AGU Book “The Sun and the Solar Wind”
Preface

The upcoming decade will mark a turning point in solar and heliospheric research, and space exploration, in general. In addition to the fleet forming the Heliophysics System Observatory for years, a new generation of space missions and ground-based telescopes will push the boundaries in Heliophysics research. Parker Solar Probe (PSP) launched in August 2018, sixty years after it was conceived as the Humanity’s first mission to enter and study a stellar atmosphere from ‘within.’ PSP has completed two of its 24 scheduled orbits and will have completed the third one on November 11, 2019. PSP will approach the Sun closer than any spacecraft before to explore the solar atmosphere to 8.86 solar radii above the surface. The data recorded during the first two orbits show an unprecedented view of the nascent solar wind. We expect more discoveries as the spacecraft flies closer and closer to the Sun. Solar Orbiter, scheduled for a February 2020 launch, will orbit the Sun up to 34 degrees out of the ecliptic and will provide the first views of the solar poles. The largest ground-based telescope ever built, the 4-m Daniel K. Inouye Solar Telescope (DKIST), will be operational next year. DKIST will be able to reveal solar structures as small as 20-30 kilometers in diameter. Similarly, the 4-m European Solar Telescope (EST) will also be operating in the next few years.

The observations and measurements from PSP and those we will get from Solar Orbiter, DKIST, EST, and other futures missions and telescopes will not only help answer long-standing science questions but also lead to significant discoveries and open new avenues for exploration. These missions are writing a new chapter of space exploration. They may lead us the building block of solar magnetism, what are the mechanisms of energy transfer from the lower layers of the solar atmosphere to the corona where it dissipates to heat and accelerate the solar wind plasma, and how solar activity is triggered and how it can be predicted to prevent the damaging effects of space weather.

Nour E. Raouafi & Angelos Vourlidas
Johns Hopkins University Applied Physics Laboratory
The Sun is the most observed and studied star in the Universe. Yet many of the processes that govern its behavior are not fully understood. These processes may be specific to certain regions (solar interior, atmosphere, or the solar wind), but the extent of their effects is much further. The solar dynamo and convection, coronal heating, the acceleration of the solar wind, flares, coronal mass ejections, and solar energetic particles are all outstanding examples of challenging solar and heliospheric problems.

In this book, we compile seven chapters that cover most aspects of solar and heliospheric physics. In the past few decades, there has been a resurgence in solar and heliospheric research due to the implementation of key space and ground-based missions and telescopes, which shed new insights into aspects that were not accessible before. The future is auspicious with the launch of NASA’s Parker Solar Probe and the upcoming ESA/NASA Solar Orbiter as well as the Daniel K. Inouye Solar Telescope (DKIST) and the European Solar Telescope (EST). The coming decade may be revolutionary in our understanding of the Sun and its environment.

Important technological inventions, along with essential advances in mathematics and physical theories made over the last few centuries led to fundamental solar and astronomical discoveries. A number of the discovered phenomena are still puzzling us and are the main pillars and axes of solar and heliospheric research. The invention of the telescope and the discovery of sunspots by Galileo in the 16th century represents a turning point in solar physics research. Soon after, the 11-year solar cycle was revealed with its long and short terms variability. The observation of the strongest flare in recorded history by Carrington in 1858 was another important milestone and the building block for solar activity and space weather. The exact nature of these phenomena remained hidden until the discovery of solar magnetism by George Hale (1908). He stated in his ApJ paper “The present paper describes an attempt to enter one of the new fields of research opened by this recent work with the spectroheliograph,” which is a testament that science advances go hand in hand with the technology. In the next half a century, three major phenomena were discovered: the coronal heating problem, the solar wind and its acceleration, and coronal mass ejections. All of these phenomena are driven by the magnetic field, which generated deep in the convection zone.

The chapter on the solar interior provides a description of the dynamo theory and the most recent advances in magnetic flux emergence as well as helioseismology.

Since the advent of the space era, significant strides were made in our understanding of the Sun along with breakthrough discoveries. Important advances in theory and computing power are tagging along, which allow access to fundamental physical processes that are otherwise impossible to explore because of the complexity of theories behind them. These advances led us to understand better the challenges facing us to comprehend how the Sun and its corona work and also what it takes to obtain the measurements need to progress. Figure 1 is an illustration of the integrated ground-space-theory system, which is a prerequisite to overcoming all the hurdles we were facing for decades.
Understanding the Sun is essential not only because we live in its extended atmosphere (i.e., the corona and the solar wind) but also because it is the only star we can study in detail. The knowledge we gain from observing the Sun and its environment provides insights into other worlds that may harbor life like our Earth.

This book provides an overview of solar physics and the advances made over the last few decades as well as the challenging problems that remain. The seven chapters cover the solar interior, the atmosphere, magnetism and radiation, plasma heating and acceleration, and solar activity. It is a comprehensive view of how our star works and what is needed to understand it better. We hope that this reference work will help researchers in other fields, young scientists, teachers, students, and the public to familiarize themselves with the status of the field as of 2019.

Figure 1: Illustration of the complex solar environment and the advances made over the last few decades and will be made in the near future to obtain breakthrough insights into challenging phenomena that are puzzling scientists for decades. Top-left: slice-view showing the Sun at different wavelengths; top-right: the fleet of heliospheric space missions; bottom-left: an image of the 4-m DKIST solar telescope; bottom-right: simulation of the structure of the solar corona for the 2017 eclipse (credit: Predictive Science Inc.).