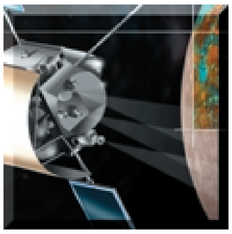

APL's Space Department After 40 Years: An Overview

Stamatios M. Krimigis

The APL Space Department came into being in 1959 to implement the APL-invented global satellite navigation concept for the Navy. The Transit System compiled unparalleled availability and reliability records. Space engineering "firsts" spawned by Transit have constituted standard designs for spacecraft systems ever since. By the mid-1960s, missions were designed to perform geodesy investigations for NASA and, later, astronomy and radiation experiments. In the 1970s, space science missions began to transform the Department from an engineering to a science-oriented organization. The program for ballistic missile defense in the mid-1980s became the principal focus of the Department's work with overlapping engineering and applied science activity, and lasted through the early 1990s. After the Cold War, science missions in both planetary and Sun–Earth connections plus experiments on NASA spacecraft shifted the projects from some 70% DoD to about 70% NASA. The unique blend of world-class science and instrumentation combined with innovative engineering represents a powerful combination that augurs well for the future of the Space Department. (Keywords: History, Space Department, Space science, Space technology.)

EARLY HISTORY

The Space Department was officially established by memorandum on 24 December 1959 as the Space Development Division, approximately 3 months after the failed launch of Transit 1A on 17 September 1959.[1] Dr. Richard B. Kershner was appointed supervisor of the division, with Theodore Wyatt as project engineer for Transit. One could argue, however, that the intellectual seeds for the new division go back to 1946, when a small group of scientists at APL under the leadership of James A. Van Allen (of the Van Allen radiation belts) began instrumenting a number of captured German V2 rockets with experiments that included cameras, visible and near-infrared spectrometers, and Geiger-Mueller counters, with the objective of measuring various spectral lines and the intensity of primary cosmic radiation as it was attenuated through the Earth's atmosphere.[2] Van Allen's group also obtained a number of detailed photographs of the visible and near-infrared surface of Earth and its cloud cover that showed for the first time the curvature of the Earth. This high-altitude research was eventually incorporated into the APL Research Center, which had been established in 1947 by Lawrence Hafstad, then director of APL. The research continued with the development of the Aerobee rocket, which was transferred to industry and became the principal sounding rocket research tool for many groups in the United States until the program was terminated in 1985. After Van Allen's departure in December 1950 to assume the leadership of the Department of Physics and Astronomy at the University of Iowa (more on this to follow), activity relating to space did not exist at the Laboratory until the rude awakening of the entire country following the launch of Sputnik on 4 October 1957.

The acquisition of Doppler data from Sputnik by Guier and Weiffenbach[3] and the subsequent formulation of the satellite navigation concept[4] gave rise to the Transit Program and made it necessary to establish a division within which the engineering development and implementation would take place. Thus came into being, 40 years ago, what we now call the Space Department. These early activities are illustrated schematically in Fig. 1.

The task undertaken by the new department was nothing short of revolutionary. For the previous 4000 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 established the principal characteristics that have 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 costs. They did so while establishing a host of technological "firsts" that have since been used routinely by the satellite industry 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.[5] It is not my intent here to give a detailed description of the excitement and enthusiasm of our colleagues, who knew that they were making history. They were a very talented bunch, and they have described their experiences in several specialized publications (see, e.g., Ref. 6 and the article by Bostrom, this issue). Rather, my purpose is to point out that Transit formed the foundation of our technology and management culture on which much of what we do today is based.

