Kinetic simulations of the magnetospheric substorms guided by mining of the space magnetometer data

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On the example of the Earth's magnetosphere, it is demonstrated how modern machine learning methods, such as the data mining (DM), can significantly improve first-principles modeling of space plasmas. Mining the multi-decade databases of spaceborne magnetometer observations[1,2] creates a detailed empirical picture of the magnetospheric magnetic field on storm and substorm scales. It shows in particular that in the growth phase of a substorm, the magnetotail current sheet is thinned and stretched in the antisunward direction, and a region of the magnetic flux accumulation (green dashed rectangle in Figure 1) forms[3]. This feature critically changes the current sheet stability leading to the formation of dipolarizations fronts (DFs), regions with the sharp increase of the northward magnetic field B_z (Figure 1b) and new X-lines in their trailing region (Figures 1c and 1d) in PIC simulations of similar plasma equilibria.[4] Weak external driving of the system causes the formation of two X-lines with steady magnetic reconnection near the more distant X-line and unsteady reconnection closer to Earth, where the electric field peaks in DFs. This combination of steady and unsteady reconnection regions is confirmed by the DM analysis.

Ion-scale thin current sheets in the night side of the magnetosphere are negatively charged and their current is dominated by electrons. Their PIC simulations[5] reveal that the change of topology is preceded by the formation of plasma watersheds (WSs), regions of diverging ion and electron flows. Ion and electron WSs differ due to different magnetization of ions and electrons, which can be quantified by their agyrotropy parameters. They are also detected in observations of reconnection by the new four-probe MMS mission.[5]

Another impressive demonstration of the DM capabilities is an almost perfect matching between a unique set of 26 points - X-lines encountered by MMS in 2017-2020 - and their global DM reconstructions.

References

[1] M. I. Sitnov *et al*, J. Geophys. Res. **113**, A07218 (2008)
[2] G. K. Stephens et al, J. Geophys. Res. **124**, 1085 (2019)
[3] M. I. Sitnov *et al*, J. Geophys. Res. **124**, 8427 (2019)
[4] M. I. Sitnov *et al*, Front. Phys. **9**, 90 (2021)
[5] M. I. Sitnov *et al*, Geophys. Res. Lett. **48**, e2021GL093065 (2021)

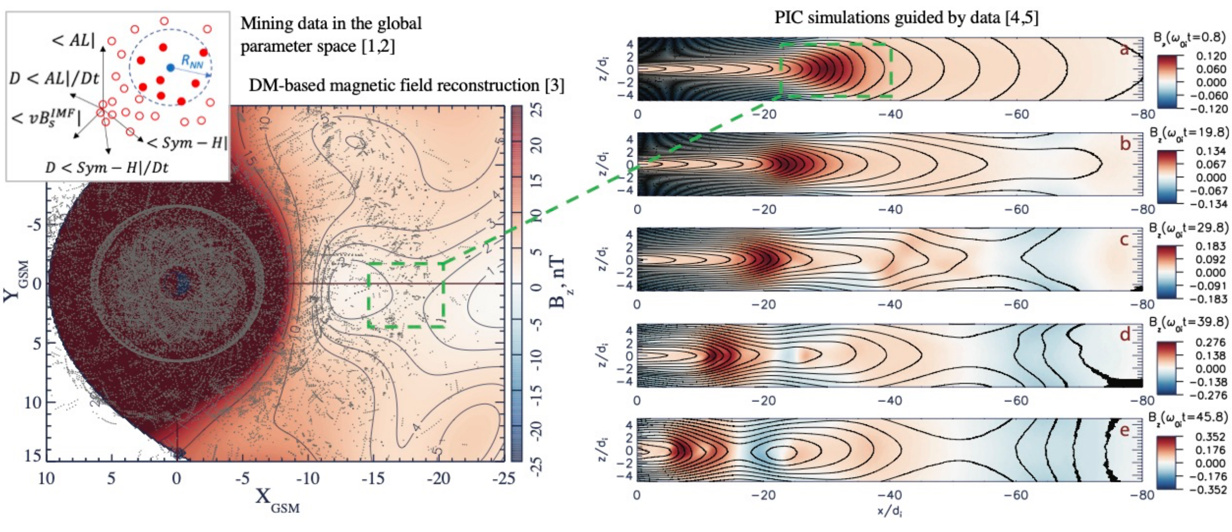

Fig. 1. Right panels (a-e) show the evolution of meridional distribution of the northward magnetic field component $B_z(x,z)$ in PIC simulations of the magnetotail current sheet guided by DM-based magnetic field reconstructions for the 13 February 2008 substorm illustrated by the left panels. The main of them shows the equatorial B_z distribution[3] at the end of the growth phase (02:30 UT), with $\sim 5\cdot 10^4$ grey dots showing the projections of the spacecraft coordinates selected for the reconstruction because they neighbor the event of interest in the space of global storm and substorm parameters parameters *Sym-H* and *AL* as well as the solar wind electric field parameter vB_s^{IMF} (inset)[1,2]. d_i is the ion inertial length and coordinates on the left are normalized by the Earth's radius $R_E \sim 10 d_i$.