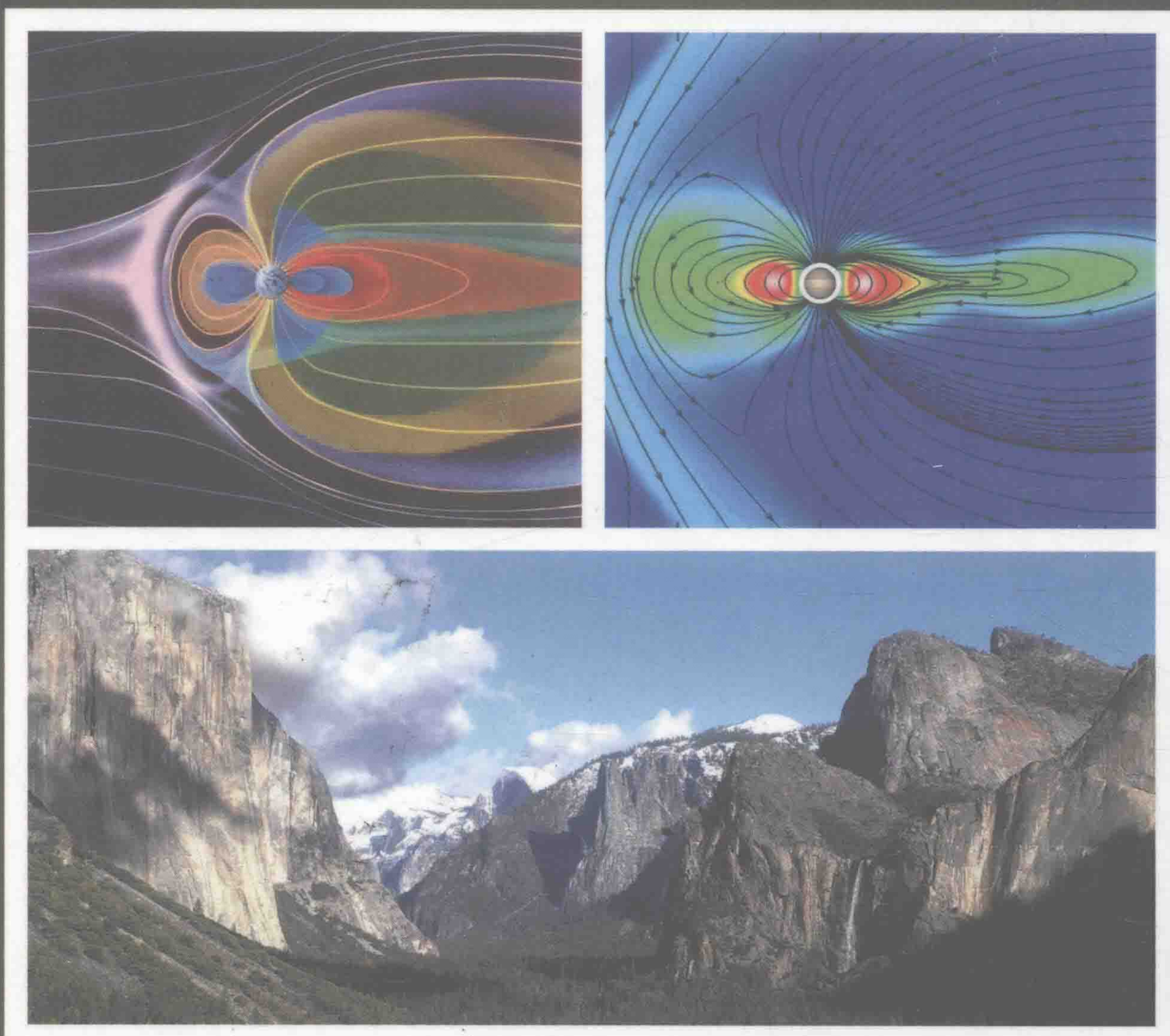
Magnetosphere-Ionosphere Coupling in the Solar System



Charles R. Chappell, Robert W. Schunk,
Peter M. Banks, Richard M. Thorne, and James L. Burch
Editors

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Cover Images:

—Photograph by Charles R. Chappell of Yosemite National Park California taken from Inspiration Point. Yosemite has been the location of two important AGU conferences on Magnetosphere-Ionosphere Coupling at Earth and the planets.

