere. Such particle acceleration has been observed across the Universe, such as the activity within the Crab Nebula (its glow in the X-ray range is due to particle acceleration). The more we understand about these interactions in the Earth's magnetosphere, the more we understand about the Universe, including vital information for understanding the effects on satellites, communications, space weather and interplanetary travel.

Dr. Nicola Fox, the Van Allen Probes deputy project scientist at JHU APL at the time, and now the Associate Administrator for NASA's Science Mission Directorate, summed it up with delight:

> Even 55 years after their discovery, the Earth's radiation belts still are capable of surprising us and still have mysteries to discover and explain.

NASA has produced a short video demonstrating the effect of a CME on Earth's magnetosphere and the Van Allen Belts.

A Man-Made 'Bubble of Protection'?

The Van Allen Probes mission team also studied wave structures within the Belts and how both radiation and magnetic effects interacted with human activity. One of the most intriguing discoveries of the Van Allen Probes was the existence of a "protective bubble" against the radiation Belts, one which surrounded the Earth and appeared to be created by Very Low Frequency (VLF) transmissions. The outward extent of this VLF bubble corresponds almost exactly to the inner edge of the Van Allen radiation belts.

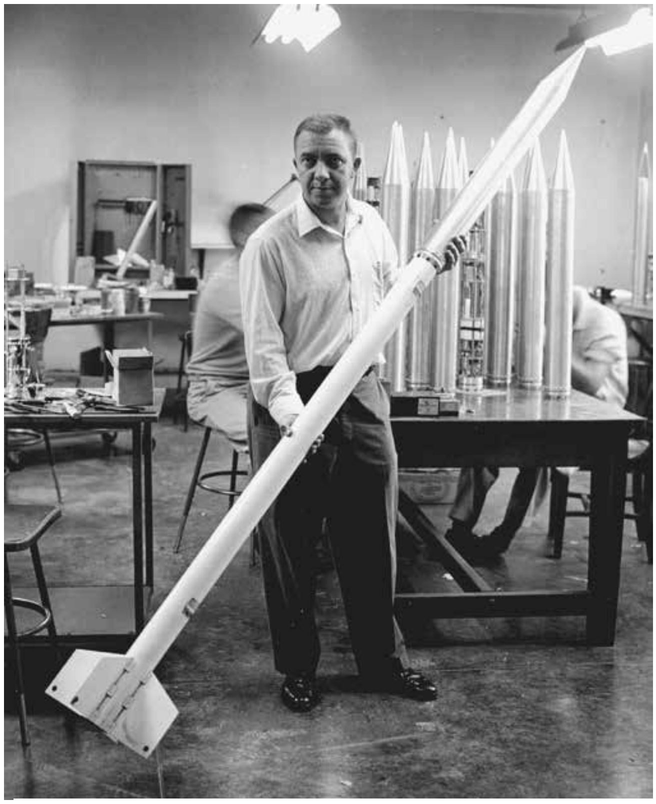
Dr. Daniel Baker, Director of the University of Colorado's Laboratory for Atmospheric and Space Physics in Boulder, speculates that if there were no human-generated VLF transmissions, the inner boundary of the Van Allen Belts would likely stretch closer to Earth. Indeed, comparisons of the modern extent of the radiation belts, from Van Allen Probe data, show their inner boundary much farther away from Earth than in satellite data from the 1960s, when VLF transmissions were more limited.

VLF signals are transmitted from ground stations, at huge powers, to communicate with submarines deep in the oceans. While these are intended for communications below the surface, they also extend out beyond our atmosphere, shrouding Earth in a VLF bubble. These VLF radio communications interact with charged particles in space, and affect how and where they move. These interactions can create a barrier around Earth that protects it against high-energy particle radiation from space. The means by which this occurs is not yet fully understood.

The team of researchers at the University of Colorado at Boulder was puzzled by the fact that incoming cosmic rays seemed to be stopped by this "hard boundary" in the Earth's atmosphere, at about 11,500 km above the Earth's surface. Dr. Baker commented:

> With further study, VLF transmissions may serve as a way to remove excess radiation from the near-Earth environment. Plans are already underway to test VLF transmissions in the upper atmosphere to see if they could remove excess charged particles.

