Space Exploration at APL: From the Beginning to the 1990s

Glen H. Fountain, David Kusnierkiewicz, and Stamatios M. Krimigis

ABSTRACT

The Johns Hopkins University Applied Physics Laboratory (APL) Space Exploration Sector traces its origins to the post–World War II high-altitude research using V-2 rockets. It became a major contributor to the U.S. space program with the development of the world's first satellite navigation system (Transit). During the first few decades of the Space Age, the Laboratory's work expanded to include significant contributions to the civilian space program as well as the country's national security. This article chronicles those accomplishments and discusses the core values that contributed to success.

INTRODUCTION

The formal origin of what was to become the Johns Hopkins University Applied Physics Laboratory (APL) Space Exploration Sector began with the invention of satellite navigation in the late 1950s. However, the first efforts linking APL to space research began in the 1940s with a team led by Dr. James Van Allen. This pioneering team set out to make high-altitude measurements of the Sun and the upper atmosphere's environment using V-2 rockets captured from Germany after World War II. From that time forward, the combination of scientific curiosity and practical engineering approaches to solving problems has enabled a talented team of people to make key contributions to both space science and engineering.

APL's accomplishments in space stem from a culture marked by a number of important attributes that have been demonstrated many times over during the course of the Laboratory's history. These attributes start with the marriage of curiosity and a systems approach to solving significant problems (what the Laboratory articulates as "critical contributions to critical challenges"). While the discipline of rigorous processes is now recognized as critical to the successful development of complex systems, APL's Space Exploration Sector has always valued the people first, understanding the necessity of a talented and dedicated staff as the first element of that success. This was especially true at the beginning, before formal processes even existed. The open atmosphere focused on getting things right and not on who gets the credit or who is to blame. This nurturing culture attracted talented, team-focused individuals to the organization because they believed that their creativity would be allowed to flourish and that they would enjoy career-long learning (see Box 1). These factors enabled the organization to find practical solutions to meet sponsors' needs. This culture continues today.

Another aspect of the Space Exploration Sector is its programs' broad base of sponsors. As part of a Laboratory and university dedicated to national service and the advancement of knowledge, the sector has endeavored to support national security in a broad sense—responding to defense-related needs on the one hand and performing research that enhances the knowledge of our world on the other hand (e.g., the sector's civilian space activities or medical applications of space technology). The ability to bridge these two domains increases the stability of the organization and opens the solution space in which staff members work to address sponsors' needs.

Another thread woven into the culture is the recognition that the ideas and systems developed at the Laboratory are not complete until they have been validated by the appropriate end user. In some cases, this implies transferring technology to commercial suppliers, and in other cases it requires publishing data and scientific results so they are available to the scientific community and the general public.

This open, nurturing atmosphere focusing on systems engineering and scientific curiosity, along with the close coupling of these two disciplines, has enabled the Space Exploration Sector to find solutions to problems that other organizations have found difficult to address—and to execute those solutions "faster, better, and cheaper."

THE ORIGINS OF SPACE EXPLORATION AT APL

At the end of World War II, the U.S. government came into possession of a number of German V-2 rockets.[1] Members of the scientific community, led by Ernst H. Krause of the Naval Research Laboratory, expressed interest in using those rockets for scientific purposes. A small group of scientists from universities and government laboratories were invited to participate. Among them was Dr. James Van Allen, then a member of the APL staff. His expertise in the development of the proximity fuze—namely the ability to design electronics to withstand high-G forces—made him an important member of this group. During the next few years, Van Allen and a group of colleagues would develop and fly instruments on the V-2 and later rockets to observe the Earth from high altitude[3] (see Fig. 1), among making other discoveries such as the UV spectrum of the Sun. Van Allen's interest was in cosmic rays at high altitude, which led in the following years to the discovery of the Earth's radiation belts, later named the Van Allen belts in his honor.

BOX 1. A CULTURE OF COLLABORATION

Taken from an early history of the organization, the following paragraph demonstrates the deliberate fostering of an open, collaborative culture in which lines of responsibility were established early. Although it specifically addresses the relationship between the electronic designer and staff members focused on assuring the reliability of electronic systems (in what became the System Assurance Group), the relationships between the teams clearly extends to the larger organization.

> In the beginning, the Reliability Project personnel tried to learn about the other personnel—especially the designers, their capabilities, how they thought, and their background and competence in general. The universal problem in quality assurance (you're interfering—you're bothering me) was immediately encountered. At this early stage, an important decision was made, namely: The Reliability Project would operate as a service project rather than as an authoritarian project. The Project would provide services, would bend over backwards to help others solve their problems, would make it clear that reliability was a general concern, *but with the circuit designer holding ultimate responsibility* [italics added]. Great care was taken to build a relationship of trust and confidence between the Reliability Project and the rest of the Space Division. Looking back, this decision has turned out to be a wise one.[2]

