Special Issue on Sun and Solar System Plasma Research: Preface Postprint

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Abstract

Over 99.9% of visible matter in the universe is in a plasma state, and plasma astrophysics is an important branch of astrophysics that provides essential theoretical foundations for understanding the formation, evolution, and explosive phenomena of celestial systems. This special issue systematically presents the research achievements of the plasma astrophysics team at Purple Mountain Observatory, Chinese Academy of Sciences, in solar and solar system plasma through 14 articles, aiming to help readers comprehensively understand the important progress and existing problems in solar and heliospheric plasma physics research.

Full Text

Preamble

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A Special Issue on Solar and Heliospheric Plasma Research: Preface

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ABSTRACT
Over 99.9% of the baryonic matter in the universe exists in the plasma state. Plasma astrophysics is therefore an important branch of modern astrophysics that provides the theoretical foundation for understanding the formation, evolution, and eruptive phenomena of astrophysical systems. This special issue presents 14 articles that systematically introduce the research achievements of the Plasma Astrophysics Group at the Purple Mountain Observatory, Chinese Academy of Sciences, in the field of solar and heliospheric plasmas. We hope these contributions will help readers gain a comprehensive understanding of the important advances and outstanding questions in solar and heliospheric plasma physics research.

Key words: Sun, heliosphere, plasma, wave-particle interaction, solar radio emission

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More than 99.9% of visible matter in the universe is in the plasma state—either fully or partially ionized, collisional or collisionless, dusty or dust-free. The nonlinear interactions among magnetic fields, charged particles, and neutral particles give rise to the rich phenomena and characteristics observed in astrophysical plasmas. Consequently, plasma astrophysics has developed into a major subfield of astrophysics.

Theoretically, we must pursue both magnetohydrodynamic (MHD) studies and kinetic plasma investigations in regimes where MHD breaks down, such as particle acceleration and wave-particle interactions. Observationally, we need multi-wavelength remote sensing as well as in-situ measurements of collisionless plasmas, since macroscopic plasma behavior is ultimately determined by numerous microscopic processes. The Sun and heliosphere represent the only stellar system where both remote sensing and in-situ measurements are possible, making it a natural plasma laboratory where multi-scale physical processes coexist. Research on solar and heliospheric plasmas not only provides important reference points for plasma physics, high-energy physics, and atomic physics, but also offers crucial clues for understanding other stars, galaxies, black hole accretion disks, jets, neutron stars, molecular clouds, active galactic nuclei, and even the intergalactic medium [1].

The in-situ measurement era of solar wind began in the late 1950s. Since then, missions such as ISEE (International Sun-Earth Explorer), Helios, Ulysses, Wind, ACE (Advanced Composition Explorer), DSCOVR (Deep Space Climate Observatory), and various planetary probes have greatly enhanced our understanding of solar wind structure and dynamics [2,3]. The 2018 launch of the Parker Solar Probe (PSP) marked humanity's first venture into the solar corona, pushing in-situ measurements of the solar wind and related research to new heights. The research group led by Professor Wu De-jin at the Purple Mountain Observatory has long been engaged in solar and heliospheric plasma physics, conducting theoretical and data analysis studies on frontier topics in solar wind plasma using the latest observations from PSP and other satellites. This special issue compiles the group's most recent progress.

This issue comprises 14 articles that, in addition to providing a comprehensive review of plasma astrophysics, specifically address the propagation dynamics of interplanetary magnetic clouds, wave-particle interaction processes in solar wind plasma, heliospheric radio emission phenomena and mechanisms, and fundamental physical processes in collisionless plasmas. The main contents are summarized below.

The opening contribution systematically discusses the crucial role of plasma astrophysics in modern astronomy and the formation of a modern plasma-based cosmology, from perspectives of cosmic evolution, large-scale structure formation, and eruptive activity phenomena. It further elaborates on the unique position of the Sun and heliosphere as a "natural laboratory" for plasma astrophysics research [4]. Subsequent reviews examine advances in magnetic cloud boundary layer structure, toroidal flux, and large-scale configurations, with particular emphasis on how magnetic reconnection affects magnetic cloud erosion and topological changes [5].