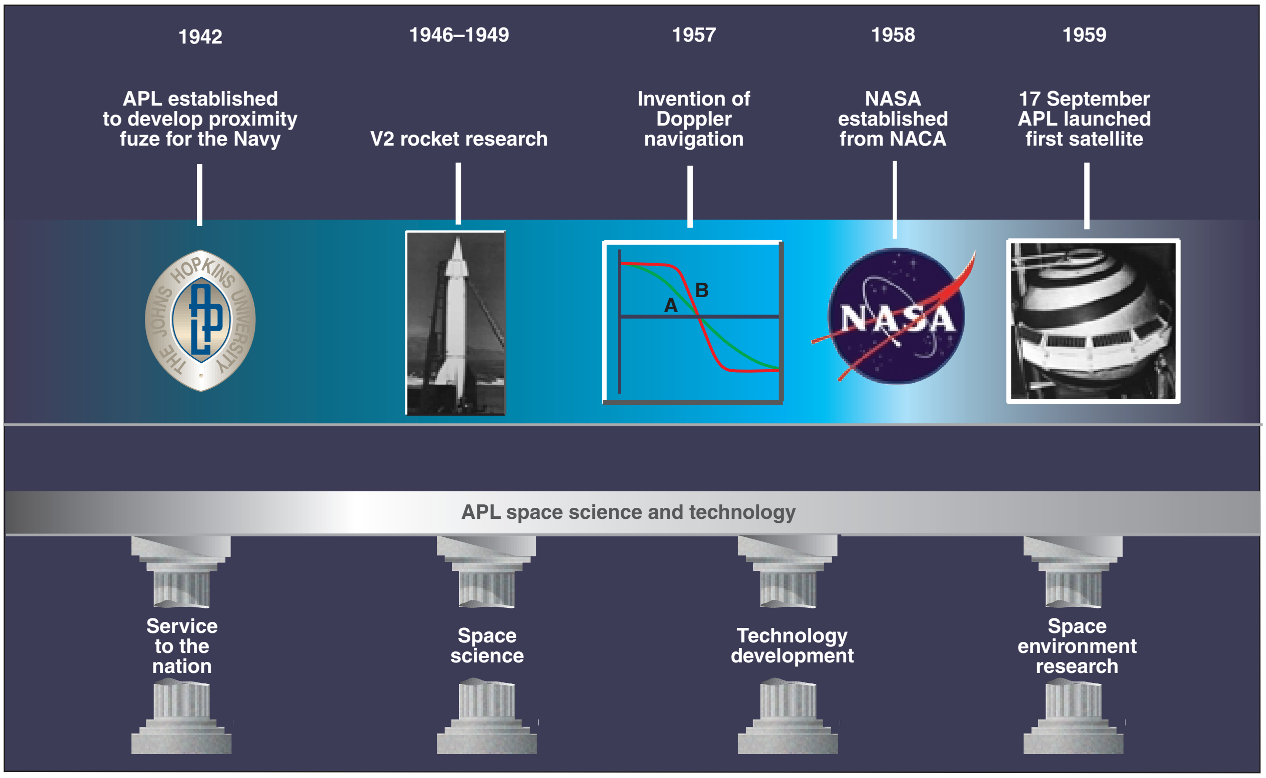

Figure 1. The evolution of space science and technology at APL: The pioneering years.

SEEDS OF THE SCIENCE ACTIVITY

The Space Department, coming out of the Transit program in the late 1960s, was a first-class engineering, technical, and management organization, with some elements of science that were necessary for assessing the space environment for an operational satellite system. The principal navigation problem having been solved, Navy support began to decline significantly while interest by other agencies, principally NASA, with a need for an experienced organization to implement science and applications programs, started to increase. Thus, while we continued to upgrade the accuracy of the navigation system and to improve the technology, that level of effort was not sufficient to maintain and improve the capabilities of the staff in engineering development.

It was in the mid-1960s that work for NASA started, understandably in the area of geodesy. The Geodetic Earth Orbiting Satellites (GEOS-A and -B), launched in 1965 and 1968, respectively, were the first NASA spacecraft to employ gravity gradient stabilization. They fulfilled all their science objectives, including measurements of Earth's gravity field to 5 parts in 10^8. These geodetic missions were followed by the launch of GEOS-C in 1975, the first full-fledged ocean radar altimeter mission, which operated for over 3 years and mapped the topography of the ocean surface to an accuracy of 50 cm. GEOS-C was followed by the Laboratory's work on the Seasat mission ocean altimeter and also on the synthetic aperture radar, which were flown on that spacecraft in 1978. A detailed survey of the Earth's magnetic field came next when the Magsat satellite, which used, for the first time, a set of microprocessors for the attitude and command systems, was flown in October 1979.

On another track, work related to radiation investigations and astronomical research began to take shape in the Department. Initially, some particle instruments were selected and flown on NASA spacecraft such as Interplanetary Monitoring Platform (IMP-4 and -5), but eventually a larger-scale program was undertaken for the Goddard Space Flight Center (GSFC) to design and implement the Small Astronomy Satellite series, SAS-1, -2, and -3. The first of these flew in December 1970 and proved a resounding success by identifying a large of number of X-ray sources, the first such survey of the X-ray sky from space. Subsequent missions performed the first gamma ray survey (SAS-2, 1972) and detailed investigation of the spectral characteristics of X-ray sources (SAS-3, 1975). This period is shown schematically in Fig. 2.

SCIENCE'S COMING OF AGE

Through the 1970s a subtle transformation began to take place in the mix of work taken up by the Space Science Branch in the Department. In the competition for investigations for what was then called the Outer