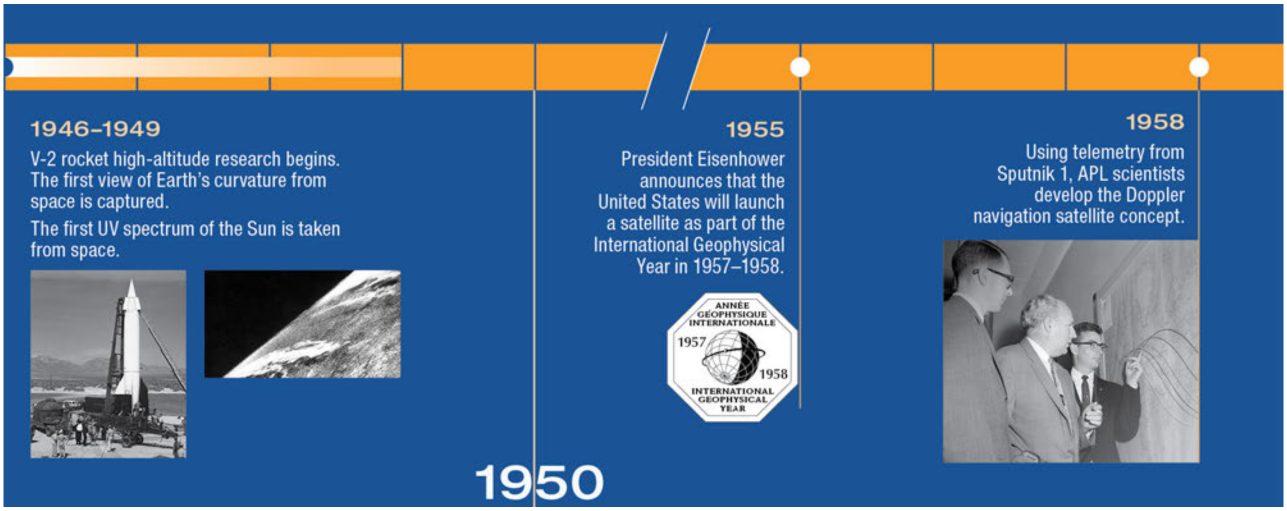


Figure 1. The evolution of space science, technology, and engineering at APL—the origins.

The high-altitude work continued under the auspices of a national committee called the V-2 Upper Atmosphere Research Panel, of which Van Allen was appointed chairman in 1947. This research led Van Allen to make one of the first (if not the first) serious scientific proposals for space research at a meeting of the International Union of Geodesy and Geophysics in Oslo, Norway, in 1948: "Then there is always the prospect of pioneering measurements at higher and ever higher altitudes. Serious consideration is being given to the development of a satellite missile which will continuously orbit around the earth at a distance of, say, 1000 km."[1]

Because of the limited number of V-2 rockets and the high cost of building and flying new ones, the researchers quickly realized that a cheaper rocket was needed. A group at APL, led by Van Allen, initiated the development of a new vehicle, the Aerobee rocket. Developed by the Aerojet Engineering Corporation and the Douglas Aircraft Company, the Aerobee was the workhorse of the space research community for many decades.

Van Allen left the Laboratory in December 1950 to continue his work at the University of Iowa, but many of his colleagues remained at APL, forming the original core of what became the Laboratory's space science enterprise. Van Allen continued to push the idea of spaceflight as a method to better understand our environment, a belief that was validated when President Eisenhower announced that the United States would launch a satellite as part of the International Geophysical Year (1957–1958).

THE INVENTION OF SATELLITE NAVIGATION

Space research laid dormant at APL until October 14, 1957, with the launch of Sputnik 1. Again scientific curiosity was married to the need for a practical solution to a critical problem. This combination resulted in the development of satellite navigation and what today is called APL's Space Exploration Sector, formerly the Space Department.

It was curiosity that motivated William H. Guier and George C. Weiffenbach to "borrow" a radio receiver from the Bumblebee Instrumentation Group so that they could track Sputnik's transmission. They quickly determined that they could accurately compute the satellite's orbital parameters from a single pass.[4] At the same time, APL was supporting the U.S. Navy in the development of the Polaris ballistic missile submarine. A major challenge was finding a way to allow the submarine to determine its position (to navigate) without exposing itself for long periods of time. In a classic case of creativity,[5] this new method of determining a satellite's orbit

