Investigation of two macroscale energization processes: the Kelvin-Helmholtz instability at the dayside magnetopause and reconnection-driven transport in the plasma sheet

Guillaume Peyrichon*[1], Jean-François Ripoll[1,2], Hazem El-Rabii[3], Adam Michael[4], Viacheslav Merkin[4], Mélanie Cosmides[1,2], Kareem Sorathia[4], and Sasha Ukhorskiy[4]

[1]CEA, DAM, DIF, F-91297 Arpajon, France – DAM Île-de-France – France

[2]Université Paris-Saclay, CEA, LMCE, Bruyères-le-Châtel, France – DAM Île-de-France, Université Paris-Saclay,Sorbonne Universités – France

[3]Institut Pprime, UPR 3346 CNRS, 86073 Poitiers, France – Institut Pprime, UPR 3346 CNRS, 86073 Poitiers, France – France

[4]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, United-States – États-Unis

Résumé

This study investigates two distinct mechanisms energizing ions within Earth's magnetosphere: the Kelvin-Helmholtz instability (KHI) at the dayside magnetopause and reconnection-driven transport in the plasma sheet, using the MAGE 3D global MHD model.

At the dayside magnetopause, we study the development of the KHI with and without a southward-to-northward (SN) turning. We show that the SN transition moves the magnetopause outward, increasing plasma density near its inner edge and creating an additional mixing layer. We establish general KHI growth rate diagrams, which depend sensitively on the transverse profiles of both flow velocity and density. In this study, we demonstrate that there are three mechanisms that lower KHI frequencies at the dayside magnetopause. First, we show that the SN transition modifies KHI frequency response: the enhanced plasma density at the shear interface suppresses small-scale KHI structures while amplifying larger-scales, acting as a low-pass filter. Consequently, KHI spectrum shifts to lower frequencies, promoting Pc5-Pc4 pulsations. Furthermore, we find multiple KHI onsets promoting various growths throughout the magnetopause: KH frequencies and growth rates are found to decrease downstream. Finally, in the rest frame, KH frequencies are lowered due to a Doppler shift (Pc6-Pc5) suggesting that KHI can amplify fast magnetosonic waves propagating along standing field lines. KHI is thought to trigger field line resonance that enhances the dayside ions radial diffusion toward the Earth.

In the plasma sheet, the energization process is dominated by magnetic reconnection, driven by the orientation and variability of the IMF. Northward IMF produces a quasi-steady tail with weak, persistent fluctuations, while southward IMF induces intermittent, bursty reconnection-mediated transport, characterized by earthward plasma jets and tailward plasmoid ejecta. Tailward plasmoids remain localized near the sheet center, with fast earthward

*Intervenant

flows deflecting above or below, consistent with split-flow channels constrained by momentum and magnetic tension. Statistical analyses, including probability density functions, lagged-increment statistics, and autocorrelation times, uncover a recurring 35–40 minute modulation across the plasma sheet, signaling global tail reconfiguration. These signatures align with spacecraft observations of intermittency, exhibiting similar fluctuation amplitudes and decorrelation times despite variations in density and velocity maxima.

Together, these processes illustrate how large-scale magnetospheric dynamics, such as KHI and magnetic reconnection, energize ions, shaping the magnetosphere's plasma variability and intermittency.