URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

Evidence of the Alfven Transition Layer in the cusp region: Global 3D PIC simulation of the solar wind - Earth magnetosphere interaction

D. Cai(1) and B. Lembege(2)
(1) CS. University of Tsukuba, Japan, http://www.cavelab.cs.tsukuba.ac.jp
(2) LATMOS IPSL/CNRS/UVSQ, 78280 Guyancourt, France

Abstract

Using 3D global Particle-In-Cell (PIC) simulations with the northward interplanetary magnetic field (IMF), we show the Alfven transition layer (ATL) that distinguishes the stagnant exterior cusp (SEC) from the magnetosheath. We show ATL extends from SEC to dayside magnetosheath both duskward and dawnward, asymmetrically. We discuss how ATL characterize the magnetosphere, which is strongly associated with the complicated ion and electron fluxes mainly due to the curvature drifts.

1 Introduction

The magnetospheric polar cusp is a significant region to transfer mass, momentum, and energy from the solar-wind to the internal magnetosphere in particular to the plasma sheet. Performing the global 3D Particle-In-Cell (PIC) simulations, these key regions and these associated local transfers have been investigated. Some key structures so-called the stagnant cusp exterior (SEC) and the Alfven transition layer (ATL) that distinguish the magnetosheath from the SEC have been fully retrieved. and are analyzed in detail. In particular, present 3D results show (i) that ATL extends above and below the cusp region and (ii) how the solar wind ion flux succeeds to penetrate the intricated cusp structures through the ATL.

2 3D Global Particle-In-Cell Simulation

In the present report, the magnetospheric cusp region, and, more particularly, the dynamics of both the cusp boundaries and solar-wind particle entries are mainly analyzed. The 3D PIC simulations are performed in three steps: (1) The interplanetary magnetic field (IMF) in an exactly northward direction is applied to understand more evidently the magnetospheric cusp signatures to compare with the statistical 3-years Cluster observations in [1]; (2) the northward IMF is changed gradually to dusk-dawn; and, (3) to southward. Comparing with our previous papers, the three-dimensional global PIC simulation with a relatively higher grid size, where one grid size equal to 0.2 earth radii, is performed [2-12]. Our new simulation results indicate that different quantities have to be adopted to evidence the three significant signatures of the magnetospheric cusp with the northward IMF [13]. They are: (1) a more draped magnetic field topology adjacent to SEC outer boundary; (2) some strong density peaks inside the cusp including multiple density humps; these peaks shift poleward and disappear for the high latitude; and (3) a strong peak in the ion field-aligned flux inside the cusp region, accompanying a tailward and sunward convection flows at low and high latitudes, respectively, as indicated in Fig. 1.

3 Alfven Transition Layer

The statistical and experimental Cluster satellite observations focusing on the magnetospheric cusp boundaries investigated by [1] have clearly shown a transition layer between the outer boundary of SEC and the magetosheath as displayed in Fig. 2. This transition layer can be defined as a layer with $\mathrm{Log}(M_A)\sim 0$, and enables the magnetosheath high-speed flow to enter from the magnetosheath to the inside cusp. This layer characterizes a transition from super-Alfvenic to sub-Alfvenic plasma bulk flow from the exterior to the interior side of the outer SEC boundary. This layer appeared mainly when the IMF is northward. This previous work is mainly based on measurements reported within a 2D meridian plane supported by Tsyganenko mode). Our 3D PIC simulation results can reproduce quite well the existence of this layer within the meridian plane for the purely northward IMF case. However, the location of this layer is different in the sense that it slightly shifts below the X reconnection region associated with the nearby magnetopause, and above the outer boundary of SEC. Moreover, our 3D PIC simulations allow us to show the global view of the cusp region. In particular, the features that are not accessible by the MHD simulations are shown. An intense analysis allows us to reproduce the characteristics of ATL that discloses to be related to the complex two different 3D spiral particles entry into the cusp region. They are due to the curvature drift and gyration. Through the thinnest ALT layer above the outer boundary of SEC, the ion fluxes are intensified and very strong. This also suggests the existence of very local ion precipitation. In addition, our 3D PIC simulation results clearly show that this thin ATL expands towards areas out and even far from the cusp region and outside the meridian plane.

In the present report, we show the complicated ATL structures and their associated ion and electron fluxes that enter into the cusp region.