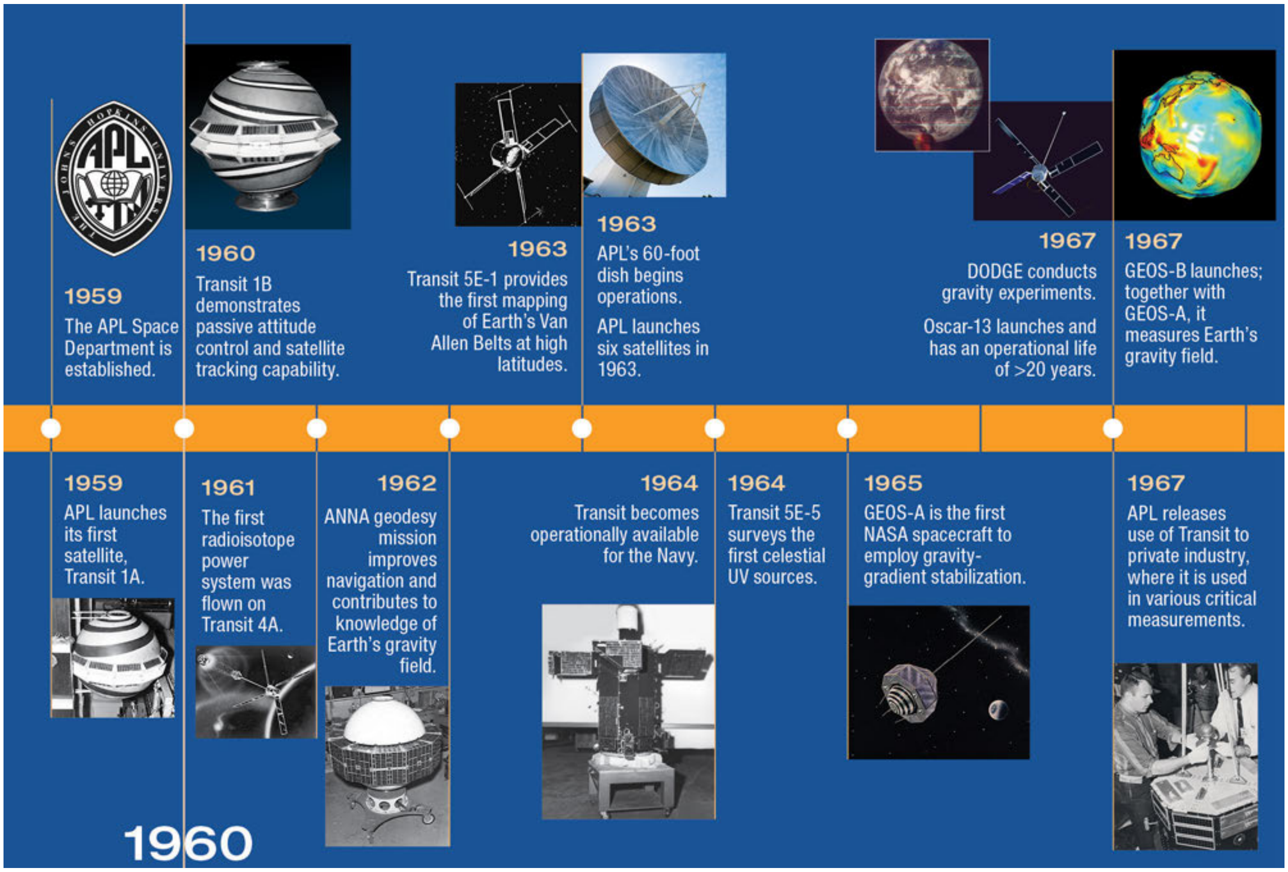


Figure 2. The evolution of space science, technology, and engineering at APL—the pioneering years.

was combined with this known need, leading Frank T. McClure to propose the use of satellites for navigation purposes.[6] This concept, in turn, led to the development of the Transit system and the establishment of an APL department dedicated to space research.

> The task undertaken by the new department was nothing short of revolutionary. For the previous 4,000 years the principal means for navigation on a global scale was similar to that used by Odysseus on his return journey to his island of Ithaca by keeping the Great Bear to his left and his eyes fixed on the Pleiades. The promise of Transit was to do away with astronomical observation as the principal means of worldwide navigation and replace it with an all-weather global system that would provide accurate locations at any point with precision unheard of for its time (less than 0.5 mile).
>
> Our predecessors, under the charismatic leadership of the first Space Department Head, Richard Kershner, succeeded admirably in their task and in the process . . . shaped the Department's culture as we know it today. Their success is all the more impressive by today's standards in that they were able to make the Transit System operational 2 years ahead of schedule and within the originally allocated cost. They did so while establishing a host of technological "firsts" that have since been used routinely . . . as basic tools of spaceflight design and implementation. A few of these include the first attitude control of a spacecraft using permanent magnets, the first solar attitude detectors, the first satellite electronic memory, the first nuclear power in a spacecraft, hysteresis rods for dumping satellite libration—and all of these before the end of 1961! These were followed by gravity-gradient stabilization, a magnetic spin/despin system, the first integrated circuits used in space, etc.[7]

In an attempt to push gravity-gradient techniques to higher and higher altitudes, the Space Department built the Department of Defense Gravity Experiment (DODGE), which took the first color image of the full Earth in 1967 (see Fig. 2). The standard the team set, solving tough engineering problems while delivering programmatic value and high system performance, has continued throughout the organization's history—both in low Earth orbit for the science and national security communities and beyond as APL spacecraft explore the solar system from one end to the other.

BOX 2. RESTORING EARTH'S GEODESY COORDINATE SYSTEM

By the mid-1960s, the knowledge of the Earth's geodesy was markedly improved, and this knowledge was necessary to achieve high precision in geolocation, with the reference point being the ground station at APL. In the late 1960s, Richard Kershner felt that it would be desirable to put the American system (Transit derived) in line with the globally recognized system (Greenwich meridian). In 1969, a Transit receiver was installed at the Greenwich observatory to measure its longitude with respect to the APL ground stations, thus restoring Earth's geodesy coordinate system.[8]

The Transit program continued through the 1990s until the second generation (GPS) was fully operational and the user base had fully transitioned to the new system. Throughout the nearly 40 years of the program's existence, APL's space scientists provided technical support. Transit led the way to the modern navigation system that we take for granted today. And the scientists and engineers at APL continued to broaden their horizons beyond navigation.

BROADENING THE HORIZON

With the Transit program, the Space Department (and APL) created a first-class scientific, engineering, technical, and management organization for space endeavors. Not only did its staff members have to solve and validate practical engineering problems (see Fig. 3), but they also had to develop a better understanding of the space environment and the geodesy of the Earth. The early work of Van Allen and his team provided a start in understanding the near-Earth environment, and work on this problem continued at APL in the 1960s. The Starfish Prime test[9] further demonstrated the space radiation environment's lethal effects on spacecraft electronics (see Fig. 4), confirming our need to better understand that environment to more reliably use space and to enhance scientific understanding. At the same time, the Transit program required a better understanding of

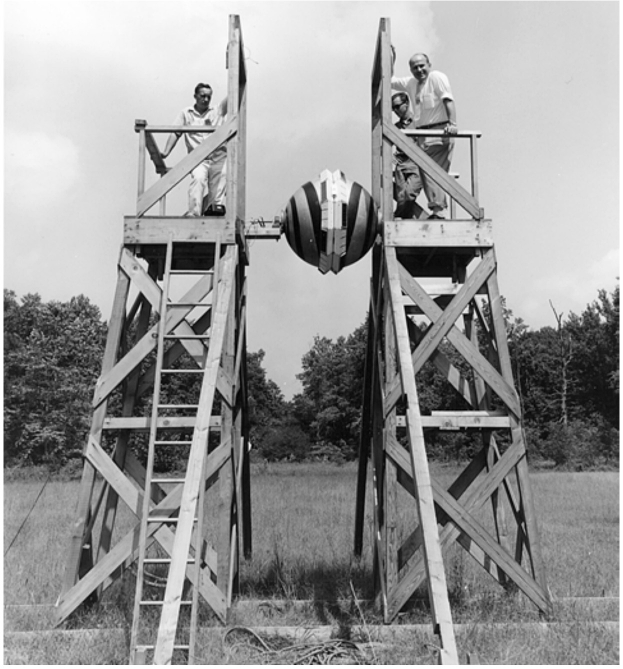


Figure 3. The yo-yo-like de-spinning mechanism being tested on APL's first satellite in 1959, under the philosophy of "test what you fly, fly what you test." James Smola (far right) is conducting the test. Also pictured are Wilfred Zimmerman (left) and David Moss (next to Smola).

