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GUEST EDITOR'S INTRODUCTION

Space physics refers to the study of the physics of fields and particles in space, and in particular those portions of space with which we are familiar from the direct measurement of its characteristics by spacecraft. This latter aspect distinguishes space physics from astrophysics, which is the study of the physics of distant objects in the universe that we observe remotely with telescopes of various descriptions, but of which we have no *in situ* knowledge.

Space physics and APL are almost the same age, although some areas of investigation, such as the study of the aurora, have a much longer history. Space physics expanded greatly with the beginning of the age of spaceflight, and APL has been involved since the earliest of those years. Even before the advent of satellites, captured German V-2 rockets were used by APL researchers in various suborbital high-altitude studies.[1] This group at APL was led by James Van Allen, who later was credited with the discovery of the Earth's radiation belts. Space physics research activities at APL have expanded substantially in the intervening years and are presently carried out by more than thirty-five Ph.D. scientists in both the Space Physics Group and the Geospace Remote Sensing Group. The current contingent of space scientists has earned a distinguished place in local, national, and international communities, as evidenced by numerous awards and distinctions from institutions such as the Maryland Academy of Sciences and the National Academy of Sciences.

With one exception, the articles in the space physics section of this issue focus on the physics of the natural phenomena that result from processes in the ionosphere and magnetosphere of the Earth, and from the interaction of the Sun with those regions. The articles cover a broad range of topics within this subject area, with varying degrees of complexity. To facilitate further an understanding of the subject of the space physics section, a short description of the magnetosphere is included in this introduction.

Two articles fall into unique categories, each for a different reason. The article by James Kinnison, Richard Maurer, and Thomas Jordan on the estimation of the expected environmental radiation damage to spacecraft components is included because the energetic particle environment responsible for such damage is an element of the physical system on which the section focuses, and calculations of radiation dose must rely on descriptions of the energetic particle environment provided by the

kind of research on which the remainder of the section is based. This article is placed at the end of the section. The other article that belongs in the space physics section, yet cannot be considered a "conventional" contribution, is the one on space physics in Antarctica by Kile Baker. This article is a fascinating human interest story as well as a scientific paper, and it provides some insight into the dedication and cooperation that sometimes characterize the pursuit of a better understanding of our environment. Baker's article may be found at the beginning of the section.

Following Baker's description of life and science in Antarctica, the series of more conventional articles on magnetospheric physics is begun with one by Brian Anderson, who discusses the topic of ultra-low-frequency (ULF) magnetic pulsations. In addition to his clear discussion of this interesting special topic, Anderson includes a particularly accessible tutorial on some of the basic physics that underlies all of the articles in the space physics section. Non-experts are encouraged to read this article first to enhance their understanding of the contributions that follow.

Kazue Takahashi continues the discussion of ULF waves, highlighting their interaction with energetic charged particles trapped in the geomagnetic field. Takahashi has published many papers on this complex subject, and he provides an authoritative overview of the broad variety of mechanisms and signatures of this phenomenon.

The fascinating study of magnetospheric substorms is described and chronicled with a well-balanced blend of background, history, and current state of research by Ramon Lopez. A substorm is a fundamental aspect of the process by which energy is transferred from the solar wind flow around the magnetosphere into the inner magnetosphere, ionosphere, and atmosphere. It has been the object of intense scrutiny by space physicists for many years, yet it remains only partially understood. Lopez's article gives the reader a window into some of the efforts at APL to further that understanding, using data from the Active Magnetospheric Particle Tracer Explorers/Charge Composition Explorer (AMPTE/CCE) spacecraft built at APL, along with many other data sets.

Ennio Sanchez, Ching Meng, and Patrick Newell move out to the boundary of the magnetosphere. Their article describes the region known as the plasma mantle, the region at high latitudes mostly on the night side and just inside the magnetopause. The earthward ends of the

field lines that thread the mantle are located in the polar cap, and Sanchez, Meng, and Newell provide an interesting discussion of the physical mechanisms thought to control the entry of solar wind plasma into the mantle, and of the use of low-altitude spacecraft observations as a probe of this region about which little is known.