Excess charged particles can appear during periods of intense space weather, such as when the Sun erupts with giant clouds of particles and energy.


University of Iowa Archives

Dr. James Van Allen holds a "rockoon," a rocket launched from a balloon, to measure cosmic ray flux at 100–110 km altitude. 1955.

The First Explorer

The Van Allen Belts were named after Dr. James Van Allen (1914–2006), a physicist at the University of Iowa, who discovered them based on experiments by himself and his team beginning in 1952, and continuing into 1953 and subsequent years.

As a young man, Van Allen had developed a strong interest in investigating cosmic rays, which he carried over into his university work. As a graduate student, he conducted measurements of the magnetic fields of the Earth over a section of his county, and this enabled him to be able to calibrate such instruments on behalf of his mentor, Dr. Thomas Poulter, who would use them during the Second U.S. Antarctic Service Expedition to the South Pole of Adm. Richard Byrd in 1933–1934.

During World War II, Van Allen served as an ordnance and gunnery officer in the U.S. Navy, and this served him well for future activities. In this role, he solved a major problem for the military by developing an artillery fuse that could both withstand the shock of the cannon, and increase the accuracy of the hits—this was called the "proximity fuse," which detonated within a designated range of the target. Van Allen used tiny springs to absorb the shock of the acceleration of the artillery, resulting in a significantly higher success rate.

The experiments to investigate the atmosphere initiated by Van Allen in 1946 began with a team of undergraduates and fellow ex-military researchers, working on board Coast Guard and naval vessels near the magnetic pole in the regions of Greenland and Newfoundland (as well as in later voyages to Antarctica).

The team had a small budget, so they would use military surplus or obsolete equipment and cobble it together to create something new. If a new part was needed, they would design and machine it themselves. His team comprised primarily his own graduate students, many of whom went on to become rocket scientists, physicists, and engineers for the U.S. space program in some capacity, such as George H. Ludwig and Carl E. McIlwain.

Some of the first experiments used what Van Allen dubbed "rockoons"—a weather balloon would be used to carry a rocket aloft to 20–25 km, at which point the rocket would ignite and go up to about 100–112 km with a modest payload of instruments, featuring a simple Geiger counter. The intention was to create a profile of the intensities of cosmic rays at high altitudes and latitudes, and to learn the nature of low-energy cosmic rays at lower altitudes and latitudes.

Most of the readings that the instruments radioed back conformed to their hypotheses, but two rockoons launched near Newfoundland transmitted unusual results—they had encountered a zone of strong radiation beginning at an altitude of about 50 km, which was far stronger than expected.

At first, they thought that there was something wrong with the instruments, but after thorough examination of the data, Van Allen in particular was convinced that they had discovered something new in the upper atmosphere. And, the Northern Lights lit the way!

NASA

Creators of Explorer 1 (left to right), William H. Pickering, James A. Van Allen, and Wernher von Braun, holding up a full-scale model at a press briefing in the early morning hours after the successful orbit was confirmed in 1958.

They noticed that the zone was in the region where the visible auroras were at their maximum—a region which is about 23° south of the northern geomagnetic pole. But, why? Why would high-intensity radiation occur in this area, and not near the geomagnetic pole? And, how could these particles have such great intensity at relatively low altitudes?

Van Allen redesigned the instruments to better detect this radiation, and through continued experiments, he established that this high-intensity region included both electrons and protons, and also existed in the southern auroral zone.

In the years leading up to the worldwide scientific cooperation of the International Geophysical Year (IGY) of 1957–1958, more experiments were conducted, and their results drove discussions among the scientists, President Eisenhower, and other government representatives, to plan the launching of a satellite to orbit over the lower latitudes, for which Van Allen's team would prepare the experimental apparatus.