Earth's gravity field and more precise information about the location of features on Earth's surface. These two lines of inquiry led the department to expand its work into space physics and geodesy. With this expansion, the organization's initial focus on only national security grew to include civilian space tasks with the sponsorship of NASA (see Figs. 2 and 5).

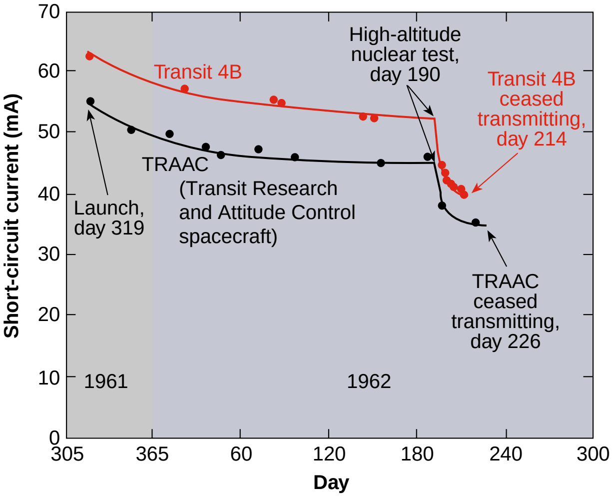
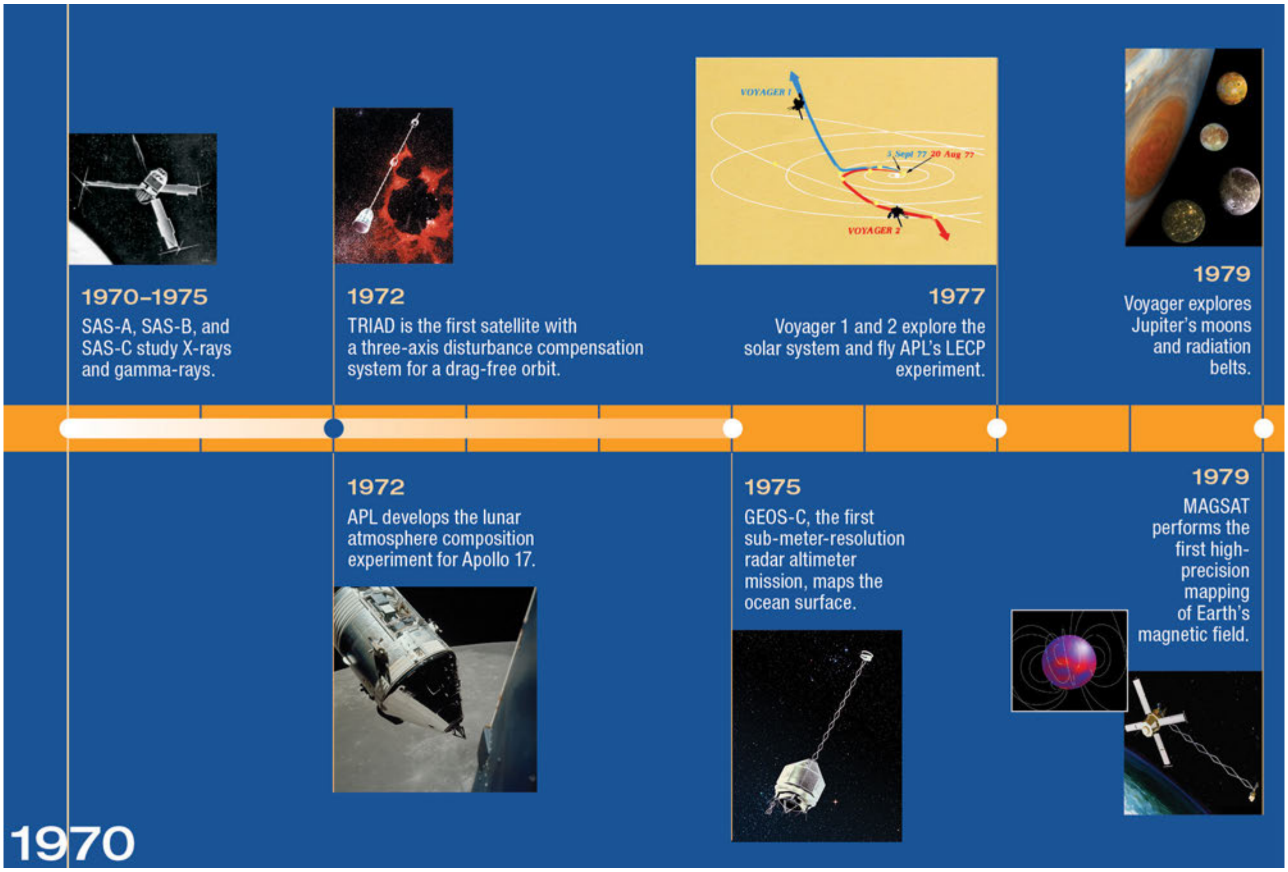


Figure 4. Short-circuit current versus time for two solar arrays in orbit at the time of the Starfish Prime high-altitude nuclear test. Degradation after the blast was due to exposure of the solar cells to a greatly increased number of energetic charged particles trapped by Earth's magnetic field. (Reproduced from Ref. 10.)

