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Editorial: Reviews in space physics

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Editorial on the Research Topic
Reviews in space physics

The present Research Topic opens the series of "*Reviews in space physics*" with a Research Topic comprising a limited number of submissions discussing the current state of research in the wide domain of Space Physics. Within the framework of this Research Topic, Frontiers will publish reviews, covering diverse aspects of heliospheric, solar, magnetospheric, and ionospheric physics. Reviews included in this Research Topic are aimed at covering processes from the upper terrestrial atmosphere to distant astronomical space, critically discussing past and future developments in theory, observation, analysis, and instrumentation.

This first 2023 Research Topic of Reviews in Space Physics contains six articles written by 60 authors. Its Research Topic focus on 1) space weather, its geo-effective mechanisms and possible threats to civilization, including radiation hazards; 2) studies of dynamical structures in the small- and large-scale solar wind and the consequences of their interaction with the terrestrial magnetosphere, with special focus on processes in Earth's magnetosheath (MSH); 3) observations and modelling of MSH plasma jets, and 4) acceleration and propagation of solar energetic particles (SEPs) and cosmic rays (CRs) in the heliosphere and beyond.

Space weather and its effects on human activities have become an important Research Topic, especially as recent global efforts inexorably embed space technology and services in everyday life. Buzulukova and Tsurutani cover the basic features of space weather and its technological effects overviewing the chain of physical processes responsible for space weather hazards, tracing from its solar origins to effects in interplanetary space and impacts at Earth. All kinds of solar phenomena causing space weather variability, from coronal mass ejections (CMEs) to coronal holes, are considered. The authors show that extreme space weather poses a risk to the technosphere and may be associated with spacecraft/satellite failures, communication/navigation issues, power blackouts and human health negative changes caused by geomagnetically-induced currents and complex ionospheric-atmospheric-thermospheric effects. A detailed overview of geomagnetic storms, substorms, and Auroral Electrojet activity intervals provides information on Sun-Earth-system-coupled responses. Future concerted community efforts required to fill the knowledge gap are discussed.

Rakhmanova et al. assign a significant geoeffective role to the coupling between MSH structures and the variable solar wind at kinetic scales. The turbulent MSH is sensitive to ~10^{-3}–10^{-2} Hz solar wind and foreshock variations of amplitudes 5%–10% above background representing so-called jets, rather than waves. Transient dynamic pressure enhancements forming jets in 3D are physically plasmoids or flux ropes or, in 2D, magnetic islands, holes, and Alfvén vortices contributing to MSH turbulence and intermittency. Aligned with the Sun–Earth line, they become geoeffective. The article advocates future diversified missions active over the entire solar cycle to investigate their role in overall Sun-Earth physics.

Echim et al. focus on the same MSH structures as Rakhmanova et al. calling them "multiscale dynamical irregularities of the background MSH plasma state". The authors review their properties in a multi-pronged effort referring to theory, numerical simulations and observations. Using ~1000 jet observations from Cluster 3, in combination with theory and simulations they observe a dawn-dusk asymmetry with stronger density perturbations along the dusk flank. At dawn, denser and colder jets dominate. Approaching the Earth, jet speeds decrease while perpendicular jet ion temperatures increase, which indicates adiabatic breaking potentially impacting ionospheric dynamics.

The presence of dangerous SEPs and CRs in the inner heliosphere is a permanent threat for human space exploration. Reames provides an in-depth review of impulsive (or ^{3}He-rich) SEP events, describing the evolution of views on the nature of SEPs with an unusual elemental composition discovered in the early 1970s and showing ratios ^{3}He/^{4}He, Fe/O enhanced above the coronal abundances later detected in high-Z elements. Impulsive SEP events with large proton excess (see Figure 1) and rare ^{4}He-pure events are discussed, and various acceleration theories are presented, from resonant plasma wave acceleration to acceleration on magnetic islands collapsing in reconnection. The significance of radio and imaging observations in discerning acceleration processes in SEPs is addressed.

Magnetic fields play a significant role in space physics, particularly in the propagation of CRs in heliospheric plasmas, preventing their escape and facilitating diffusion. Spatial properties and temporal variations of the magnetic fields, modulated by turbulence and intermittency, determine the path and the intensity of CRs in the heliosphere, the interstellar and intracluster media. The heliosphere shields ~70% of galactic CRs, and knowing the way they propagate to the Earth is very important for radiation monitoring and protection. The current issue contains two articles concerning this Research Topic.

Lazarian et al. provide an overview of recent theoretical findings on CR propagation in turbulent magnetic fields in astrophysical plasmas and summarize the key implications and mechanisms involved. They discuss details of how pre-existing magnetohydrodynamic turbulence impacts parallel and perpendicular CR diffusion, as well as perpendicular super diffusion of CRs. Parallel diffusion prevails only in ideal plasma. In realistic astrophysical plasmas perpendicular diffusion cannot be ignored because magnetic fluctuations in trans-Alfvénic turbulence are comparable to the mean magnetic field, being even larger in super-Alfvénic turbulence. In strong turbulence, the magnetic field becomes not frozen into the plasma, which leads to super diffusion at small scales. Perpendicular diffusion of CRs is impacted by turbulent magnetic fields regulated by Alfvén modes, while parallel diffusion depends on resonance broadening effects and transit-time damping interactions.

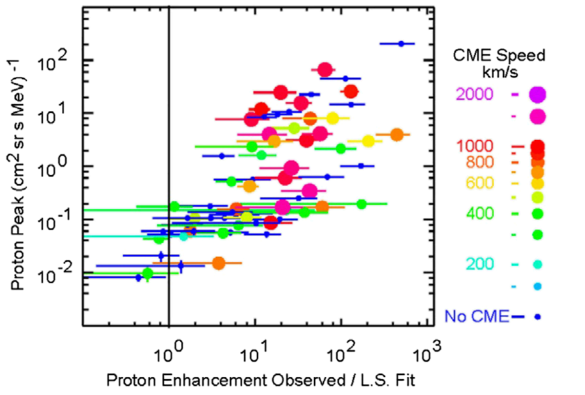

FIGURE 1
Scatter plot of proton peak intensity at 2–2.4 MeV vs. relative proton excess for impulsive SEPs associated and not associated with CMEs (from Reames, distributed under the terms of the Creative Commons Attribution License (CC BY)). CME speed is given in colored dots, and non-CME events - in blue. Reames distinguishes 4 SEP-types: Small impulsive SEP1 (protons fit power law of heavier ions), SEP2 (impulsive with enhanced proton excess; accelerated by CME-driven shock), SEP3 (gradual; re-accelerated SEP1, ion dominated), and SEP4 (gradual; shock accelerates primarily ambient population). Most CMEs with the speed >500 km/s accelerate SEPs, with non-CME SEP sources contributing to the pool of events with high excess as well. Non-CME SEPs are probably shock-enhanced SEP2s seeded by SEP1s and ambient coronal seed particles. The proton excess plot allows distinguishing pure SEP events from those in which SEPs are re-accelerated.

Opher et al. focus on global processes in the heliosphere related to CR transport. Rather than a more traditional review, the article presents key questions and problems through a comprehensive description of the proposal for the now NASA-funded DRIVE science center SHIELD, studying the structure and dynamics of the heliosphere through integrated research. The authors indicate knowledge gaps that can be filled with building self-consistent global models of the heliosphere and its interaction with the interstellar medium as well as creating CR transport models. The article outlines the SHIELD research plan and discusses the ways the center will contribute in predicting variations of the radiation environment of the Earth and studying the evolution of pickup ions and their impact on heliospheric processes.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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