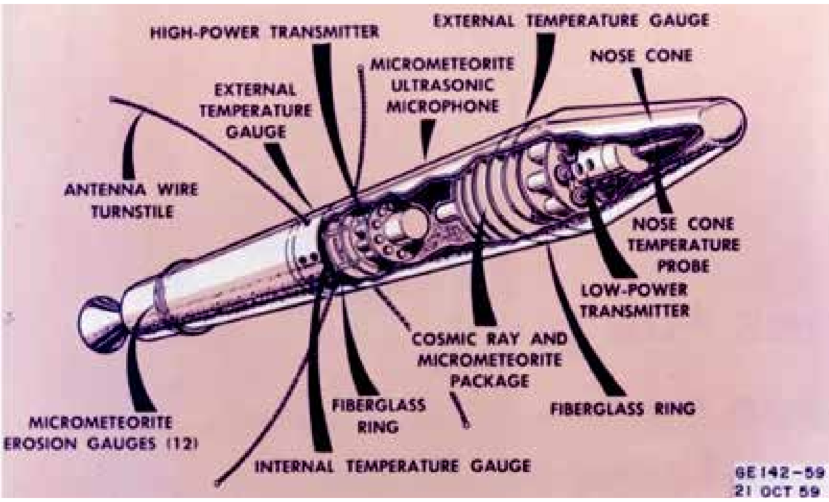
After World War II, Wernher von Braun and other scientists associated with the German wartime rocket project at Peenemünde were brought to the United States and deployed primarily at the White Sands Missile Range in New Mexico, as part of a broad effort by the government to develop rockets for military purposes. The reality of the "space race" and the dawn of a new era for manned exploration, put a premium on new scientific discoveries. There was also stiff competition between the U.S. Navy (*Vanguard*) and the U.S. Army (*Jupiter-C*) as to whose rocket would be the first to launch.

As the failures and difficulties with the launches of the Vanguard rockets set back U.S. efforts, the Soviet Union stunned the world with the successful launching of *Sputnik* in October 1957. It's notable that the frequencies of the two radio beacon signals that were assigned to *Sputnik* were 20.005 and 40.01 MHz, easily detectable by ham radio operators and governments alike. The Soviet scientists clearly wanted the world to be able to track it! (You can listen to the sounds of the first satellites here.

Explorer 1 was the first U.S. satellite, launched on Jan. 31, 1958, followed by the *Explorer 3* (March), *Explorer 4* (July) and the *Pioneer 3* in December 1958. The work of Van Allen's team intersected the interests of the fledgling Jet Propulsion Laboratory (JPL), then under the direction of William Pickering (1910–2004), who wanted to pivot JPL away from military projects and into planetary science. The results of these first launches gave the scientists another puzzle: At high altitudes over the equatorial region, the apparent counting rate of the Geiger counters went down very low, even dropping to zero for several minutes. But, at lower altitudes, they saw counting rates that were in the "expected" range of 30–50 counts per second.

Once again, Van Allen and his team were confounded: Was it their instruments? They considered the alternative that perhaps the cosmic rays didn't strike the uppermost parts of the atmosphere over the tropics, but

FIGURE 4



NASA, JPL-Caltech

A cutaway drawing showing the insides of Explorer 1. The Geiger counter was in the nose cone.

this seemed untenable. Compounding that, although the Explorer 1 was broadcasting continuously, it didn't have a recording device—its signals could be picked up only intermittently, when it came within range of a ground station. This aspect was resolved with the development of a recording device placed on the satellite which would record for an entire orbit, and then transmit the entire data to a ground station.

This device was installed on *Explorer 2*, which failed to achieve orbit. *Explorer 3* was launched successfully on March 26, 1958—it confirmed the previous readings. Still perplexed, the researchers then hypothesized that the instrument was becoming jammed due to high levels of radiation which, they supposed, temporarily overwhelmed the counter. In other words, the discovery was not "in the data," but required the insight of the human mind.

Discovery of the Second Belt

The International Geophysical Year (IGY) created an opportunity for Van Allen to investigate these regions of high-intensity radiation in a more comprehensive way and with increased urgency. Van Allen and his team gained increased financing, along with enthusiastic support from the JPL, the National Academy of Sciences, the Army Ballistic Missile Agency and the Cape Canaveral Air Force Base. With the subsequent missions of *Explorers* 3 and 4, and *Pioneer 1* (**Figure 4**), the second main torus of the Van Allen Belts was discovered.