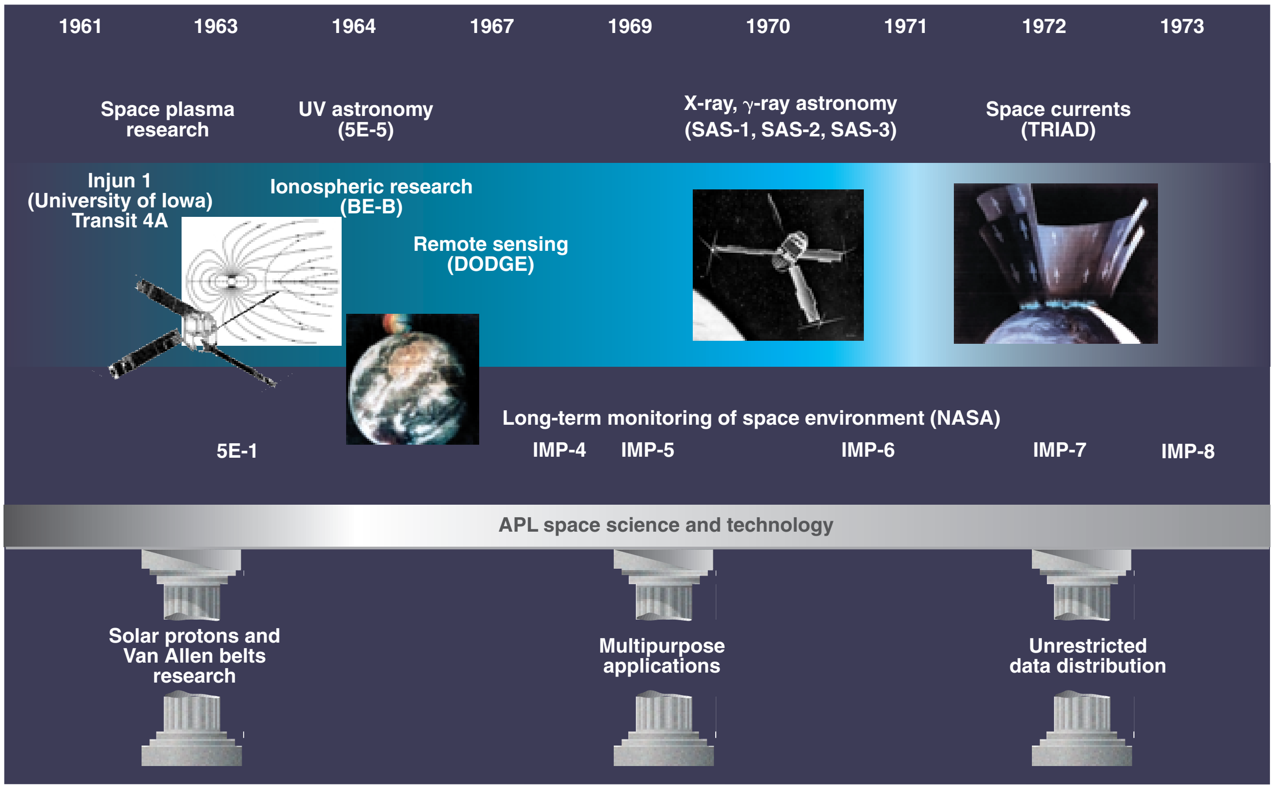

Figure 2. The evolution of space science and technology at APL: The discovery years.

Planets Grand Tour missions, we were selected in 1971 to build the Low Energy Charged Particle (LECP) instruments, which were flown on what were subsequently called the Voyager 1 and 2 spacecraft launched to the outer planets in 1977 and still operating. Also, the Department was selected to build the instruments for the Galileo Jupiter orbiter (also still operating) and the particle instruments on the Ulysses spacecraft, which was to investigate the solar wind outside the ecliptic plane for the first time. Furthermore, a program that involved the first artificial plasma releases in the solar wind was selected in a consortium led by the Department which included, as principal partner, the Max-Planck Institute for Extraterrestrial Physics in Garching, Germany. The Active Magnetospheric Particle Tracer Explorers (AMPTE) program became a first in the Department in that it involved building a spacecraft whose principal purpose was not to test new technology but rather to perform an experiment in space science that addressed some of the basic questions on the interaction of a plasma with the solar wind and the formation of cometary tails. It was also the first time we had proposed and won a total "end-to-end" mission where the science, engineering, instrument development, launch operations, mission operations, and analyses and publications were undertaken as an entire entity.

The AMPTE mission marked the coming of age of space science activity in the Department in that our exceptional engineering talents and capabilities were focused on implementing a science program that was endeavoring to accomplish a large number of "first-ever" measurements in space plasma research. The program created a new paradigm within NASA space science, whereby a single investigator group undertook the implementation of a well-focused science mission and was given wide latitude in the manner in which the mission was to be implemented. The Office of Space Science at NASA today has adopted this mode of program implementation for both its Discovery and Explorer missions (more on that later). This development came none to soon in the history of the Department since directed programs from government agencies to the Laboratory were not readily available and maintenance of the core capabilities of the staff and the skills necessary to perform an end-to-end mission were coming under severe pressure.

The Space Department (and APL) has always excelled in identifying missions and solutions to problems and then persuading sponsors that these represent the best investments for the difficult-to-come-by research and development funds. The decade of the 1980s was no exception. Following the premature failure of the Seasat spacecraft in 1978, the requirement continued to exist for improved knowledge of Earth's geoid, which was to have been obtained by the altimeter on that mission and was to be used by the Navy. The Space Department persuaded the Navy that an inexpensive mission could be designed and implemented in less than 3 years and would provide the data that the Navy so desperately needed. Thus came the Geosat mission, undertaken by the Laboratory in 1982 and flown in 1985. It lasted far beyond its design life of 18 months and provided the world's oceanographic community with the first continuous and comprehensive set of altimeter data, including the observation of the movement of waters from the eastern to the western Pacific during El Niño development.

While all of this activity was going on in the early 1980s, smaller programs were also thriving. The refurbished navigation satellite bus that became the HILAT mission sponsored by the Defense Nuclear Agency (DNA) was launched in 1983 and obtained the first daylight pictures of the aurora using an ultraviolet (UV) imager.[7] A follow-on mission was distinguished by the fact that the spacecraft bus was retrieved from the Smithsonian Institution after a 15-year stay and was refurbished and flown with a full instrument suite in 1987. The Polar BEAR spacecraft was highly successful for the following 3 years in obtaining a large number of very special measurements, including multispectral auroral images. Both instances illustrate how the legacy of the Transit program continued to pay dividends for the Department. The reason was that the original set of navigation satellites had been lasting much longer (mean-time-to-failure of 14 years) than initially predicted; consequently, those spacecraft that were intended to replace them in orbit were languishing in their storage containers, and it became possible to refurbish the bus and perform other missions for the Air Force and DNA. When the Navy demurred from releasing the last two spares, the use of the satellite exhibited in the Air & Space Museum became an obvious answer to performing the Polar BEAR mission for the Air Force. A wooden model is now hanging in the Smithsonian in its place. A summary of this period is shown schematically in Fig. 3.