The cohtribution by David Sibeck addresses the effects of nonuniformities in the solar wind flow past the magnetosphere on the transfer of mass, energy, and momentum from the solar wind to the magnetosphere. Sibeck includes some insightful analysis of multiple spacecraft and ground-based data sets to illustrate his model of this interaction, and he also highlights the contributions of the AMPTE program toward furthering these studies.

Chris Paranicus and Andrew Cheng take us to a different and unique system, the magnetopause of Uranus, where a process not encountered in the Earth's magnetosphere but common to most of the outer, giant planets helps to shape the distribution of energetic particles in the Uranian magnetosphere. This process is the absorption of energetic particles by moons and rings within that planet's magnetosphere (the Earth's moon remains well beyond the trapping regions of the inner terrestrial magnetosphere, so analogous processes do not operate here).

Patrick Newell, Simon Wing, Ching Meng, and Vincent Sigillito change the pace a bit and show how the emerging technique of computer neural network systems can be applied to the analysis of spacecraft data. They describe how the network operates and summarize some of the results of its application in cataloging low-altitude spacecraft data according to the physical region sampled.

THE SPACE ENVIRONMENT
NEAR EARTH

The near-Earth space environment is dominated by the Earth's magnetic field and its interaction with the tenuous gas of ions and electrons (plasma) that fills the region. Beyond the volume of space entrained by the Earth's magnetic field (the magnetosphere) is the interplanetary medium. There, the solar wind (a plasma of density $\approx 10^7/m^3$ and temperature $\approx 10^5$ K, primarily composed of protons and electrons) flows at 300 to 800 km/s away from the Sun and is deflected around the magnetosphere by the pressure of the Earth's magnetic field. A shock wave forms sunward (upstream) of the interface (known as the magnetopause) between the magnetosphere and the solar wind plasma, and the solar wind is heated and decelerated at this so-called bow shock.

At the base of the magnetosphere, where the magnetic field enters the upper atmosphere, some of the atmospheric atoms are ionized by ultraviolet radiation and X-rays from the Sun. This ionization forms a plasma, known as the ionosphere, which has a much greater density than that found in the magnetosphere. In the solar wind and the magnetosphere, the plasma density is sufficiently low so that coulomb collisions are extremely rare, and the charged particle dynamics are dominated by the interaction of the charged particles with the macroscale magnetic and electric fields that thread the space. In the lower levels of the ionosphere, collisions between the neutral atmospheric constituents and the charged particles become frequent, and the charged-particle (especially ion) dynamics are strongly modified by the collisions.

Figure 1 is a schematic of the magnetosphere, obtained by combining the results of many spacecraft measurements over tens of years into a statistical picture. The magnetosphere is divided into several sub-regions, each with its own plasma and field characteristics. Additionally, whereas the internal field of the Earth is basically a dipole field with some higher multi-pole terms, the external field is modified by the interaction with the solar wind. The distortions in the dipole shape produced by this interaction result in several different current systems within the magnetosphere, such that the currents and field morphology are self-consistent.

