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EDITORIAL
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Editorial: Micro- to Macro-Scale Dynamics of Earth's Flank Magnetopause

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Editorial on the Research Topic

Micro- to Macro-Scale Dynamics of Earth's Flank Magnetopause

The Earth's magnetopause is a boundary between the shocked solar wind and the magnetosphere and host to diverse physical processes such as the velocity shear driven Kelvin-Helmholtz instability (KHI), the magnetic shear driven magnetic reconnection, and the excitation of various plasma waves and turbulence. They are fundamental processes that occur within the heliosphere and throughout the Universe. Understanding their generation and effect have been advanced via individual *in-situ* observations and theoretical and numerical modeling on various spatiotemporal scales. Yet, the evolution of these processes along the flank-side magnetopause and corresponding impacts on the solar wind-magnetosphere-ionosphere coupling leave room for enhanced and coherent understanding. This Research Topic serves as a forum to bring existing and new pieces of understanding together to construct the comprehensive picture of those local processes evolving from the dayside magnetopause via the flanks down to the distant tail magnetopause.

Eleven papers published in this Research Topic present the most recent perspectives on the Kelvin-Helmholtz waves or vortices (KHWs/KHVs) and accompanying kinetic processes using new observations or established/advanced models. KHWs/KHVs provide a pathway for energy transfer from the velocity shear layer to the Earth's magnetosphere via the coupling between KHWs and Alfvén waves (Chaston et al., 2007). Kim et al. emphasize the generation of secondary KHWs and their dominancy in energy transfer due to a stronger mode conversion to the shear Alfvén waves than primary KHWs. The energy transfer is also mediated via the excitation of global ULF (ultra-low frequency) waves driven by KHWs, as conceptualized by Zhu and Kivelson (1989). Kronberg et al. and Petrinec et al. using conjunctions of multiple spacecraft or ground magnetometers identify the close linkage between magnetopause KHWs and coincident ULF waves. Additionally, Petrinec et al. use the theory, developed by Johnson et al. (2021), that KHVs at the magnetopause can couple to the ionosphere and generate micro-scale field-aligned currents. They employ KHV observations at the magnetopause to predict micro-scale upward field-aligned current structures in the auroral oval, which are then compared with ionospheric observations.

Five articles among those eleven papers are focused on magnetic reconnection. Hwang et al. report detailed properties of in-plane (velocity-shear plane) reconnection under the combined shear flow, guide field, and density asymmetry. Another in-plane reconnection under such conditions but without being associated with KHWs (Tang et al.) indicate that the flank-magnetopause reconnection recloses the open field lines generated by the primary (dayside) magnetopause

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reconnection. This modifies the classical Dungey cycle, where the reclosing occurs near the nightside magnetotail. Ma et al. and Eriksson et al. investigate out-of-velocity-shear-plane reconnection, so-called mid-latitude reconnection (Faganello et al., 2012) that occurs due to a 3D twist of mid-latitude magnetospheric fields and engulfed magnetosheath fields induced by the low-latitude KHVs. Eriksson et al. identify double (northern and southern) mid-latitude reconnection via counter-streaming ion beams. Ma et al. show that the KHV-induced double mid-latitude reconnection leads to significant transport and mixing of multi-species ions. Dokgo et al. investigate the localized energy conversion facilitated by wave-particle interactions observed at the reconnection current sheet inside a KHV-induced flux rope. Their observation supported by linear wave theory shows that the electrostatic beam-mode waves thermalize electrons effectively. Hwang et al. also report that the electrostatic waves may pre-heat a magnetosheath population that is to participate into the reconnection process, leading to two-step energization of the magnetosheath plasma entering into the magnetosphere via KHV-driven reconnection.

While the statistics indicate that KHWs occur most frequently under the northward IMF (interplanetary magnetic field), their occurrence under southward IMF is not rare (Kavosi and Raeder, 2015), as reported by Kronberg et al. and Petrinec et al. in this Topic. Two additional papers, via numerical modelling, address the behavior of the magnetopause or the evolution of KHWs under this condition. The former study by Park et al. shows the result of 3D global MHD simulations of dayside reconnection, KHVs generated in the inner boundary of the magnetopause, and a cross-polar-cap potential increase under weakly southward IMF. Based on 2D and 3D fully kinetic simulations modeling an *in-situ* observation event of KHWs during southward IMF, Nakamura et al. reveal that a turbulent evolution of the lower-hybrid drift instability near the magnetospheric side of the KHW rapidly disturbs the KHW structure and causes an effective transport of plasmas across the magnetopause. These studies suggest collaborative effects of reconnection and KHWs in the solar wind transport, implying that the diffusive transport induced by KHWs may be active at the flank magnetopause during southward IMF.

Four papers in this Topic are dedicated to the evolution and effect of dayside transients including KHWs from the dayside magnetopause along the magnetopause flank down to the distant-tail magnetopause. Wilder et al. compare three KHW events at different locations along the magnetopause flank in the aspect of the occurrence of double layers and electrostatic solitary waves. Both indicative of kinetic-scale activity are most prevalent in the early phase of KHWs and become less common as vortices grow. Mejnertsen et al. use the 3D MHD code to trace dayside flux ropes of a variety of topology that determines the propagation and evolution of flux ropes. Flux ropes containing field lines connected to both hemispheres propagate along flanks and eventually dissipate due to non-local magnetotail reconnection. Wang et al. employ the 3D global hybrid (kinetic ions, fluid electrons) code to analyze the 3D magnetopause distortion driven by foreshock transients propagating anti-sunward. These external transients result in a transient appearance of the magnetosphere as observed by satellites sitting in the flank magnetosheath. The resultant magnetopause distortion also generates compressional magnetic-field perturbations within the magnetosphere and localized field-aligned currents into/out of the ionosphere. Brenner et al. focus on the energy transfer through the magnetopause occurring at dayside, flank, and tail regions during CME-driven storm conditions. According to them, while dayside reconnection is an important process for the energy transfer, the surface fluctuations at flanks dominate the Poynting flux injection, which dominates the energy entry to the magnetosphere.

Němeček et al. statistically analyze the inverse magnetic-field gradient across the magnetopause events whose occurrence rate increases toward flanks and under strong southward IMF. The intensive reconnection during southward IMF drives strong magnetospheric currents that overheat the magnetospheric plasma, which leads to a diamagnetic effect (decrease in the magnetic field) and increases the plasma pressure on the magnetospheric side.

KHWs/KHVs are ubiquitous in planetary magnetospheres. Delamere et al. review these processes on Saturn's magnetopause environment from the perspective of 2D and 3D hybrid simulations that resolve the ion kinetic scale. They also investigate heavy ion effects and find that the heavy ions not only modify the growth rate of KHI but also reduce Alfvén speed which increase the fraction of resonant particles in the wave-particle interaction, thus, affecting mass transport across the magnetopause. These results would be applied to other KH-unstable planetary magnetopause.

As organized in this editorial, articles published in this Research Topic emphasize the role and impact played by the magnetopause dynamics in mass, momentum and energy transfer between the solar wind and magnetosphere. Unprecedented high-resolution *in-situ* observations and analytic/numerical studies are integrated to shed light on how this transfer is facilitated throughout the entire magnetopause over micro-to macro-scales. We believe that articles collected in this Topic present the most active fronts of the magnetospheric research field and promote a comprehensive understanding by filling gaps in the role and importance of flank-magnetopause processes bridging the dayside and distant tail dynamics.

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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