EXPERIMENTS IN STRATEGIC DEFENSE

The propensity for innovation could not have served us better during the mid-1980s, when it became evident that the AMPTE and Geosat programs would not be sufficient to sustain the organization for the rest of the decade. The Strategic Defense Initiative (SDI) concept, enunciated by President Reagan in 1983, gave rise to a nationwide discussion on the feasibility of such a program and necessitated a demonstration that it is possible to have two thrusting objects in space collide with each other. This emerging national priority became the testing ground where people with

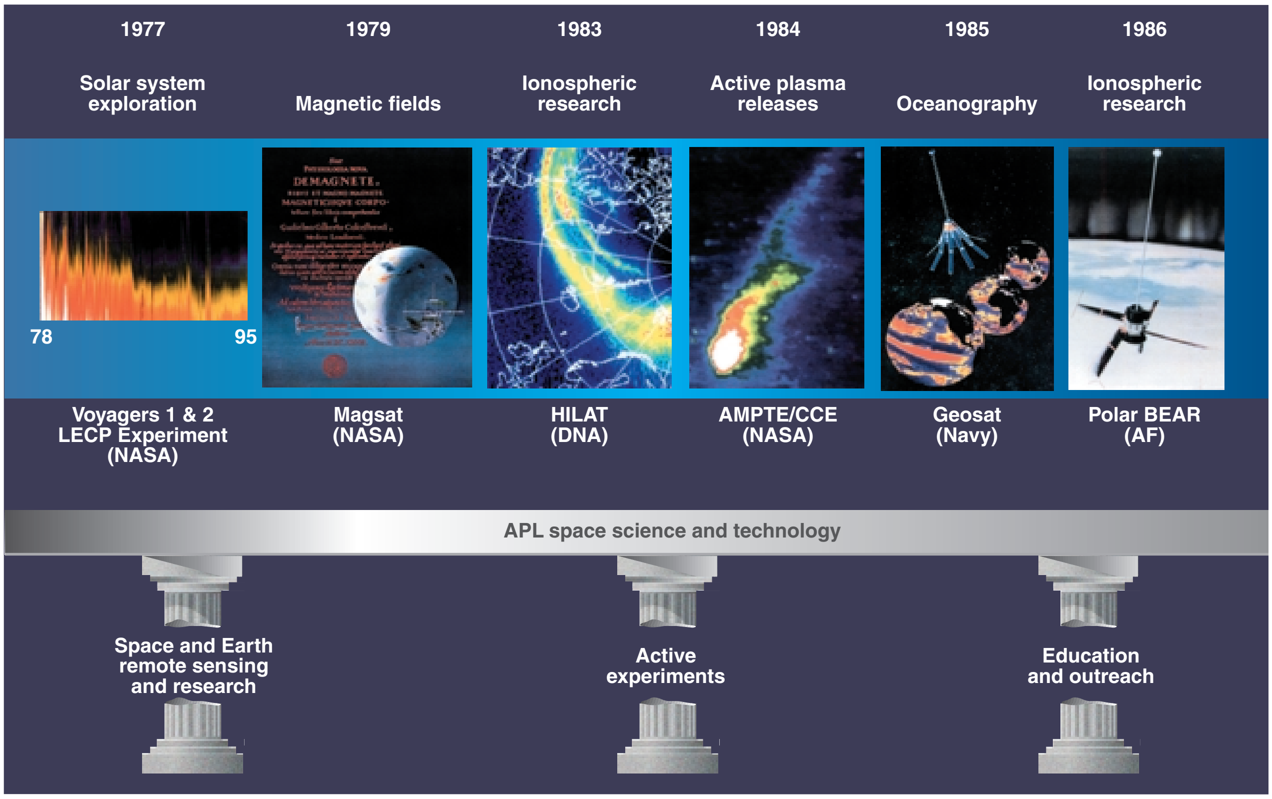

Figure 3. The evolution of space science and technology at APL: The developing years.

innovative ideas, sound judgement, skills, and daring could have a decisive influence on the outcome of a national debate.

The Space Department's imaginative plan for what became known as the Delta 180 mission was put together by John Dassoulas, Mike Griffin, and their team. Under the leadership of then SDI Director General Abrahamson and Colonel (now retired three-star General) Malcolm O'Neil, the program initiated a new era of intense technical and system engineering activity that served the Department and the country well through the late 1980s and into the end of the Cold War. The Delta 180 mission was implemented within a year from inception, was spectacularly successful, and generated some unique and surprising information on rocket plumes as seen in the UV part of the spectrum. The 1986 accomplishment was followed by a "sensors" mission named Delta 181 that flew in 1988 and, eventually, by a "surveillance" mission called Delta 183 that was flown in 1989. All three missions won high praise from their sponsors and the at-large community for their combination of technical excellence, programmatic flexibility, cost performance, and speed of implementation.

By the end of the 1980s our activities were dominated to a large extent by work for the SDI Organization, mostly in engineering a new mission that came to be known as the Midcourse Space Experiment (MSX). The technological leap forward represented by MSX has been detailed elsewhere.[8] MSX was a technology-intensive program that honed our design and engineering skills and necessitated the contemporaneous development of new technologies not flown previously on any civilian or DoD spacecraft. A most notable innovation was the inclusion of hyperspectral imagers and spectrometers that have produced unique data since the 24 April 1996 launch and have yet to be duplicated by any of the current or forthcoming missions. Throughout this period, additional science instruments were being designed and flown not only on planetary (Galileo) and heliospheric (Ulysses) missions but also on Earth-orbiting spacecraft such as Upper Atmosphere Research Satellite (UARS) and Geotail. The space science activity in the Department had grown substantially from a handful of researchers in the early 1960s to a strong and vibrant branch of over 50 people who were able to compete and win many first-class investigations on NASA and DoD missions. Their publications constituted a significant (several percent) fraction of the refereed literature in the field of space plasma physics. This period is summarized schematically in Fig. 4.

