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Hybrid simulations of the formation and evolution of magnetosheath jets

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Magnetosheath jets are localized structures of enhanced dynamic pressure that are frequently observed in the Earth's magnetosheath. Jets with a sufficient scale size can traverse the magnetosheath to impact the magnetopause, triggering indentation, magnetic reconnection, and subsequent global magnetospheric responses. Understanding the formation of these jets, especially the geoeffective ones, is crucial for studying their role in the solar wind-magnetosphere coupling.

Previous studies have shown that magnetosheath jets are closely related to shock ripples, shock reformations, and foreshock compressive structures, all of which are linked to the evolution of foreshock waves excited by ion beam instabilities. However, the complete evolution from ion beams to downstream magnetosheath jets and the specific roles of solar wind parameters remain unclear.

In this study, we investigate this process using hybrid simulations. Our results show that shock-reflected ions form a hot beam near the shock front, which excites quasi-parallel propagating waves. These waves interact non-linearly, forming a new, non-propagating perpendicular mode. This new mode is unstable in the foreshock plasma configuration, leading to its growth into large-amplitude, large-scale compressive structures. The interaction of these compressive structures with the shock front generates the downstream magnetosheath jets. Because these structures do not propagate in the plasma reference frame, they can interact with fixed positions on the shock front for an extended period when the shock angle is near-zero. This condition is therefore favorable for the formation of large-scale magnetosheath jets.

References

[1] Hietala, H., Laitinen, T. V., Andréeová, K., Vainio, R., Vaivads, A., Palmroth, M., Pulkkinen, T. I., Koskinen, H. E. J., Lucek, E. A., and Rème, H. (2009). Supermagnetosonic jets behind a collisionless quasiparallel shock. Physical Review Letters, 103(24).

[2] Raptis, S., Karlsson, T., Vaivads, A., Pollock, C., Plaschke, F., Johlander, A., Trollvik, H., and Lindqvist, P.-A. (2022). Downstream high-speed plasma jet generation as a direct consequence of shock reformation. Nature Communications, 13(1).

[3] Ren, J., Lu, Q., Guo, J., Gao, X., Lu, S., Wang, S., and Wang, R. (2023). Two-dimensional hybrid simulations of high-speed jets downstream of quasi-parallel shocks. Journal of Geophysical Research: Space Physics, 128(8).

[4] Suni, J., Palmroth, M., Turc, L., Battarbee, M., Johlander, A., Tarvus, V., Alho, M., Bussov, M., Dubart, M., Ganse, U., Grandin, M., Horaites, K., Manglayev, T., Papadakis, K., Pfau-Kempf, Y., and Zhou, H. (2021). Connection between foreshock structures and the generation of magnetosheath jets: Vlasiator results. Geophysical Research Letters, 48(20).

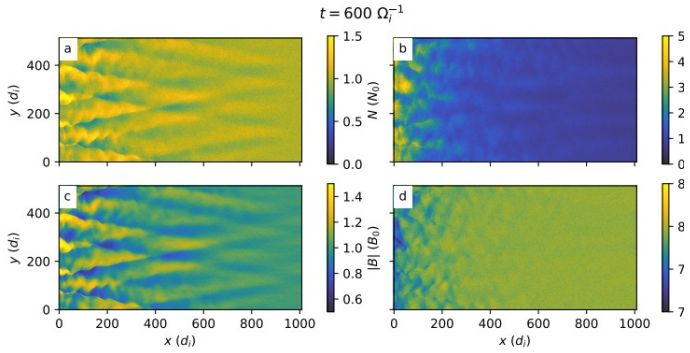

Figure 1: The compressive structures evolved from the upstream waves in a foreshock-only simulation. The quasi-periodic structures akin the ones presented in reference [4].

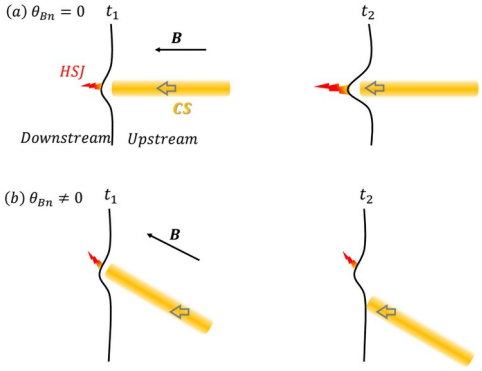

Figure 2: The sketch of the generation mechanism of large-scale high-speed jets (HSJs). Large scale jets only forms when the shock angle is close to zero.