The regions, with a short description, are the following: (1) the *bow shock*, the shock that forms upstream of the Earth in the solar wind, decelerating the solar wind flow from supersonic to subsonic, and heating the solar wind plasma; (2) the *magnetosheath*, the subsonic heated solar wind that is deflected and flows around the obstacle presented by the magnetosphere; (3) the *magnetopause*, the current layer that forms the interface between the magnetosheath solar wind plasma and the magnetospheric magnetic field and plasma, and through which the magnetic field rotates from its nearly random orientation in the magnetosheath to its well-modeled orientation in the magnetosphere; (4) the *radiation belts* (also known as the Van Allen belts, after their discoverer), doughnut-shaped regions characterized by very high energy ions and electrons trapped in the magnetic bottle formed by the dipole field for long periods of time (days to years, depending on energy and altitude); (5) the *ring current*, a current composed of moderately energetic ions in the equatorial magnetosphere, which overlaps the radiation belts in space and which varies in intensity, depending on the extent to which the magnetosphere is being excited, or energized, by the solar wind buffeting it (to give the reader a concept of the scale of Fig. 1, the ring current is nominally 3–5 Earth radii from the center of the Earth); (6) the *plasma sphere* (also co-spatial with the radiation belts but generally earthward of the ring current), that portion of the magnetosphere within which ions and electrons that escape from the ionosphere can be confined for long periods of time (many days), and which consequently contains a cold, dense, mostly hydrogen plasma; (7) the *plasma sheet*, a moderately hot plasma region confined in the (8) *magnetotail,* that region of the magnetospheric magnetic field farther from the Earth than the ring current and radiation belts, and which is drawn out and distorted in the anti-solar direction as a consequence of the interaction with the solar wind; (9) the *cross-tail current sheet*, the current that flows across the magnetotail as required to support the sudden reversal in the sign of the magnetic field between the Northern and Southern hemispheres within the plasma sheet; (10) the *tail lobes*, those regions in the magnetotail above and below the plasma sheet, characterized by very low density and cold plasma, and within which the downstream portion of the magnetic field eventually crosses the magnetopause and interconnects with the so-
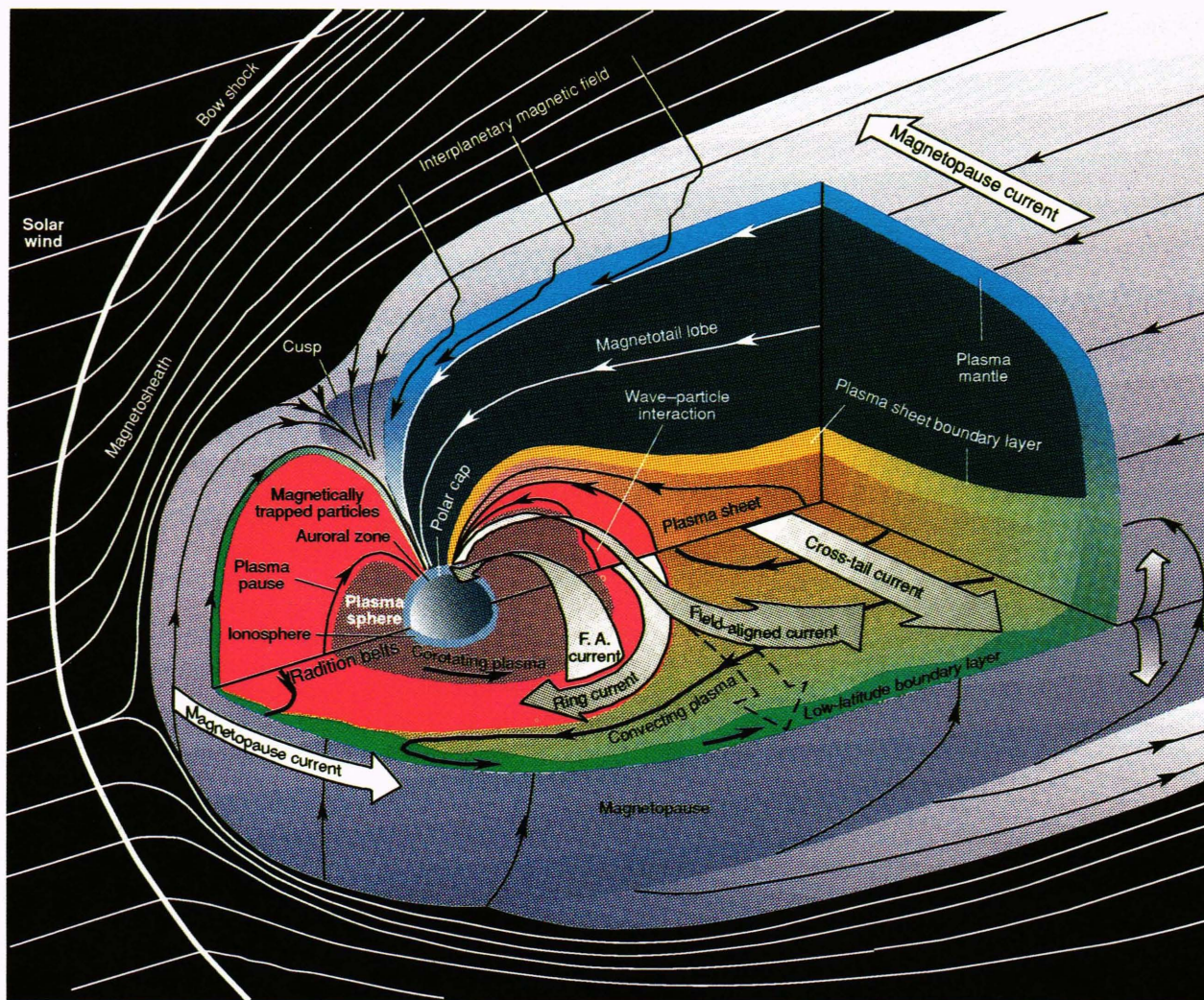
Figure 1. Schematic of the Earth's magnetosphere, provided as a reference for the space physics articles in this issue. The text describes the regions depicted in the figure.