ERA OF MORE SCIENCE MISSIONS

With the end of the Cold War in 1991, the SDI mission begun to lose its priority and the emphasis on space-based defenses was basically abandoned. It became clear that our activities had to be refocused into areas that were directed more toward the nation's basic science enterprise in space. Such work and projects were already well under way. Together with the California Institute of Technology and the University of Maryland, we had spearheaded a new program as a follow-on to the detailed plasma composition measurements of the magnetosphere performed with AMPTE, but this time with emphasis on detailed composition and isotopic measurements of the solar wind, solar energetic particles, and cosmic rays under the name of Advanced Composition Explorer (ACE). This mission was competitively selected by NASA in 1986 and was under study by 1989, at which time a final selection was made to proceed with implementation in the early 1990s. The ACE mission was to follow the AMPTE model with a single principal investigator (Dr. Edward Stone of the California Institute of Technology) and a number of lead investigators who were to design and supply the instruments. The Department was responsible for designing and building the spacecraft bus as well as two of its nine instruments.

Meanwhile, the 1980s had been a virtual wasteland for the nation's planetary exploration program. The plan to encounter comet Haley during its perihelion in 1986 was scrapped, the Galileo mission to Jupiter had been repeatedly delayed, and the Planetary Observer Program, the first of which was to be Mars Observer, had exceeded its original cost goals of approximately $200 million per mission and was substantially delayed and marching toward a cost of over $500 million. By the late 1980s it was clear that a new strategy was required. The Solar System Exploration leadership at NASA Headquarters, together with the science community, decided to initiate a series of workshops that were intended to develop a new strategy for the program. As part of the strategy, it was decided to reexamine the issue of having a small, low-cost, fast-paced program that would use techniques other than those traditionally employed in planetary missions. Out of the 1989 workshop came a science working group that eventually formulated the definition of the Discovery program. The legacy of the AMPTE mission and the paradigm of the ACE study performed at the Laboratory served as examples for the definition of the Discovery program. The Department was asked by NASA to do a feasibility study for a near-Earth asteroid rendezvous mission (NEAR) that had been previously studied by the Jet Propulsion Laboratory (JPL) as a follow-on to Mars Observer and estimated to cost a similar amount (about $500 million).

NASA funded competing studies at APL and JPL on the definition for this mission, with a requirement for a total cost not to exceed $150 million in FY92 dollars. Both studies were completed by May 1991 and presented at the meeting of the NASA-appointed ad hoc Science Definition Team. The studies had reached strikingly

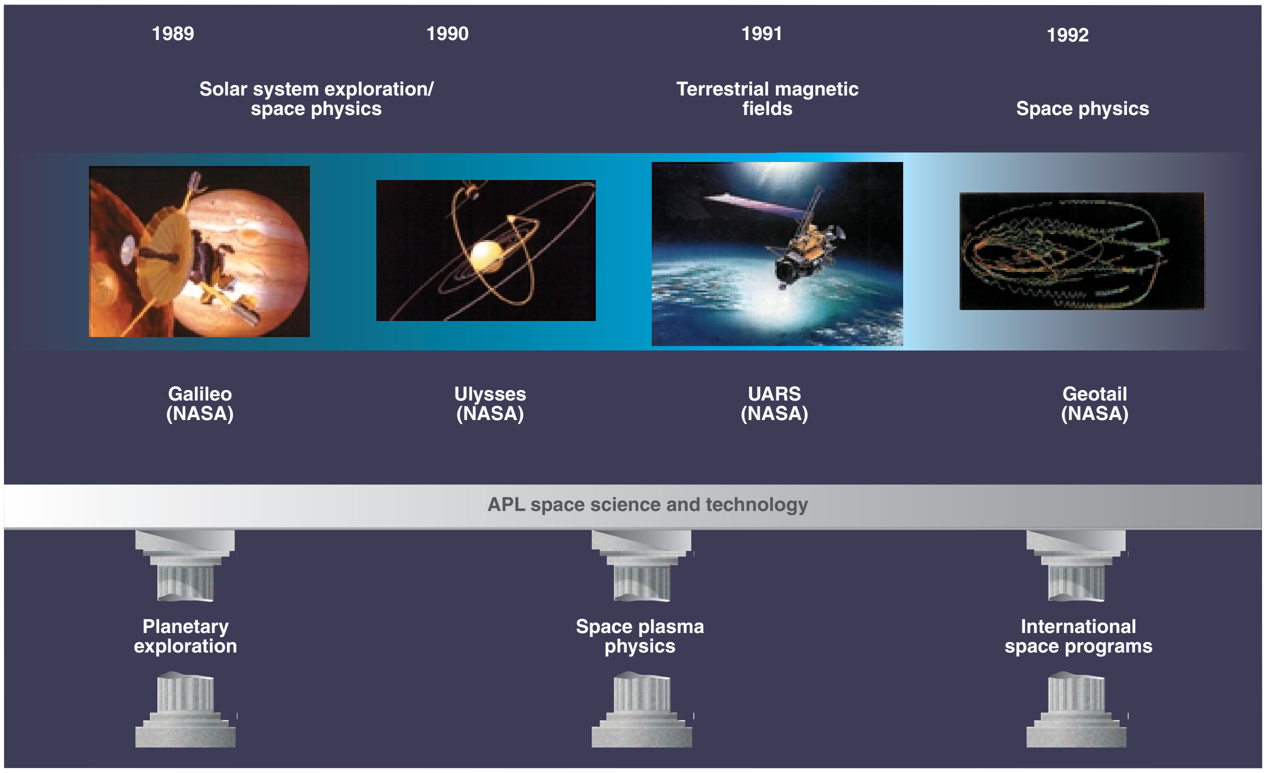

Figure 4. The evolution of space science and technology at APL: Active programs, 1989–1992.

