Scientific Space Research at APL: Guest Editors' Introduction

Richard W. McEntire and Ching-I. Meng

Basic research in the space sciences at APL dates back to 1946, when Dr. James Van Allen and a small group of scientists launched instrumentation on captured V2 rockets and later, in 1947, on APL-developed Aerobee rockets.[1] The major APL space program, however, began about 10 years later.[2] In 1958 the concept of Doppler satellite navigation was invented in the APL Research Center, and over the next few years the Space Department was established to create the first satellite navigation system.[3,4] It became apparent that designing reliable space systems required an understanding of the space environment, and in 1960 two physicists, Drs. Carl Bostrom and George Pieper, joined the Space Department to measure and conduct basic research on that environment. (It was a promising start—Bostrom later became the fifth Director of APL, and Pieper became Director of Space Sciences at NASA's Goddard Space Flight Center.) Over the next two decades the group they founded grew to over 30 people and launched 40 research instruments on 29 Navy, NOAA, and NASA satellites.

Since then, that initial small research group has grown and split and grown and split many times. The family of APL Space Department groups thus created, all primarily dedicated to performing or supporting basic scientific research in space, now comprises over 150 staff, including 94 Ph.D. scientists and engineers. Research areas range from the Earth (studies of the ocean surface[5–9] and atmosphere,[10–12] as well as ionospheric and magnetospheric particles, fields, currents, and emissions[12–18]) to the surface of the Sun,[19] to the inner and outer planets,[20–24] and all of the space between to the outer edges of the solar system.[23] When missions currently under way are completed, scientific instruments designed, built, and operated by APL scientists and engineers will have flown by, or orbited, and returned scientific data from every planet in the solar system, several asteroids, and the Kuiper Belt. This is an amazing, and nearly unique, record—and one of which to be very proud!

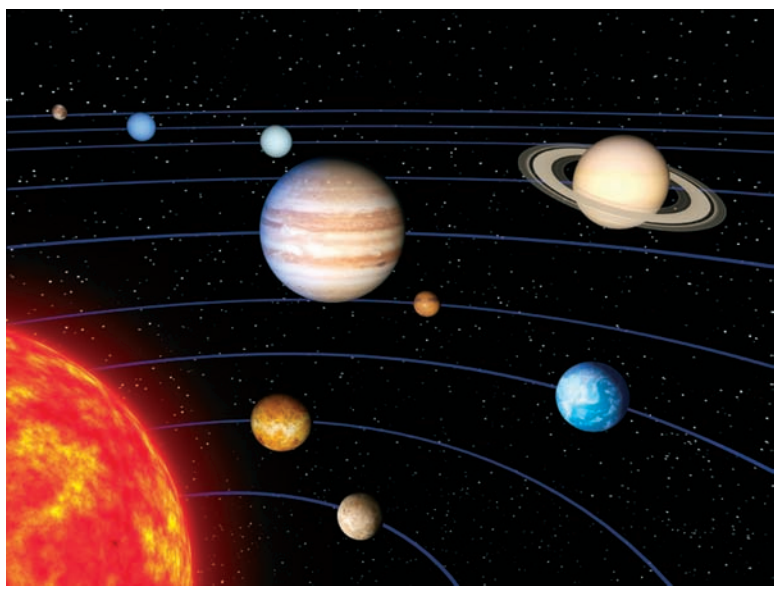
The APL Space Department's research interests and breadth of expertise have expanded with the nation's space program. We started with many missions to measure and understand our home environment, including energetic particles and magnetic fields around the Earth (the Van Allen belts and beyond). This led outward to studies of energetic particles in the huge magnetospheres of the outer planets and particle acceleration at the Sun and in the interplanetary environment (the heliosphere). It also led inward to optical and radar remote sensing and *in situ* measurements of energetic particles, fields, and currents in the Earth's aurora, ionosphere, and upper atmosphere. In recent years we developed remote sensing techniques to image energetic particle populations inside planetary magnetospheres and are now doing so on the NASA IMAGE mission at Earth and the Cassini mission at Saturn. APL space scientists have also played a major role in integrating existing knowledge and new missions into plans for the new, overarching NASA and NSF field of "space weather"—with the ultimate goal of being able to predict major energetic particle events (and their effects) from the Sun, in interplanetary space, and in the Earth's environment. Also in recent years we have undertaken a very active research effort in planetary science focusing on the formation and evolution of asteroids, moons, and planetary surfaces. This effort started with the NEAR mission which orbited (and then landed on) the near-Earth asteroid Eros.[20,21] Now, however, APL planetary scientists are deeply involved in missions (and planning for new missions) to Mercury, the Earth's Moon, Mars, Jupiter, Saturn, Pluto, and throughout the solar system.

All of this basic research is primarily supported by NASA scientific space missions (for which we are competitively chosen) and by roughly 100 research grants from NASA, NSF, and other government funding sources. Our ultimate product is new scientific knowledge that is communicated in over 450 research papers and publications per year. This special issue of the *Technical Digest* is intended to give a snapshot of some of APL's interesting ongoing research, covering a range of topics from ice on the Earth, to the surface of the Sun, to planetary magnetospheres, to planetary atmospheric winds, and back to ice again throughout the solar system.

In the first article Monaldo et al. describe an important area of research: ocean wind field mapping from space. They lay out the basic principles whereby satellite-based radar can make remote measurements of wind speed near the ocean surface. They then describe a system they have developed that can use near-real-time satellite synthetic aperture radar data to create high-resolution maps of ocean surface winds, particularly in coastal areas. The authors illustrate the importance of this capability with two examples: scientific studies of the dynamics of coastal wind fields near complex terrain and practical applications in wind power generation.