lar wind magnetic field, rather than crossing the equatorial plane and connecting with its counterpart in the opposite hemisphere, as in the "closed-field" regions of the magnetosphere; (11) *field-aligned currents* (also known as "Birkeland currents," after their discoverer), the currents that flow parallel to the magnetic field, and whose earthward ends enter the ionosphere in the regions known as the (12) *auroral zones*, which are the regions lying between about 60° and 80° north and south latitudes in the ionosphere and upper atmosphere, where auroral emissions (both visible and ultraviolet) are excited by the collisions of energetic electrons accelerated at high altitude; (13) the *polar cap*, that portion of the ionosphere that lies at higher latitudes than the auroral zones and forms the earthward end of the lobe magnetic field lines; (14) the *cusp*, the funnel-shaped portion of the magnetic field where the field equatorward of the structure connects with the field of the opposite hemisphere over the dayside, while the field poleward lies in the lobes (this region is unique in that it provides an avenue of unimpeded access for solar wind [magnetosheath] plasma to penetrate all the way to the

atmosphere); (15) the *plasma mantle*, a boundary layer that forms between the magnetopause and the lobes on open field lines; (16) the *low-latitude boundary layer*, the boundary layer that forms between the magnetopause and the closed-field regions of the magnetosphere; and (17) the *plasma sheet boundary layer*, the boundary layer characterized by beams of energetic charged particles, and which forms between the magnetotail lobes and the plasma sheet. The *ionosphere* is depicted in Figure 1 as the thin layer that forms a concentric shell just above the surface of the Earth.

The short descriptions just given will serve to orient the reader of the space physics articles. One other area on which I will briefly touch is that of charged-particle motion in the magnetosphere. Charged particles moving in a magnetic field experience a force perpendicular to the perpendicular component of their motion. Consequently, they can flow freely in a direction parallel to the magnetic field, but are constrained to move on a circular path perpendicular to the magnetic field. Without going into detail on the physics behind the description, the effect of the nearly dipolar field found throughout
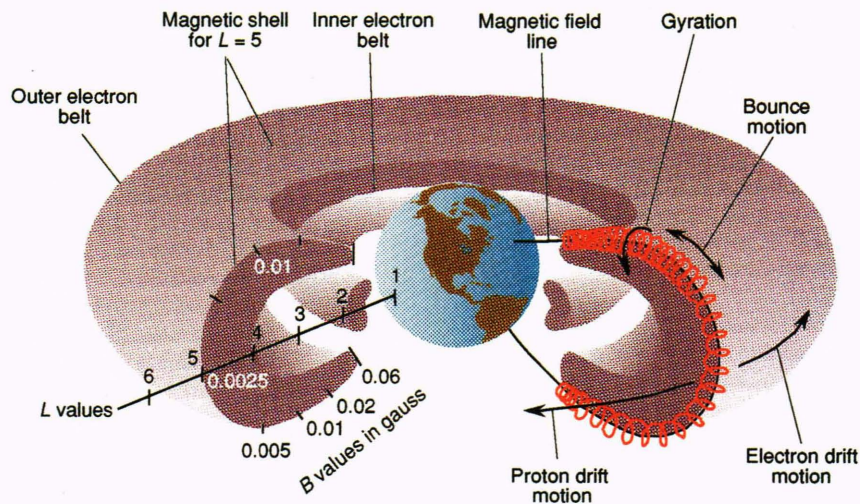
Figure 2. Energetic charged-particle motion in the Earth's dipole magnetic field. Particles gyrate about the field (cyclotron motion), bounce between the strong field at low altitude in the Northern and Southern hemispheres, and drift in paths that encircle the Earth, so that the combined motions, integrated over time (or over many particles), trace out "shells" centered on the Earth's dipole axis. *B* is the magnetic field magnitude, and *L* is the equatorial distance to the field line in units of Earth radii.