different conclusions: the APL study estimated that the NEAR mission could be done for about $110 million, while the JPL study concluded that is was impossible to have such a mission for the $150 million cap set by NASA. By early 1992, NASA had decided to select another mission (the Mars Environmental Survey [MESUR] Pathfinder) that had been studied at the Ames Research Center as the first Discovery mission, and assigned JPL as the NASA center to implement it. At the same time NASA informed APL that NEAR would be the second Discovery mission and would be implemented by the Space Department with launch in 1998 to rendezvous with the asteroid Eros. The evolution of NEAR to become the first Discovery mission and the details of the initiation of the Discovery program are given elsewhere.[9] This last period in the Department's activities is shown schematically in Fig. 5.

The principal point here is that in the early 1990s the Space Department's activities were transformed from an 80% share supported by SDI/Ballistic Missile Defense Organization (BMDO) to approximately 70% supported by NASA, mostly as a result of the ACE and the NEAR flight missions. It was a remarkably rapid transition between FY93 and FY94, but one whose seeds had actually been planted in the mid-to-late 1980s and coincidentally bore fruit at a time when we needed a new set of sponsors and a different complexion in the mission suite. The arrival of the TIMED (Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics) program in the mid-1990s, the first of the Solar Terrestrial Probe missions, again with a capped cost of approximately $100 million in FY94 dollars and intended to emulate the Discovery paradigm, completed the transition. Thus, the APL Space Department is now firmly established as a major national resource in the conduct of the nation's space science program.

DISCUSSION

I have endeavored to paint a picture of an organization that began as an enthusiastic group of pioneers awed by the dawn of a new technology age some 40 years ago and matured into an organization that has become a science and engineering enterprise of the highest caliber. It all began with the Transit all-weather global navigation system. That system helped propel America into the space age, sparking a large number of firsts in space engineering, technology, and science, and led to the eventual development of today's Global Positioning System. Transit formed the foundation of what we are and what we do in the Space Department today. The remarkably short time from initial concept to operational availability was achieved by a group of professionals who were able to design, build, launch, and operate some 20 spacecraft (7 of which did not reach orbit) in approximately 4 years. Such an accomplishment is thought to be impossible today, the intervening 40 years of technological progress

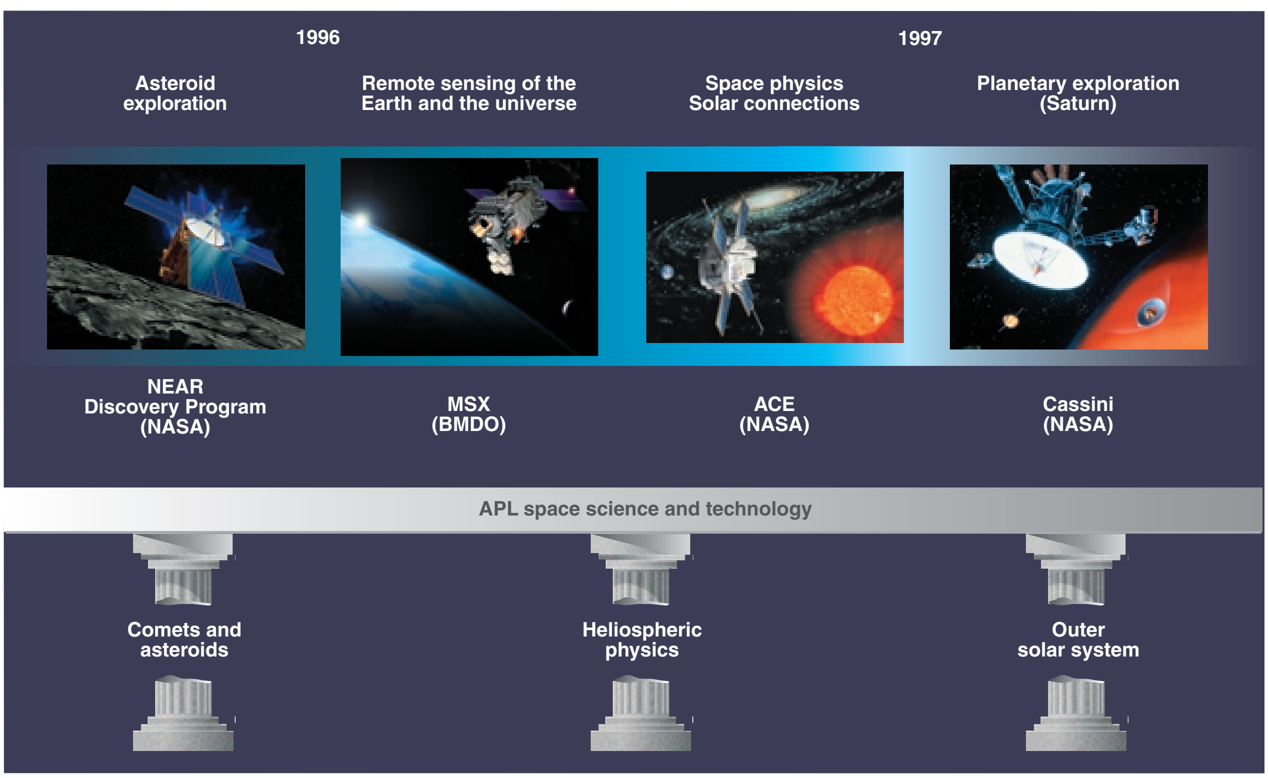

Figure 5. The evolution of space science and technology at APL: Active programs, 1996–1997.

notwithstanding. Once the Transit navigation system was declared operational, the technology developed and its implementation were transferred to industry, an objective that again set a paradigm for a principal endeavor of many national laboratories today. It is the legacy of invention, innovation, risk taking, diversity, and versatility of the Transit pioneers that formed the Department's culture and guides us in our work.