Leuschen and Raney then describe initial results from airborne surface height data collected with the APL Delay Doppler (D2P) radar over land ice and sea ice. Data from satellite-based altimeters are essential to understanding long-term trends in the Earth's ice cover. There are, however, important differences in heights measured over ice and snow between laser and radar altimeters. These differences are related to snow cover and surface conditions, and campaigns with the APL airborne radar are helping us understand these differences. It is important to be able to accurately monitor long-term changes in ice sheet thicknesses, since such changes seem to be under way and have major implications for future climate and sea-level changes.

In the next article Rust et al. describe work by the APL solar research team leading toward the prediction of solar flares and the huge associated coronal mass ejections that can cause very violent "space weather" at the Earth or wherever spacecraft or astronauts go. They have developed both empirical methods and complex physics-based tools in an effort to improve the reliability of predictions. In the near future, new data sources, such as the dual spacecraft of the NASA/APL STEREO mission, should allow major improvements in real-time forecasts of both solar activity and the resulting space weather.



APL scientific instruments have flown or are flying to every planet in the solar system (illustration by Richard Freas).

Bernasconi et al. then describe the experimental foundation of the APL observational solar research program and recent scientific advances that have been made using these observations. With funding from NASA and NSF, they have developed two different types of balloon-borne telescopic imaging sensors: one is capable of imaging with high-resolution temperature variations across the visible surface of the Sun and the other can image the vector magnetic field above and emerging from this surface. Their instruments have scored a number of solar "firsts," and the data have made possible scientific advances in understanding solar active regions and solar flares in addition to possible sources of variations in solar output. The next balloon flight in December 2006, and possible future balloon and satellite missions, will be important to our knowledge about solar dynamics.

The magnetosphere around an astrophysical body is that volume of space in which the internal magnetic field of the body is dominant, rather than any external magnetic field. Energetic neutral atom (ENA) imaging is a relatively new and important technique in space physics research. It enables, for the first time, remote global imaging of the dynamics of the huge volume of hot plasmas and energetic ions in planetary magnetospheres, and also at the boundaries of the heliosphere. ENA imaging began with the realization that some energetic nuclei detected escaping from the Earth's magnetosphere were able to do so because they had been neutralized in charge-exchange interactions with the Earth's very thin extended atmosphere, and that these ENAs could allow remote imaging of their source populations. The first ENA image was published by an APL scientist.[25] Subsequent experimental and theoretical development, at the Laboratory and elsewhere, has resulted in specifically designed ENA telescopes in orbit around the Earth and flying to Mars, Jupiter, and Saturn. APL is perhaps the world leader in this area of research, and Brandt et al. describe the history, evolution, and results of the technique.

Paranicas et al. discuss the general area of space physics studies of planetary magnetospheres and heliospheric boundaries. In so doing, they extend the ENA imaging discussion of Brandt et al. to include other remote observation techniques and results. The authors describe the different solar system magnetospheres that have been explored (often, in major part, by APL instruments), their topology, the sources of their enclosed plasmas and energetic particles, and the impact of these particles on lunar and planetary surfaces.

Space and planetary scientists at APL are deeply involved in comparative studies of physical processes in the different planetary environments in the solar system. We can model many of the processes that are important at Earth, and as more data have become available from the other planets we are able to expand and test those models under quite different conditions. The result has often been an increased understanding of these physical processes, including an understanding of how the processes operate at Earth. One example is the way comparative studies in planetary magnetospheres have enhanced our understanding of the processes important in the Earth's magnetosphere. Another is comparative studies of the dynamics of planetary atmospheres. Zhu gives an overview of the fundamental processes driving atmospheric dynamics and how they can be handled in models of increasing complexity and dimension. He shows how his innovative first-principles model correctly predicts the superrotation of Venus' upper atmosphere (which has an angular velocity 60 times greater than the planet!). The same model makes testable predictions for the superrotation of Titan's atmosphere. Much closer to home, the model predicts that—during transient events that loft large clouds of dust into the Earth's atmosphere—superrotation could have occurred at the Earth, possibly with deleterious effects on dinosaurs.

In the last article Prockter discusses our present knowledge of the occurrence, history, and morphology of ice in solid bodies throughout the solar system. Ice is frequently present in the inner solar system (on Earth, Mars, and possibly in places on our Moon and Mercury) and a significant constituent of many bodies in the outer solar system. Knowledge of ice is important for possible operational reasons on Earth's Moon and Mars and for understanding the surface and internal structure of Mars; the moons of Jupiter, Saturn, Uranus, and Neptune; and Pluto and the Kuiper belt objects. In the outer solar system there are geologically active moons spewing water vapor and other phenomena such as under-ice oceans and cryovolcanoes. And everywhere, surface features made up of, or heavily influenced by, ices can be found. APL has been and will be significantly involved in studies of many of these bodies, with instruments on the way to Mercury, Mars, and Pluto (and the Kuiper Belt), in orbit at Saturn, and as part of an active research program studying icy moons such as Europa and Triton. We still need to expand our knowledge about the role of ice in the solar system.

Clearly, groundbreaking basic research in space science has been a part of APL's focus, almost from the beginning. We hope you enjoy these eight articles and come away with a sense of a few of the topics that are being addressed, right now, in space science at APL. This is only a small subset of our ongoing research and missions. Space really is an endless frontier—mankind has much to learn, and APL is continuing to make critical contributions in this area to the nation and the world!

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