6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

# Cross-scale dynamics driven by plasma jet braking in space

C. M. Liu[1,2,3], A. Vaivads[2], Yu. V. Khotyaintsev[3], D. B. Graham[3], and *MMS* team

[1] School of Space and Environment, Beihang University, Beijing, China, [2] Space and Plasma Physics, KTH Royal Institute of Technology, Stockholm, Sweden, [2] Swedish Institute of Space Physics, Uppsala, Sweden

e-mail (speaker): cmliu@buaa.edu.cn

Plasma jets are ubiquitous in space. In geospace, jets can be generated by magnetic reconnection. These reconnection jets, typically at fluid scale, brake in the near-Earth region, dissipate their energies, and drive plasma dynamics at kinetic scales, generating field-aligned currents which are crucial to magnetospheric dynamics. Understanding of the cross-scale dynamics is fundamentally important, but observation of coupling amongst phenomena at various scales is highly challenging. Here we report, using unprecedently high-cadence data from NASA's Magnetospheric Multiscale Mission, the first observation of cross-scale dynamics driven by jet braking in geospace. We find that jet braking causes MHD-scale distortion of magnetic field lines and development of an ion-scale jet front which hosts strong Hall electric fields. Parallel electric fields arising from the ion-scale Hall potential generate intense electron-scale field-aligned currents, which drive strong Debye-scale electrostatic solitary waves. Debye-scale waves conversely limit intensity of the field-aligned currents, thereby coupling back to the large-scale dynamics. Our study can help understand how energy deposited in large-scale structures is transferred into small-scale structures in space.

Using high-cadence data from the MMS mission, we demonstrate that jet braking induces coupling amongst phenomena from MHD scale and down to Debye scale. When jets are slowed down and get diverted into dawn-dusk direction in the near-Earth region, they push nearby magnetic field lines, leading to distortion of the magnetic field line. A clear feature associated with such distortion is the bipolar change of $B_y$ component during neutral sheet crossing, which is seen in our observation and also in recent MHD simulation[1].

Jet braking is confirmed to be connected with the establishment of kinetic-scale structures at the ion-scale jet front. Intense sub-ion-scale Hall electric fields, established in response to the jet evolution, are observed at the front. On the front's low-density side, intense tailward Hall field is observed, which has been predicted by recent PIC simulations[2] but never reported in observations hitherto. We find that the intense tailward Hall field can constitute a strong potential difference close to ion thermal energy, therefore they can reflect and brake the local ion flow.

The sub-ion-scale Hall physics is observed to be related with the formation of the electron-scale electron beam. Recent kinetic analysis[3] suggests that electrostatic Hall potential arising from Hall fields at the front varies along the magnetic field line since local values of plasma parameters are different. The varying Hall potential along the magnetic field line thus will cause parallel electrostatic potential along the field line and therefore parallel electric field. The consequent parallel electric field is predicted to peak within the Hall $E_x$ peak consistent with our observations where the electron beam and the Hall $E_x$ peak are simultaneously detected. In our case, the consequent field-aligned currents are intense (~400 nA m-2), at least an order of magnitude larger than previously reported.

The electron-scale beam is found to be further constrained by Debye-scale turbulence. Owing to their slow phase speed, these electrostatic waves can couple the fast electrons to background slow ions, leading to braking of the beam and therefore limiting intensity of the field-aligned currents developed at larger scales. Our observations, demonstrating cross-scale dynamics driven by jet braking, may help understand how energy deposited in large-scale structures is transferred to small-scale structures in space.

References

[1] Birn, J., & Hesse, M., 2014, JGRA, 119, 3503
[2] Drake, J. F., Swisdak, M., Cassak, P. A., & Phan, T. D. 2014, GeoRL, 41, 3710
[3] Ganguli, G., Crabtree, C., Fletcher, A. C., Tejero, E., Malaspina, D., & Cohen, I. 2018, NatSR, 8, 17186