The early years were clearly characterized by engineering innovation, with only that degree of science necessary to implement an operational system. During the late 1960s and early 1970s, the seeds of science "for science's sake" had been planted and our work evolved to support science missions, whether in-house or from NASA. However, the Department remained solidly an engineering organization rooted to its history and in service of the nation's security needs as a principal and overriding thrust. It was in the late 1970s and early 1980s that science activity in the Department came of age, in the sense that it evolved from isolated instruments and experiments on various missions to addressing significant scientific problems that could be tested by the implementation of an entire mission, including spacecraft, instruments, data analyses, and publication.

While all of this was going on, quite successfully, the issue of strategic defense against nuclear attack became an overriding national priority with space as a significant, or even dominant, component. Once again we were called upon to implement innovative, one-of-a-kind experiments that provided the basis for addressing the many issues that arose in the national debate on the feasibility of strategic defense. The end of the Cold War found the Department still engaged in high-technology spacecraft designed to address a host of technical issues associated with observing moving objects in space, through the MSX Observatory.

At the same time, a number of initiatives undertaken in the 1980s bore fruit, and we found ourselves implementing a mission not only to study the composition of galactic and solar matter with unprecedented precision through the ACE mission but also to demonstrate a new paradigm for the NASA planetary program: whether it was possible to design and implement a planetary mission whose costs would be at least 3 times lower than what had been achieved previously and doing it all with a schedule that could not exceed 36 months. It was clear that the era of "better, faster, cheaper" on a national scale was upon us, and no organization was better prepared to seize the moment than the Space Department. We had been at the forefront of the "better, faster, cheaper" methodology for our entire existence as an organization. The NEAR mission has been a great success so far and was acknowledged as such by the science and technology communities as articulated by the NASA administrator when he visited APL on 15 April 1996, following the successful launch and initial operations of NEAR. I quote some of his words: "You have really blazed the trail. I believe APL is one of the most outstanding, can-do organizations in the world, and an organization is nothing more than the people and the leadership. In essence, we put into your hands the future of the planetary program at NASA."

Today the Space Department finds itself in the position of having been selected for not only the Comet Nucleus Tour (CONTOUR) Discovery mission to be launched in 2002 but also the MESSENGER mission, which is to orbit the planet Mercury in 2009 and is scheduled for a launch in 2004. Furthermore, the Department is leading the implementation of the Stereoscopic Solar Terrestrial Relations Observatory (STEREO) mission for NASA/GSFC with an anticipated launch in late 2003. Thus, the future of the Department (summarized in Fig. 6) in NASA space science investigations is firmly established.

That does not imply, of course, that our enthusiasm for national security programs is at all diminished. We are participating in the Discoverer II program with the Defense Advanced Research Projects Agency (DARPA) and other agencies, and continue our work with BMDO in a number of technology areas as well as operating the MSX spacecraft for data collection and analyses. We have recently embarked on a new program to link university research with operational support of the services in near-term forecasts of, among other things, ionospheric and magnetospheric "weather." These and other programs continue to elicit significant support among our staff and represent an important thrust of our strategic plan for the future.

Our efforts have been assisted substantially by the advice and guidance we have received over the past few years by an external Advisory Board, constituted in 1992, to assess the scientific and technological scope of current and future programs of the Department. The Board has a rotating membership of nine people serving for 3-year terms (for a two-term maximum), and an effort is made to properly balance the expertise of the members across the diverse projects and activities of the Department. The Board meets annually at the Laboratory and, based on that meeting, submits a report to Department management with its evaluation and recommendations.

In 1999, membership of the Board was Dr. Louis J. Lanzerotti, Chairman (Bell Laboratories); Dr. Carl O. Bostrom (former Director of APL); Dr. Otis B. Brown (University of Miami); VADM Glenwood Clark, Jr., USN (Ret.); Dr. John V. Evans (COMSAT Corporation); Dr. William R. Graham (former Science Advisor to the President); Dr. Gerhard Haerendel (Max Planck Institute for Extraterrestrial Physics); Dr. Bruce Murray (California Institute of Technology); and LTG Malcolm R. O'Neill, USA (Ret.). Previous members have