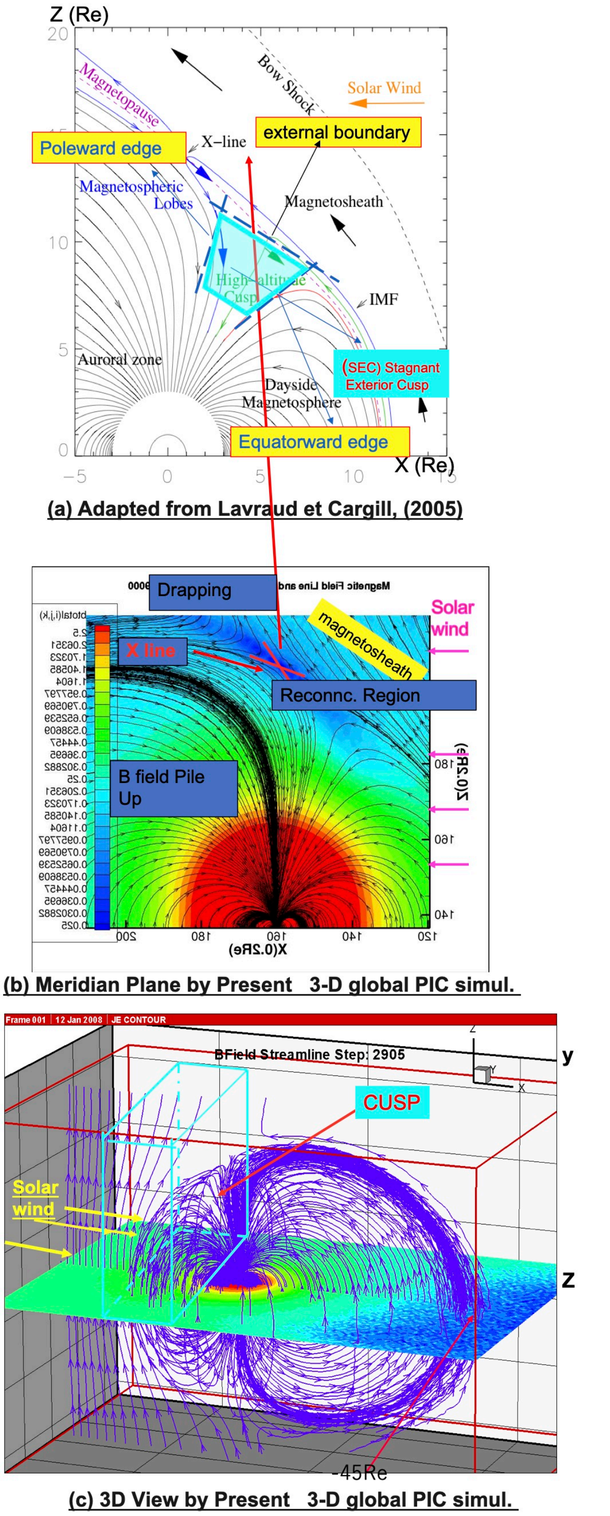

Figure 1: Meridian planes of (a) schematic and (b) simulation near the polar cusp regions. (c) The global view of earth magnetic field. The light blue box is SEC.