The investigations of the radiation belts built on Van Allen's work with Explorer 1 and 3, resulting in Injun 1, which was launched with Transit 4A. A key technology in this work was the development of solid-state detectors to replace the Geiger tubes flown earlier (see Box 3). The radiation measurements were complemented with measurements of Earth's magnetic field on missions such as the Transit Improvement Program's TRIAD spacecraft. This early work helped to establish the fundamental understanding of the radiation belts and their relationship to Earth's magnetic field. A major discovery was the identification of huge currents aligned with Earth's magnetic field, a totally unexpected finding that has constituted a basic tool of magnetospheric physics ever since.[11] The research was extended under NASA sponsorship to include investigations of the interplanetary environment with instruments on NASA's Interplanetary Monitor Platform (IMP) series of missions during the 1960s and early 1970s and the AMPTE (Active Magnetospheric Particle Tracer Explorer) program in the early 1980s, and it would extend into the next century with the Van Allen Probes and Parker Solar Probe (formerly Solar Probe Plus) missions.



1970–1975
SAS-A, SAS-B, and SAS-C study X-rays and gamma-rays.

1972
TRIAD is the first satellite with a three-axis disturbance compensation system for a drag-free orbit.

1977
Voyager 1 and 2 explore the solar system and fly APL's LECP experiment.

1979
Voyager explores Jupiter's moons and radiation belts.

1972
APL develops the lunar atmosphere composition experiment for Apollo 17.

1975
GEOS-C, the first sub-meter-resolution radar altimeter mission, maps the ocean surface.

1979
MAGSAT performs the first high-precision mapping of Earth's magnetic field.

Figure 5. The evolution of space science and technology at APL—the discovery years.

BOX 3. FROM GEIGER TUBES TO SOLID-STATE DETECTORS

Geiger tubes were used by Van Allen and others in the sounding rockets and on Explorers 1 and 3; however, they had a number of drawbacks, including their size and inability to easily determine the type of radiation and its energy. A new solid-state detector was developed by George Piper and two of his graduate students, Carl O. Bostrom and Donald J. Williams, at Yale University. This group moved to the Laboratory in 1960 to continue their investigations of Earth's radiation environment. Their work enabled the Laboratory to continue its leadership in the area of space physics. Two solid-state detectors were flown as part of the University of Iowa's Injun 1 payload, and they produced an excellent set of data, both for the radiation belts and for solar proton access over Earth's polar caps.[12] Stamatios "Tom" M. Krimigis, then a graduate student at Iowa, analyzed this data set for his master's thesis. He then proceeded to design a solid-state detector instrument flown on Mariner 4 to Mars as part of his Ph.D. project. Later, after Krimigis completed his Ph.D. under Van Allen at the University of Iowa and served as assistant professor of physics there, Carl Bostrom convinced Krimigis to join the Laboratory.

To meet Transit's key navigation accuracy requirements, better knowledge of the Earth's gravity field was required, and the coordinates of locations on Earth's surface needed significant improvements. This work to support the national security sponsors was complemented by NASA's thrust to improve the general state of knowledge of Earth's systems. Nothing perhaps better exemplifies this work than the series of missions built by the Laboratory and designated the Army-Navy-NASA-Air Force (ANNA) spacecraft flown in the early 1960s. These missions were followed by a series of NASA-sponsored Geodetic Earth Orbiting Satellites (GEOS-A, -B, and -C). This work enhanced the gravity model, leading to improvements in navigation by over two orders of magnitude by the late 1960s. Further improvements gained another order of magnitude by the end of the Transit program[13] and (with GEOS-C's radar altimeter) enabled the first measurements of the global ocean height to 50 cm. With these efforts, the team met the Navy's original requirement and facilitated general improvements in navigation (see Box 2).

The GEOS-C radar altimeter and its successors demonstrate another trait of the key role that the Lab's space sector (and APL at large) plays in solving critical challenges for a widening sponsor base. GEOS-C demonstrated the utility of spaceborne radars in mapping the