How did Van Allen know that his design was wrong, and not just that the instruments were failing? How do you design an instrument to detect things that you don't know are there?

For those of you who don't believe you're "bright enough" to be a scientist, this is what Van Allen had to say:

> I've never thought of myself as particularly brilliant. I've run across so many people in my life that can run circles around me in sheer brilliance and understanding; but I don't run across many that have the same quality of persistence and perseverance that I do. When I am really onto something, I am going to still be on it ten years later if that is what it takes to get the answer. It's the kind of thing that keeps driving me onward, is that there is always something you should know if you really want to get the whole picture.

Van Allen could truly be called the "Father of the Space Age," due to his foundational role in America's space program, and a driving force for increased scientific exploration for his entire life. His biographer wrote:

> Throughout his career, Van Allen played a crucial role in numerous space programs, including the *Pioneer, Mariner,* and *Voyager* missions. He utilized his expertise to design scientific instruments, analyze data, and draw critical insights into the nature of space environments. Beyond his scientific contributions, Van Allen had a deep commitment to education and public outreach. He actively engaged with the public, frequently giving lectures and writing articles to promote scientific literacy and generate interest in space exploration. His dedication to education led him to establish the James Van Allen Foundation, which aimed to provide support for educational activities in the fields of science, engineering, and technology.
>
> James Van Allen's impact on the scientific community and space exploration can hardly be overstated. His discoveries and research paved the way for future generations of space scientists, and his direct role in developing spacecraft

instrumentation set the stage for numerous successful space missions. Van Allen's lifelong pursuit of knowledge and his passion for sharing it with the world have left an indelible mark on the scientific community and continue to inspire scientists and space enthusiasts alike.

Van Allen exemplified the best disposition of a scientific mind, similar to other great thinkers, ranging from Johannes Kepler to Louis Pasteur, and from Pierre and Marie Curie to Lyndon H. LaRouche, Jr. We find that this kind of mindset also includes the quality of courage—one must dare to assert a new discovery, which transforms the way we understand our Universe. What invariant do we find in their thinking? How could they "see" a solution in their mind—which is "unseen" by the senses—yet they know it to be true? The common-sense notion is that if you can see, touch, or taste something (with any of your senses), then you know it's "real." But, we can understand that in the scientific method, it is the *mind* that perceives a new truth; as the poet John Keats conveys in his sonnet, "On First Looking into Chapman's Homer": "... Then felt I like some watcher of the skies/ When a new planet swims into his ken…."

The International Geophysical Year

The International Geophysical Year (July 1957 – December 1958) demonstrated how scientists of the world could collaborate in the area of research and discovery that transcended the politics and tensions of the day. It was a global program of different aspects of geophysics and Earth's planetary environment.

This was the height of the Cold War; the Soviet Union had successfully launched the first artificial satellite, *Sputnik*. The years 1956–1958 also saw several international crises which threatened transnational cooperation, such as the Suez Crisis, the Hungarian Revolution (both in 1956), and the Syrian Crisis (1957). In spite of having a less than optimum international political climate, and although disagreements certainly did arise, the scientific community cooperated in the IGY for the good of all mankind.

Although it had been preceded by two International Polar Years (1882–1883 and 1932–1933), during which international scientific studies focused on the polar regions, the plan for the IGY was to not wait another 50 years, but to move it up to a 25-year interval. This was the brainchild of one of the leading scientists of the day, Lloyd Berkner. He floated the idea at a dinner party held in the home of Dr. James Van Allen in Silver Spring, MD in April 1950; Van Allen enthusiastically endorsed the idea. Following a few years of organizing for it via several scientific agencies and institutions, the IGY was organized to begin July 1957 and end in December 1958, mostly to take full advantage of the 11-year cycle of the Sun at its maximum activity. Each nation would finance its own teams.