much of the magnetosphere on the charged-particle motion within it can be described by a combination of three cyclic motions: (1) gyration, (2) bounce motion, and (3) azimuthal drift. These motions are illustrated in Figure 2.

Gyration is the spiral motion of a particle about the magnetic field that results from a combination of parallel motion and circular motion perpendicular to the field. Bounce motion is the name given to the motion of the gyrating particles back and forth from one hemisphere to the other. This motion occurs because the gyrating particles must conserve their total energy, as well as the ratio of their perpendicular energy to the magnitude of the magnetic field. The latter conservation rule follows from the conservation of the magnetic moment due to the circular current represented by the gyrating charge. The consequence of the two conservation requirements is that as the particle enters a stronger field region (as is found in the converging field region at low altitudes in the dipole field), the parallel energy is lost to perpendicular energy until no parallel energy remains. The gradient in the field parallel to the field acts on the magnetic moment of the particle, forcing it back toward the weaker field region, and the particle reverses its parallel motion, or "mirrors" from the strong field region. In general, a particle undergoes many gyrations about the magnetic field in completing one bounce between hemispheres.

The third type of motion, azimuthal drift, is a consequence of the gradient and curvature of the magnetic dipole field. As the particle gyrates and bounces, its "guiding center," or center of gyration, moves azimuthally about the Earth, and equatorially trapped particles move along contours of constant magnetic field magnitude. This motion is the slowest of the three motions. The result of the combination of the three motions for many particles is that similar particles tend to be distributed in toroidal, or shell-shaped, regions symmetric about the equator and centered on the magnetic axis. In regions where strong electric fields exist, or where the magnetic topology deviates markedly from a dipole, these simplifications to the description of the motion of

charged particles break down, and it is often in such regions that the most interesting physics occurs.

It has been a pleasure to be the Guest Editor of the collection of articles on space physics at APL. In approaching this task, I have in many cases solicited contributions from individuals who are not as well known at the Laboratory as the more senior members of the space physics staff, and who have not had many opportunities to contribute to the *Johns Hopkins APL Technical Digest* in the past, although many have published extensively in external, refereed journals. The contributors to this collection are a mix of postdoctoral appointees, contractors, and senior staff, whose responsiveness and dedication throughout this process have been greatly appreciated. I would also like to thank all those who served as reviewers for the space physics articles. Their contributions have enhanced both the content and the presentation of the articles.

REFERENCE

[1] Hopfield, J. J., and Clearman, H. E., Jr., "The Ultraviolet Spectrum of the Sun from V-2 Rockets," *Phys. Rev.* **73**, 877 (1948).

THE AUTHOR
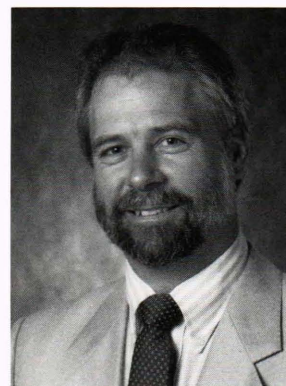
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