Since the solar wind is continuously heated as it travels from the corona into interplanetary space, this issue explores possible turbulence-driven heating mechanisms and outstanding problems in solar wind heating [6]. These mechanisms include Alfvén waves [7] and electromagnetic ion cyclotron (EMIC) waves, the latter having substantial observational evidence upstream of Mars [9]. Furthermore, non-thermal features of solar wind electrons, such as temperature anisotropy and beam distributions, may excite instabilities (including electron acoustic heat flux instability and lower hybrid heat flux instability) that accelerate the solar wind through wave-particle interactions [10]. PSP observations of various high-frequency electrostatic waves in the near-Sun solar wind have created new opportunities for studying wave-particle interactions in this region [11].

Radio emission represents the macroscopic manifestation of microscopic plasma kinetic processes, and its generation mechanisms remain controversial. In addition to the classical plasma radiation mechanism, the electron cyclotron maser mechanism has received increasing attention [12]. Radio observations from the distant heliospheric termination shock [13] and near-Sun observations from Parker Solar Probe [14] promise to help clarify these mechanisms, while particle-in-cell simulations can help distinguish their observational signatures [15].

The highly nonlinear nature of plasmas primarily originates from wave-particle interactions, and significant progress has been made recently in the quantitative theoretical study of these interactions [16]. Collisionless dissipation mechanisms constitute a fundamental theoretical challenge in understanding eruptive phenomena in solar and heliospheric plasmas. The chaotic motion of charged particles caused by magnetic field inhomogeneity can serve as an important source of current dissipation, leading to anomalous resistivity (termed "chaos-induced resistivity"). Recent space-based in-situ measurements and numerical studies suggest that chaos-induced resistivity may play a key role in magnetic reconnection [17].

These 14 articles on solar and heliospheric plasma research encompass both theoretical and observational work, summarizing recent achievements while offering bold perspectives for future development. We hope this special issue will provide domestic colleagues with a comprehensive overview of solar and heliospheric plasma physics research, and more importantly, inspire more young researchers to join this challenging and promising field.

References

[1] Chen P F. SSPMA, 2021, 51: 119632
[2] Zhang T L, Lu Q M, Baumjohann W, et al. 2012, Science, 336: 567
[3] Tsurutani B T, Zank G P, Sterken V J, et al. 2022, arXiv e-prints, arXiv:2209.14545
[4] Wu De-jin, Chen Ling. Acta Astronomica Sinica, 2023, 64: 24
[5] Feng Heng-qiang, Zhao Yan, Wang Jie-min. Acta Astronomica Sinica, 2023, 64: 25
[6] Zhao Guo-qing, Feng Heng-qiang, Wu De-jin. Acta Astronomica Sinica, 2023, 64: 26
[7] Xiang Liang, Wu De-jin, Chen Ling. Acta Astronomica Sinica, 2023, 64: 27
[8] Li Qiu-huan, Yang Lei, Xiang Liang, et al. Acta Astronomica Sinica, 2023, 64: 28
[9] Li Jia-wei, Yang Lei, Wu De-jin. Acta Astronomica Sinica, 2023, 64: 31
[10] Sun He-yu. Acta Astronomica Sinica, 2023, 64: 29
[11] Shi Chen. Acta Astronomica Sinica, 2023, 64: 30
[12] Tang Jian-fei, Wu De-jin, Zhao Guo-qing, et al. Acta Astronomica Sinica, 2023, 64: 32
[13] Chen Ling, Wu De-jin, Li Yi-lun, et al. Acta Astronomica Sinica, 2023, 64: 33
[14] Ma Bing, Chen Ling, Wu De-jin. Acta Astronomica Sinica, 2023, 64: 35
[15] Zhou Xiao-wei, Wu De-jin, Chen Ling. Acta Astronomica Sinica, 2023, 64: 34
[16] Zhao Jin-song. Acta Astronomica Sinica, 2023, 64: 36
[17] Wang Zhen, Chen Ling, Wu De-jin. Acta Astronomica Sinica, 2023, 64: 37

Note: Figure translations are in progress. See original paper for figures.