Harold Bullis, in *The Political Legacy of the International Geophysical Year,* wrote:

> The [IGY] … represents the largest, most complex, and most comprehensive international scientific undertaking thus far conceived and successfully carried out by scientists. Sixty-seven nations participated, represented by 20,000–40,000 scientists and as many volunteer observers, manning about 4,000 principal stations and an equal number of secondary stations and sites scattered throughout the world from pole to pole….
>
> Throughout the 18 months of activity, scientists generated an unprecedented aura of international cooperation and good will as they attacked the scientific problems while largely avoiding the political ones. Their efforts were hailed variously as "a major turning point in history," as opening up "a new era in the history of the human race," and as having been "the single most significant peaceful activity of mankind since the Renaissance and the Copernicus revolution." In view of these assessments by responsible observers, the IGY was an attractive subject for analysis of possible contributions of science to the conduct of international affairs.

It was in the midst of this environment that *Explorer 1* was launched, and Van Allen was able to make his remarkable discoveries of the radiation belts around the Earth. The successful launch of an artificial satellite in orbit around the Earth was considered by most to be the most significant event resulting from the IGY; the study of Antarctica was considered the second most important.

President Dwight Eisenhower addressed the nation on June 30, 1957, on the opening of the IGY the next day:

> The scientists tell us that they cannot possibly anticipate all of the valuable scientific knowledge that will result from their efforts. They be-

lieve that many of the facts thus acquired will give us new understanding and new power over the forces of nature.

As I see it, however, the most important result of the International Geophysical Year is the demonstration of the ability of peoples of all nations to work together harmoniously for the common good. I hope this can become common practice in other fields of human endeavor.

The United States is proud to have a part in this great scientific undertaking....

USPS

The remarkable 1958 commemorative U.S. postage stamp for the IGY, showing a detail of Michelangelo's "Creation of Adam" in the Sistine Chapel against a profile of the Sun's corona.

Studies were conducted in the following areas of research: auroras and airglow; cosmic rays; geomagnetism; glaciology; gravity; ionospheric physics; accurate measurement of latitudes and longitudes relative to the center of the Earth without a plumb line; meteorology; nuclear radiation; oceanography; seismology; solar activity; and studies of the upper atmosphere.

The studies on cosmic rays and nuclear radiation were most notable: Author Bullis, in his book on the IGY, commented on cosmic ray studies:

> Cosmic rays ... were found to be influenced by solar activity, with diminished cosmic ray intensity being noted during periods of high sunspot activity. However, fundamental questions concerning the origin and nature of cosmic rays remained unanswered. [Walter] Sullivan commented that cosmic ray physics "... emerged from the IGY as ... the broadest-ranging of all man's intellectual endeavors," dealing not only with the immense concepts of galaxies and intergalactic space, but with the opposite spectrum of atomic and nuclear particles and forces as well.

The Legacy of the IGY and Van Allen

The "spinoffs" from the IGY, involving as they did international cooperation, sparked an increase in the teaching of math, engineering, and science in schools; the general public viewed science as more "relatable" in their day-to-day lives; and the IGY served as a foundation for several international treaties, such as the Antarctic Treaty of 1959, and the Outer Space Treaty of 1967.

A 1958 commemorative U.S. postage stamp created for the occasion of the IGY depicts the "Creation of Adam" by Michelangelo from the Sistine Chapel in the Vatican, against a backdrop of solar flares from the surface of the Sun. Such *Götterfunken* of the Creator's connection to all mankind can serve as an exemplar for the kind of optimistic cooperation—a new kind of statecraft—in which the spirit of discovery, the spirit of IGY, and the love of truth can usher in a brilliant era for mankind.

The overarching effect of such peaceful and scientific cooperation was that of optimism for the future of mankind. These scientists could not be called, "apolitical," but political in the most profound sense—that of statecraft and diplomacy. The current proposals of the Schiller Institute to urgently revive the principles of the 1648 Treaty of Westphalia, and Helga Zepp-LaRouche's Ten Principles of a New International Security and Development Architecture to move the world toward peaceful solutions to end the anguishing danger of World War III, are congruent with such an optimistic perspective.

If mankind is to fulfill its deepest yearnings and create a future for our beloved young people, and those as yet unborn, we must again look up to the heavens, and send new explorers out into the great void, to discover humanity's magnificent mission.

For Further Reading

The University of Iowa Physics Department has posted a biographical sketch of Van Allen.

Abigail Foerstner, *James Van Allen: The First Eight Billion Miles*, University of Iowa Press, 2007.