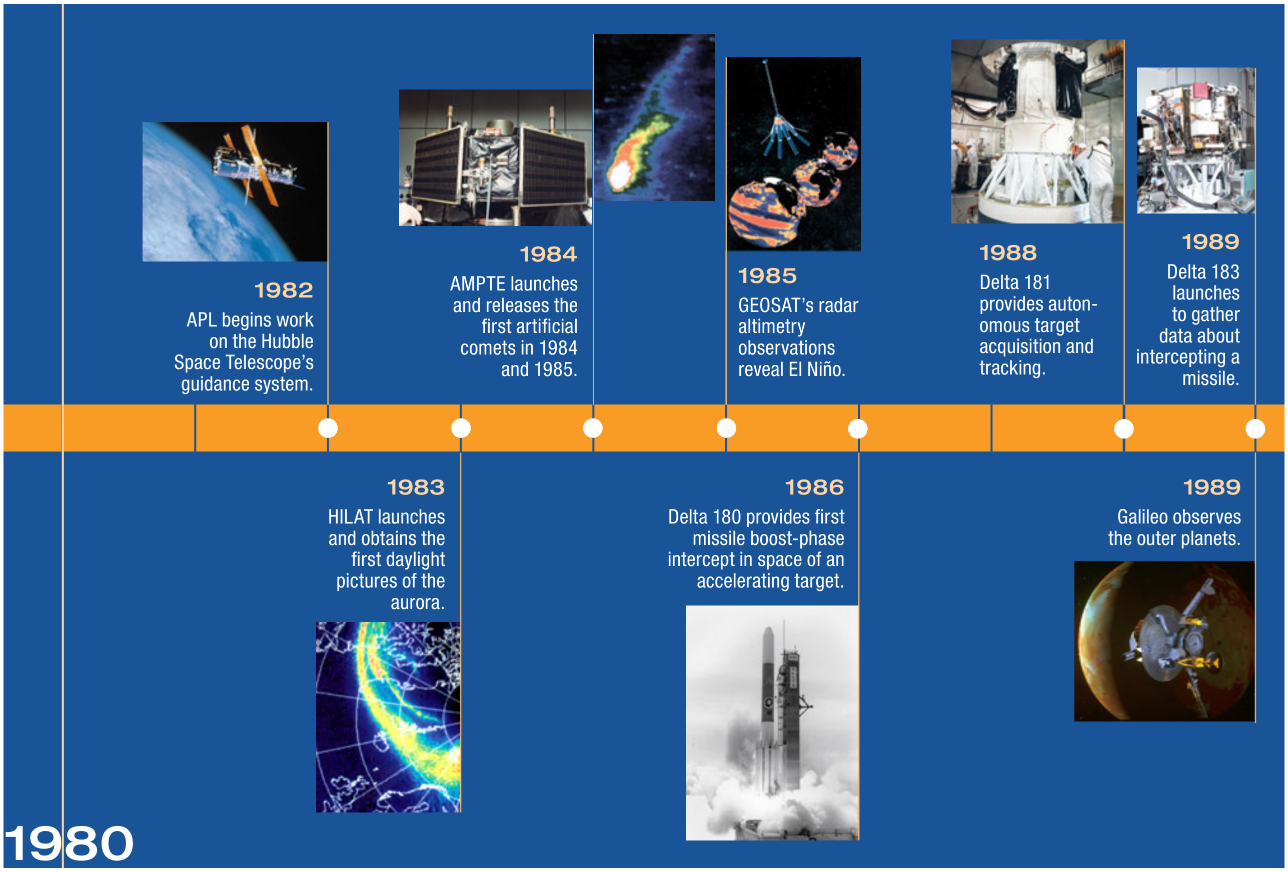


Figure 6. The evolution of space science and technology at APL—discovery expands.

world's oceans, their currents, and the morphology of the ocean floor hidden beneath. But to be successful, the radar system first had to work. The original plan for GEOS-C called for the radar to be supplied by a contractor via a separate NASA contract. It soon became apparent that the contractor was struggling to meet the instrument requirements. In concert with NASA, the APL program management team reached out to radar experts in APL's Fleet Systems Department (now the Air and Missile Defense Sector) to get the radar system to the finish line and into space. The resulting instrument's success led NASA (with SEASAT in 1978 and TOPEX in 1992) and the Navy (with GEOSAT in 1985) to come to the Laboratory for three additional satellite ocean radar altimeters systems to further refine the ocean height measurements with resulting precision of 2 cm.[14] These instruments also led to a real understanding of the oceanic behavior that underpins the El Niño phenomenon (see Fig. 6).[15]

From the middle of the 1960s through the early 1980s, APL's space sector contributed to an ever-widening set of activities in both space science and engineering, even applying space-related technologies in other fields. A number of biomedical applications that incorporated these innovations, such as the rechargeable pacemaker, were developed by staff members of APL's Space Department. The capability APL developed for making environmental measurements in space, begun first by Van Allen's group and then continued for the Transit program, led to additional research into Earth's ionosphere (BE-B and HILAT) and beyond into the heliosphere with instruments on board NASA's IMP spacecraft. With these successes, NASA selected the Laboratory to supply the Low Energy Charged Particle (LECP) instruments (and science investigation leadership) on the Voyager mission (see Box 4). The Laboratory developed the spacecraft for the three small astronomy satellites, which first verified and mapped the emissions of X-ray and gamma-ray sources in the universe (and provided key evidence for the existence of black holes), as well as the MAGnetic Survey SATellite (MAGSAT) to map in detail Earth's magnetic field. The discoveries of SAS-A, later named Uhuru, resulted in the Nobel Prize being awarded to Dr. Riccardo Giacconi, the mission's principal investigator. These successes led to further expansion of APL's space science work (described in the article by Krimigis et al., in this issue, covering the years from 1990 to the present).

BOX 4. THE LOW ENERGY CHARGED PARTICLE EXPERIMENT

NASA conceived of a "Grand Tour" of the outer planets, which became the Voyager mission. The mission consisted of two spacecraft with a number of remote sensing and *in situ* measuring instruments. One of the instruments selected for Voyager, and the accompanying scientific investigation, was proposed by Tom Krimigis and a team of colleagues from APL; the Universities of Maryland, Kansas, and Arizona; and Bell Laboratories. It is important to note that several of the proposers (Krimigis, George Gloeckler, Charles Y. Fan, and Thomas P. Armstrong) were former students of Van Allen and also of John Simpson of the University of Chicago, two of the pioneers of the U.S. space program who had also proposed instruments that were not selected by the NASA committee. The instrument was named the Low Energy Charged Particle (LECP) experiment. It used solid-state detectors entirely and included a stepper motor that allowed the detector to point in different directions about a circle so that the researchers could determine how the particle flux changed in intensity and composition as a function of direction. As the spacecraft entered the Jupiter system, the LECP instrument detected sulfur and oxygen (among other things), which were later determined to be products of the volcanic eruptions on the Galilean moon Io. The LECP instrument continued to measure the local charged particle environments as it passed by Saturn, Uranus, and Neptune. In 2012, the Voyager 1 spacecraft passed beyond the region dominated by the Sun (the heliosphere) and into interstellar space. The LECP instrument, with its stepper motor now having worked for nearly 40 years, continues to collect data on the charged particle environment and cosmic rays in the galaxy. The stepper motor was tested to 500,000 steps, more than enough for the expected 4-year trip to Jupiter and Saturn, but it has now accumulated nearly 7 million steps without failure.

"THE BEST FIREFIGHTING ORGANIZATION"

In the mid-1980s, the United States began to take ballistic missile defense seriously with President Reagan's Strategic Defense Initiative. The director of that initiative, Lieutenant General James Abrahamson, was looking for a demonstration of the United States' capability to defend against a ballistic missile threat. He reached out to various organizations in the space defense industry, and they all told him that such a demonstration would take many years and would cost billions of dollars. That kind of response was not a solution to his problem, so he turned to APL for a "proof-of-concept" demonstration. The Laboratory (led by the staff of its Space Department) developed a solution to meet his needs, demonstrating the Lab's systems engineering capability to understand a problem, define a solution, and demonstrate that solution in a time frame and at a cost that other organizations could only envy.