—A schematic drawing by Charles R. Chappell of the outflow of the Earth's ionosphere as it moves outward to become a source of plasma for the magnetosphere.

—A simulation model image of the magnetosphere of Saturn showing the effect of its ionosphere on the shape of the magnetic field and the concentrations of different ions trapped in the magnetosphere (*Jia et. al.*, this volume)

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PROLOGUE

The Earth and other planets in the solar system have atmospheres that vary in chemical composition and density depending on the processes that have taken place during the origin and evolution of the planet. As the different wavelengths of sunlight shine on the atmosphere, the atoms and molecules can be ionized, becoming electrically charged particles that can be energized further and moved upward away from the planet. This ionized layer, the ionosphere, is guided dynamically by electric and magnetic fields that are present at the planet. The strength and shape of the planetary magnetic field are influenced by the internal structure of the planet itself, and these factors can vary from the weakest intrinsic magnetic field at Mercury to the strongest at Jupiter.

As the outer atmosphere of the Sun is accelerated away as an ionized gas, it becomes the solar wind that streams outward through the solar system and affects the different planets. This highly variable solar wind interacts with the magnetic fields of the planets and creates electric fields that influence the motion of the charged ionospheric particles and that can accelerate them to much higher energies, thrusting them upward into the magnetic envelope that surrounds the planet. This process establishes the ionosphere as a very important source of the energetic charged particles that can be found around the different planets. At Earth, this magnetic envelope containing charged particles is called the magnetosphere.

Early studies of the Earth's magnetosphere measured these energetic particles and found that they were of similar energies to the protons, alpha particles, and electrons of the solar wind. This led to an initial conclusion that the energetic particles of planetary magnetospheres came from the solar wind and not from the planet itself. With the subsequent development of particle instrumentation that could determine the mass of these energetic particles, it was found, surprisingly, that there were significant amounts of particles with masses typical of the atmosphere and ionosphere of the planet and not of the solar wind, e.g., oxygen, nitrogen, and even molecular ions. This discovery in the 1970s established a new way of thinking about the processes by which the magnetospheres of the Earth and the planets were filled. These magnetic "buckets" can be filled from the inside out as well as the outside in.

Our early ideas about how things work, however, often form paradigms that are hard to change. This has been the case with the Earth's magnetosphere, where a large segment of the research community has not yet adjusted to the idea that the ionosphere may be a significant and oftentimes dominant source of the energetic plasma that is found in the Earth's space environment. The same is true for the planetary environments. Over the 40-year period of study of the Earth and planetary space environments, the confluence of new measurement techniques, extraordinary planetary missions, and coupled dynamic models has opened the door for a dramatic new paradigm-changing understanding. This history set the stage for the 2014 Yosemite Chapman Conference on Magnetosphere-Ionosphere Coupling in the Solar System. This resulting monograph is at the center of this exciting discovery and new scientific knowledge.

The first step needed was to bring together the space scientists who study the ionosphere with those who study the magnetosphere, and let them learn from each other. This had been the goal of the first Yosemite conference, four decades earlier. That conference started a movement toward a different awareness of the coupled nature of the system, but there was at that early time, no inclination that the ionosphere could actually be supplying charged particles, or plasma, to form the energetic regions of the magnetosphere where particles had energies up to a million times that of the ionospheric particles.

The second step needed was to bring together scientists who study the Earth's space environment with scientists who study the other planetary environments. This had begun in a limited way, but the 2014 Yosemite conference was intentionally designed to create this cross-discipline interaction, teaching, and learning. It was very successful in doing this, and this monograph captures this knowledge and makes it available to the broader international heliophysics and planetary science communities.

In addition to the cross-discipline merger of the scientists, the conference was designed to feature the history of this research. This was captured through the unique use of video that was made at the first Yosemite conference in 1974. This video was digitized for use at the 2014 meeting. Excerpts of the 1974 video were used to introduce each session, showing "the way we were" in 1974 and its implied comparison with "the way we now are" in terms of our understanding of the coupling of the ionosphere with the magnetosphere, not just at Earth but also at other planets. Many of the video excerpts were of renowned scientists in our field who are no longer alive.