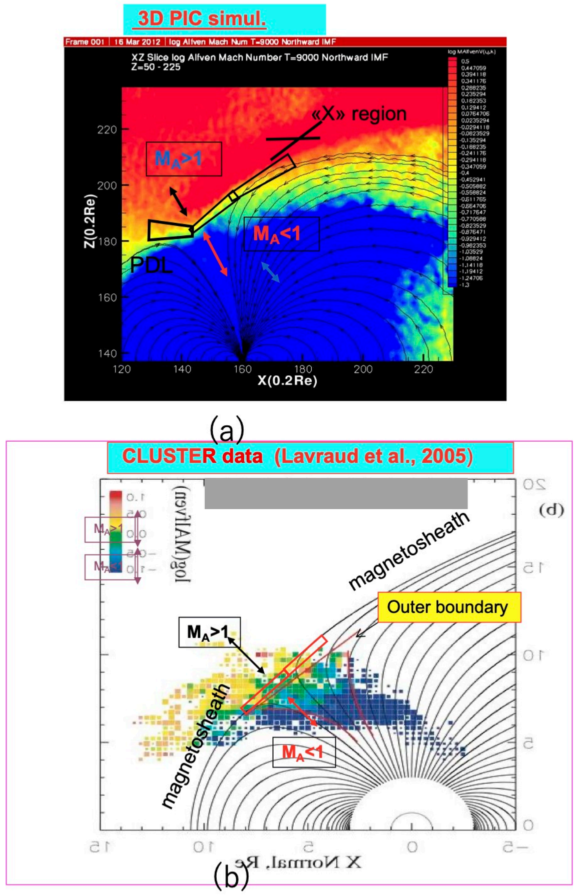

Figure 2. The Alfven transition layer shown as log M_A contour plot: (a) log M_A plot in this simulation, and (b) log M_A plot in the three-year statistical Cluster observations. (taken from [13])

6 Acknowledgements

We would like to thank the Research Institute of Sustainable Humanosphere for providing access to Advanced Kyoto-Daigaku Denpa-Kagaku Keisanki-Jikken (A-KDK) supercomputers.

7 References

1. B. Lavraud *et al.*, "Cluster observations of the exterior cusp and its surrounding boundaries under northward IMF," *Geophysical research letters,* vol. 29, no. 20, pp. 56-1-56-4, 2002.

2. O. Buneman, T. Neubert, and K. I. Nishikawa, "Solar wind-magnetosphere interaction as simulated by a 3-D EMparticle code," *Plasma Science, IEEE Transactions on,* vol. 20, no. 6, pp. 810-816, 1992.

3. D. Cai, K. Nishikawa, and B. Lembege, "Magnetotail field topology in a three-dimensional global particle simulation," *PLASMA PHYSICS AND CONTROLLED FUSION,* vol. 48, no. 12B, p. 123, 2006.

4. D. Cai, W. Tao, X. Yan, B. Lembege, and K. Ä. Nishikawa, "Bifurcation and hysteresis of the magnetospheric structure with a varying southward IMF: Field topology and global three‚Äêdimensional full particle simulations," *Journal of Geophysical Research: Space Physics,* vol. 114, no. A12, 2009.

5. D. Cai, X. Yan, K. Ä. Nishikawa, and B. Lembge, "Particle entry into the inner magnetosphere during duskward IMF By: Global three‚3-dimensional electromagnetic full particle simulations," *Geophysical research letters,* vol. 33, no. 12, 2006.

6. [D. S. Cai, Y. Li, T. Ichikawa, C. Xiao, and K. I. Nishikawa, "Visualization and criticality of three-dimensional magnetic field topology in the magnetotail," *Earth Planets Space,* vol. 53, p. 1011, 2001.

7. B. Lembege, D. Cai, W. Tao, and K. Nishikawa, "Signatures of substorm triggering in the magnetotail during IMF," 2008.

8. K.-I. Nishikawa and S.-i. Ohtani, "Global particle simulation for a space weather model: Present and future," *Plasma Science, IEEE Transactions on,* vol. 28, no. 6, pp. 1991-2006, 2000.

9. K. I. Nishikawa, "Particle entry into the magnetosphere with a southward interplanetary magnetic field studied by a three-dimensional electromagnetic particle code," (in English), *J Geophys Res-Space,* vol. 102, no. A8, pp. 17631-17641, AUG 1 1997.

10. K. I. Nishikawa and S. Ohtani, "Global particle simulation for a Space Weather Model: Present and future," *IEEE Transactions on Plasma Science,* vol. 28, no. 6, pp. 1991-2006, 2000.

11. K. I. Nishikawa and S. Ohtani, "Evolution of thin current sheet with a southward interplanetary magnetic field studied by a three-dimensional electromagnetic particle code," (in English), *J Geophys Res-Space,* vol. 105, no. A6, pp. 13017-13028, JUN 1 2000.

12. K. I. Nishikawa and S. Ohtani, "Particle simulation study of substorm triggering with a southward IMF," (in English), *Dynamic Processes in the Critical Magnetospheric Regions and Radiation Belt Models, Proceedings,* vol. 30, no. 12, pp. 2675-2681, 2002. [Online].

13. D. Cai, A. Esmaeili, B. Lembège, and K. I. Nishikawa, "Cusp dynamics under northward IMF using three ‐ dimensional global particle ‐ in ‐ cell simulations," *Journal of Geophysical Research: Space Physics,* vol. 120, no. 10, pp. 8368-8386, 2015.