The task set by General Abrahamson was to demonstrate in space the intercept of an accelerating missile and to do so within 1 year. Members of the Lab's staff provided the concept after being initially briefed on the problem late in the winter of 1985. The concept was approved by General Abrahamson, and the Laboratory was designated as the lead laboratory for the task.

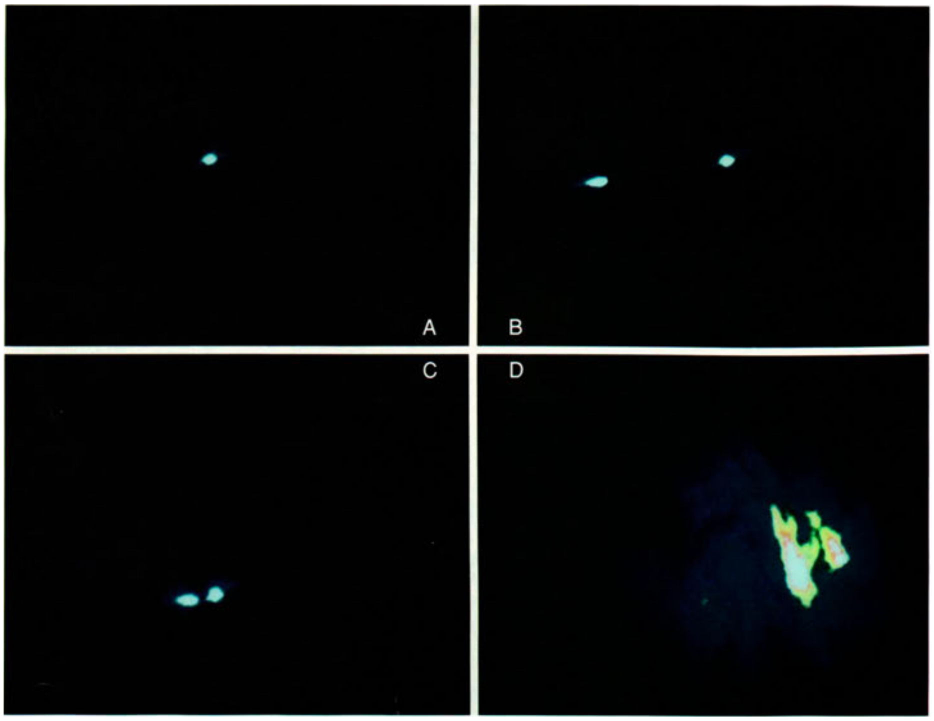


Figure 7. The Delta 180 endgame intercept (computer-enhanced) as viewed in the visible spectrum from an observing aircraft. A, the sensor module; B, the interceptor approaches; C, close approach; D, direct hit. (Reprinted from Ref. 16.)

When asked why the Laboratory was directed to lead the task, General Abrahamson replied, "Why would I give the task to an organization that told me it couldn't be done?" (personal communication of M. D. Griffin).

APL began working on the task in earnest in April 1985. The leadership for the task, which entailed systems engineering and overall management, included members of APL's Space Department; staff from across the Laboratory and from other aerospace organizations played other critical roles. The key idea of the demonstration (designated Delta 180, which was the serial number of the Delta rocket used) was to launch both the target and the interceptor on the same rocket and to use existing hardware elements that could be modified to meet the intercept requirements. (Launching the target and the interceptor on the same rocket was an important innovation in that it allowed a demonstration of the intercept concept within the terms of the 1972 Anti-Ballistic Missile Treaty between the United States and the Soviet Union.) To verify the success of the demonstration, the team had to develop instrumentation that would fly on the target vehicle to measure the environment prior to the intercept. The development of a worldwide test range was required to track both the target and the interceptor on their flights, which would terminate over Kwajalein Island in the Pacific.

Working in partnership, the Laboratory and the government were able to define the necessary systems, identify existing hardware, and put the required contracts in place within a couple of months of the initial approval to proceed. The hardware was designed, modified, assembled, and tested over the ensuing months, and it was delivered to the launch site (Cape Canaveral Air Force Station) by May 1986 (see Fig. 6). All was ready for the demonstration. However, after another Delta rocket failed in early 1986, the flight demonstration was postponed until September 5, 1986. The successful demonstration (see Fig. 7) provided the evidence needed to convince skeptics that ballistic missile defense could be achieved and set the program on sound footing.[16] In 1990, the leadership of APL's space enterprise canvased its sponsors to determine their view of the Lab's performance. One sponsor commented that APL's "Space Department is the best firefighting organization in the country."

HERITAGE

The Delta 180 mission led directly to additional ballistic missile defense space missions (Delta 181, Delta 183, and the Midcourse Space Experiment, or MSX) in the following years, and it served as a precursor to a significant role that the Laboratory now serves, under the leadership of the Air and Missile Defense Sector, more broadly across the Missile Defense Agency. It also reinforced the culture established in the early years of APL's space enterprise that contributed to groundbreaking developments completed in extremely short time frames and at competitive costs. The 1980s also demonstrated another key aspect of successful organizations: the ability to maintain excellence in the face of leadership transition. Richard Kershner retired as head of the Space Department at the end of 1979, and a new set of leaders began to emerge. Delta 180 is an interesting example in that the project manager (John Dassoulas) teamed with a young aerospace systems engineer (Mike D. Griffin). In the scientific area, leadership transferred from Carl Bostrom and eventually to Tom Krimigis. This transition in leadership and the continued demonstration of the ability to tackle critical challenges provided the springboard to the successes of the 1990s and beyond. The transition to Krimigis also proved timely: with the collapse of communism in Europe at the end of the 1980s and early 1990s, interest in and budgetary support for missile defense waned. However, new leadership at NASA was ready for new approaches to conducting space science missions—approaches that perfectly matched the APL space organization's tradition.