For many of the young researchers who were at the 2014 meeting, it was the first time that they had ever seen and heard some of these amazing pioneers in their field. These excerpts are made available to the reader through URL links given throughout this monograph. The full video of the 1974 meeting, which was digitized by the Television Archive at Vanderbilt University, is available online in the digital library at Utah State University in connection with their Center for Space Science and can be found at http://digitalcommons.usu.edu/yosemite_chapman/1974/.

In addition to the original video, arrangements were made to have the 2014 Yosemite conference recorded in HD color video. This video includes all of the talks from the 2014 conference and is also available at the Utah State University online digital library. It is found at http://digitalcommons.usu.edu/yosemite_chapman/2014/. This monograph contains URL links to videos of the original talks related to each of the chapters. The uniqueness of this video cannot be overemphasized. The viewer can watch a space scientist at the 2014 meeting in his eighties watching and commenting on a video of himself in his forties or the video of a very special PhD advisor of 40 years ago being watched and remembered by his previous PhD student! These are amazing scenes, not only for the comments related to what we have learned over this career-long four decades, but also the way we looked and talked in the early 1970s, near post-Woodstock era, as contrasted to today. This video element of the monograph adds unique supplemental value to this entire endeavor. These two online videos bring tremendous personal depth to the monograph. I am certain that nothing like this exists in our field of research, and I would be surprised if it exists in any other fields of space science. It is a most significant time capsule of ambience that has brought much more significance to the Yosemite conference and to this monograph.

The flow of the monograph chapters has been set up in the same way that the Yosemite Chapman Conference was arranged. The rationale for the flow had two themes. In the larger sense, more measurement and modeling of magnetosphere-ionosphere coupling has been done at Earth than at the planets. Because of this, the monograph begins with a look at the research that has been done at the Earth. Since the Earth-centered research forms the foundation for both measurements and modeling at the other planets, the relative number of papers has been weighted toward research that has been done in the Earth's space environment.

Within this larger theme, the chapters have been arranged in order to build up our understanding of each environment based on a progression of processes that follow the dynamics of the ionospheric source and its movement upward into the magnetosphere with its resulting effects. Hence, the monograph chapters begin with the ionospheric source, followed by the upward movement of the particles, then the influence of the low energy ionospheric particles in creating/affecting the higher energy particle populations of the magnetosphere and finally the modeling that has been has been carried out to predict the ionospheric outflow and its merger into the overall magnetospheric models.

Following the foundation established by the research in the terrestrial environment, the chapters turn to the planets and begin with the relevant measurements that have been made followed by the modeling of ionosphere-magnetosphere coupling that is now being done at the planets, much of it based on earlier modeling at the Earth. The monograph is completed with an assessment of where we stand in our understanding and a look at a future mission that would address the very important areas where more measurement and study are needed.

In conclusion, the reader/viewer is in for a treat with this monograph. It chronicles the advancement of knowledge in this interdisciplinary field and brings together the work of space scientists from around the world. It is an intellectual and visual journey though our exploration and discovery of the role that the ionosphere plays in determining the filling and dynamics of the space environments of the Earth and the planets. It covers a career-long experience that begins with the earliest ideas about this topic that came on the scene in the early 1970s and ends with an explanation of the new paradigm for the role of the ionosphere at the Earth and other planets of our solar system.

So sit back, enter the first URL given in the Table of Contents into your laptop, and watch an excerpt of the talk given by Jim Burch in 1974. Then read his introductory chapter from the 2014 conference and, if you desire, enter the URL given in his chapter and watch Jim give the 2014 talk himself. Then proceed through the video/chapter parade and enjoy seeing special people from our past in combination with the new discoveries and knowledge of the present—all done in the magnificence of Yosemite National Park, one of the most beautiful places on spaceship Earth!

Rick Chappell, *Vanderbilt University*
February 2016

Images from the 1974 and 2014 Yosemite Conferences

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