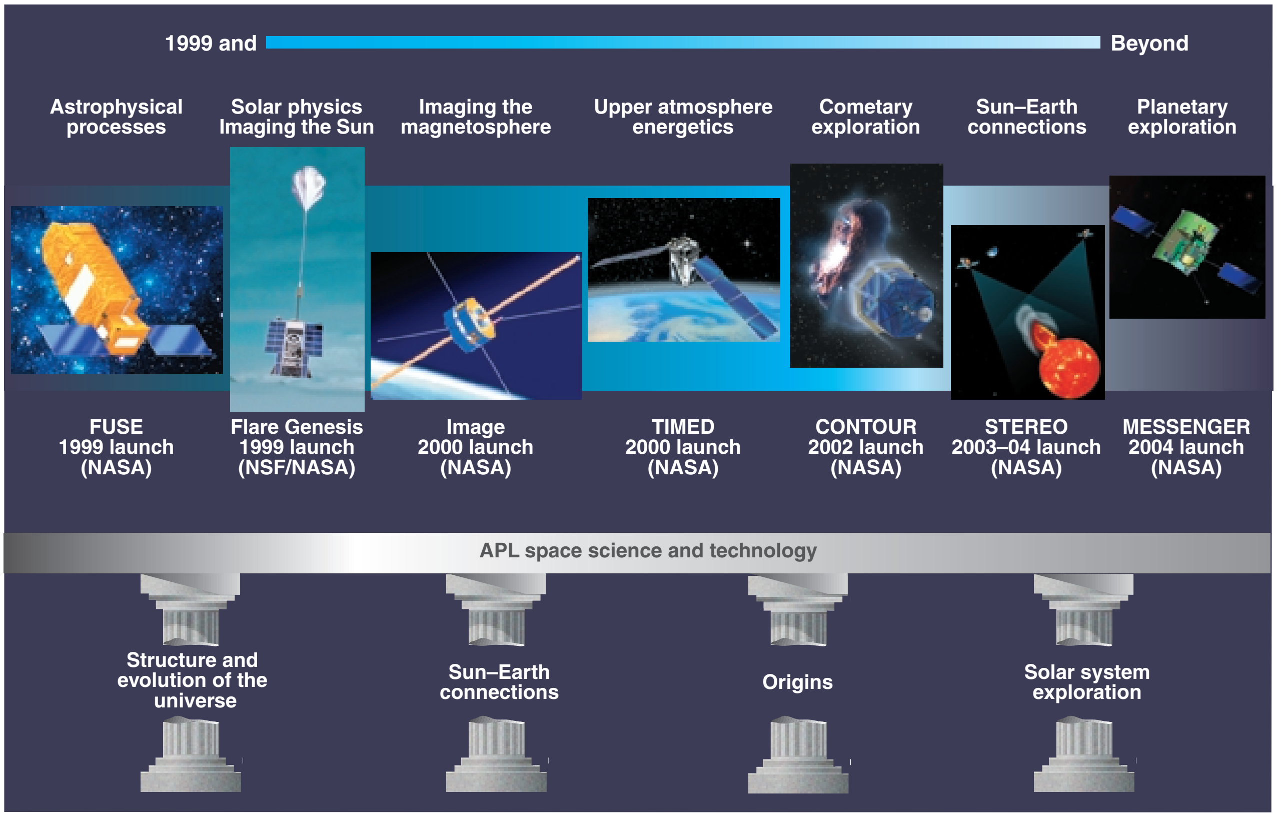

Figure 6. The evolution of space science and technology at APL: The future (1999 and beyond).

included Dr. John W. Townsend (former Director of GSFC), Dr. Frank T. Redd (Utah State University), and RADM Robert K. Geiger (Ret.).

Thanks to the Advisory Board, the Space Department has had the benefit of the collective wisdom of the community and a formal way to gain advice and outside perspective that is hard to obtain in meeting the day-to-day challenges of overseeing such a multifacted set of programs.

I have often been asked whether the Space Department is science or engineering driven. It is difficult to respond to simple questions about a complex organization with a yes or no answer. When it comes to space, science and engineering are inextricably linked. One cannot exist without the other. Engineering enables science, and science provides the purpose for doing the engineering. The Space Department has been able to achieve remarkable coherence in the way the engineering and science activities coexist and thrive. Our colleagues in the outside community often marvel at the degree of "seamless" teaming of our scientists and engineers as we work with other organizations in putting together proposals or implementing missions. This is a paradigm that has been nurtured throughout the years by the legacy of the Transit pioneers, the successes of the technical and scientific endeavors, and the team spirit that has been a hallmark of the APL organization as a whole. The Space Department is a clear example of an organization in which it is possible to do science within what many would have perceived in the past as an engineering culture. Not only is it possible to do science, science actually thrives in the environment that has been created. We are now well positioned to enter the 21st Century and are looking forward to the next 40 years.

On a more personal note, I promised in the introduction that "more would follow" on Van Allen's departure in 1950 to become Department Head of Physics and Astronomy at the University of Iowa. His discovery of Earth's radiation belts in 1959 came about from his instruments on Explorer-1, the first U.S. satellite launched in 1958. He visited the University of Minnesota in 1960, where I was an undergraduate working in the laboratory of Professor John Winckler and building ionization chambers for balloon flights. We struck up a conversation, whereupon he suggested that I apply for graduate school at the University of Iowa. I arrived there in the fall of 1961, and within a year I had started working on data from a University of Iowa satellite, Injun 1, which included the first solid-state radiation detectors flown in space, provided by APL scientists.[10] While doing my master's thesis, I got to know theAPL colleagues (George Pieper, Carl Bostrom, Donald Williams, and the late Al Zmuda) and was persuaded by Bostrom that APL was the place where I should develop my professional career. I have never regretted my decision.

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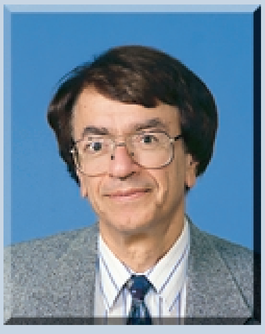
THE AUTHOR



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