REFERENCES

[1] Van Allen, J. A., *Origins of Magnetospheric Physics*, Smithsonian Institution Press, Washington, DC (1983).

[2] Colleagues of R. B. Kershner, "History of the Space Department – The Applied Physics Laboratory – 1958 – 1978," JHU/APL, Laurel, MD (1979).

[3] Holliday, C. T., "Seeing the Earth from 80 Miles Up," *National Geographic* **98**(4), 511–528 (Oct 1950).

[4] Guier, W. H., and Weiffenbach, G. C., "Theoretical Analysis of Doppler Radio Signals from Earth Satellites," *Nature* **181**, 1525–1526 (1958).

[5] Koestler, A., "The Act of Creation," Hutchinson & Co., London (1964).

[6] McClure, F. T., "Satellite Doppler as a Means of Ship Navigation," Memorandum, JHU/APL, Laurel, MD (18 Mar 1958).

[7] Krimigis, S. M., "APL's Space Department after 40 Years: An Overview," *Johns Hopkins APL Tech. Dig.* **20**(4), 467–476 (1999).

[8] "Fine Line of Time: Experiment at Longitude Zero," *APL News*, JHU/APL, Laurel, MD (Jul 1969).

[9] "United States Nuclear Tests, July 1945 through September 1992," DE95006143, U.S. Department of Energy, Washington, DC (Dec 1994).

[10] Ebert, W. L., and Hoffman, E. J., "Quality and Reliability: APL's Key to Mission Success," *Johns Hopkins APL Tech. Dig.* **20**(4), 496–506 (1999).

[11] Zmuda, A. J., Heuring, F. T., and Martin, J. H., "Dayside Magnetic Disturbances at 1100 Kilometers in the Auroral Oval," *J. Geophys. Res.* **72**(3), 1115–1117 (1967).

[12] Krimigis, S. M., Van Allen, J. A., and Armstrong, T. P., "Simultaneous Observations of Solar Protons Inside and Outside the Magnetosphere," *Phys. Rev. Lett.* **18**(26), 1204–1207 (1967).

[13] Vetter, J. R., "The Evolution of Earth Gravitational Models Used in Astrodynamics," *Johns Hopkins APL Tech. Dig.* **15**(4), 319–335 (1994).

[14] Monaldo, F., "TOPEX Ionospheric Height Correction Precision Estimated from Prelaunch Test Results," *IEEE Trans. Geosci. Remote Sens.* **31**(2), 371–375 (1993).

[15] "The Oceanography Report," *Eos* **69**(31) (2 Aug 1988).

[16] Dassoulas, J., and Griffin, M. D., "The Creation of the Delta 180 Program and Its Follow-ons," *Johns Hopkins APL Tech. Dig.* **11**(1 and 2), 86–96 (1990).

Glen H. Fountain, Space Exploration Sector, Johns Hopkins University Applied Physics Laboratory, Laurel, MD

Glen Fountain is a program manager in APL's Space Exploration Sector. He received B.S. and M.S. degrees in electrical engineering from Kansas State University in 1965 and 1966, respectively, and joined APL in 1966. During his early career, he was a member of APL's technical staff that developed a number of space missions for both DoD and NASA. From 1974 on, he has held a number of line and project management positions in APL's Space Department (now Space Exploration Sector). From 2004 through 2015, he was the project manager of the New Horizons mission to Pluto, which launched in January 2006 and made observations of the Pluto system in 2015. He has been recognized for his work in various ways, among them the AIAA Von Braun Award for outstanding space program management (2007), NASA Exceptional Public Service Medals (2008, 2016), and the Space X/AIAA Award for technical excellence (2015). His e-mail address is glen.fountain@jhuapl.edu.

David Kusnierkiewicz, Space Exploration Sector, Johns Hopkins University Applied Physics Laboratory, Laurel, MD

David Kusnierkiewicz has worked in APL's Space Exploration Sector since 1983. He has designed and built hardware for many NASA and DoD space missions and was the mission systems engineer for the New Horizons mission until postlaunch commissioning in 2006. He is also the mission systems engineer for the NASA TIMED mission that has been operating in low Earth orbit since launch in 2001. He has been the chief engineer of the sector since 2004. He received bachelor's and master's degrees in electrical engineering from the University of Michigan in 1976 and 1982, respectively. His e-mail address is dave.kusnierkiewicz@jhuapl.edu.

Stamatios M. Krimigis, Space Exploration Sector, Johns Hopkins University Applied Physics Laboratory, Laurel, MD

Stamatios Krimigis is emeritus head of APL's Space Exploration Sector; occupies the Chair of Science of Space at the Academy of Athens; and is principal investigator on NASA's Voyagers 1 and 2 and the Cassini–Huygens missions. He received a Ph.D. in physics from the University of Iowa (1965) and served on the faculty. He joined APL in 1968, becoming chief scientist (1980), Space Department head (1991), and emeritus head (2004). He has built instruments that have flown to all planets in our solar system, beginning with Mariner 4 to Mars in 1965. He has published nearly 600 papers in peer-reviewed journals and books. He is a three-time recipient of NASA's Exceptional Scientific Achievement Medal, the European Geophysical Union's Cassini Medal (2014), the American Institute of Aeronautics and Astronautics Van Allen Space Environments Medal (2014), the National Air and Space Museum (NASM) Trophy for Lifetime Achievement (2015), the American Astronautical Society Space Flight Award (2016), the NASM Trophy for Current Achievement (New Horizons Team, 2016), and the NASA Distinguished Public Service Medal in 2016. His e-mail address is tom.krimigis@jhuapl.edu.