Categorizing FTE-like Boundary Layer Signatures Produced by the Kelvin-Helmholtz Instability Using Hall-MHD Simulations and Virtual Spacecraft

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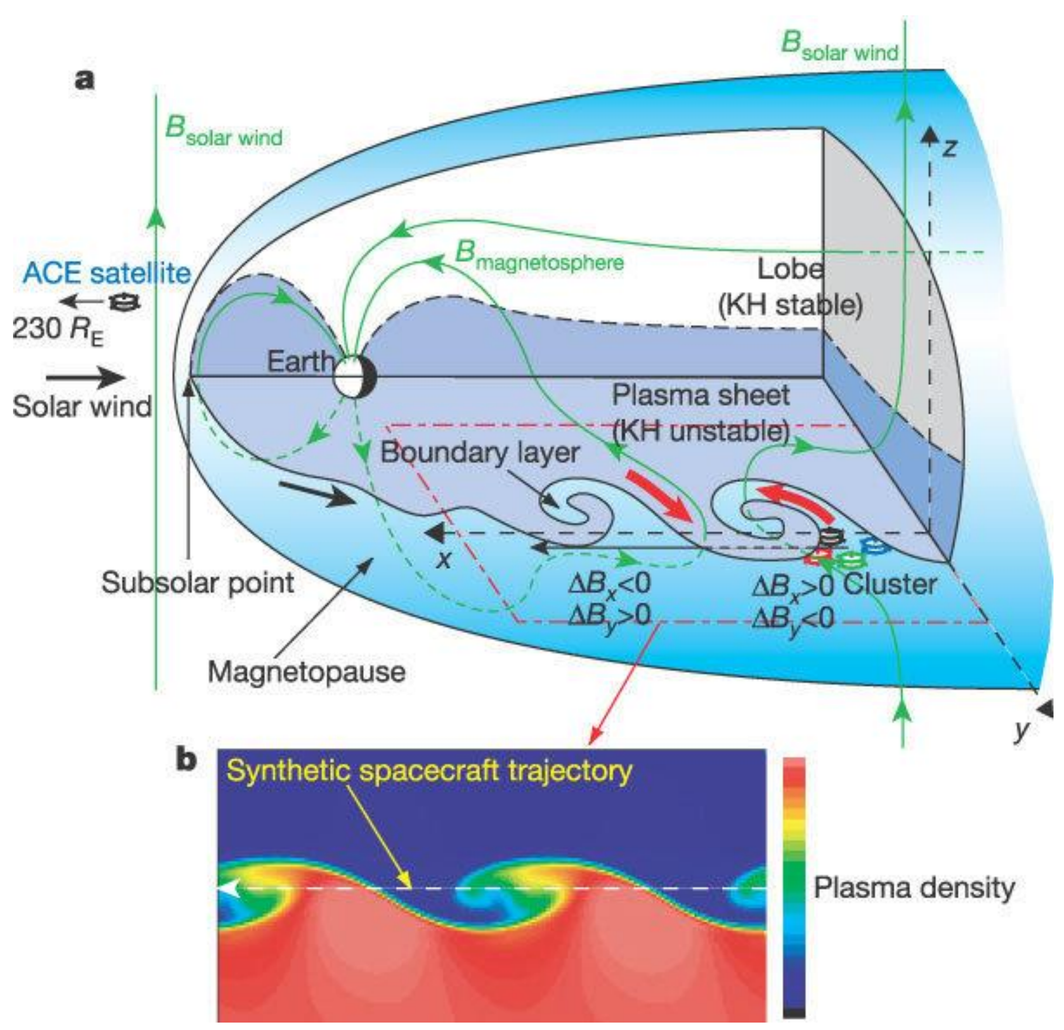
INTRODUCTION

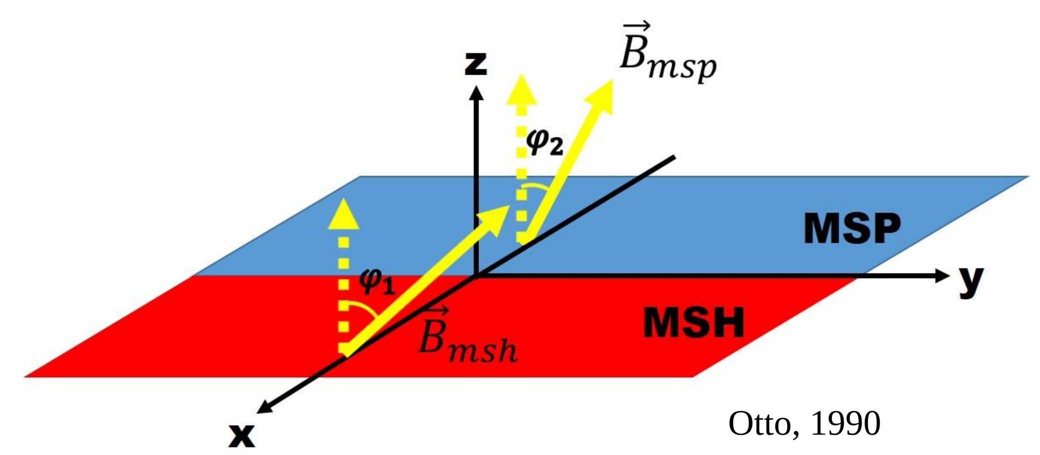
Kelvin-Helmholtz instability (KHI) and magnetic reconnection (Dungey, 1961) are two fundamental processes at the planetary magnetospheres that lead to plasma transport over the magnetospheric boundary (Nykyri & Otto, 2001). The Kelvin-Helmholtz Instability occurs at the interface between two fluids with velocity shear. From the Bernoulli principle, the deformation of a boundary causes a constriction that leads to increased velocity and reduced pressure. The expansion of the boundary by contrast leads to reduced flow and an increased pressure. The resulting pressure gradient forces, pointing into opposite directions, trigger the formation of a vortex and make waves grow and become unstable



Hasegawa et al., 2004

◄ Figure 1. Three-dimensional cutaway diagram of Earth's magnetosphere. The K-H vortex structure can be observed at the flank of magnetosphere.

▼ Figure 2. The illustration of simulation geometries. Yellow arrows denote the total magnetic field orientation in magnetosphere and magnetosheath.



Otto, 1990

MOTIVATION

The spacecraft often report a reversal of the normal component of the magnetic field (b_n) when crossing the magnetopause. These bipolar variations of the B_n are one characteristic signature of the flux transfer events (Russell & Elphic, 1978). Flux Transfer Events (FTEs) are generally accepted to be produced by the magnetic reconnection at the dayside magnetopause. However, there are still other possible mechanisms which create FTE-like features in the boundary layer. Kelvin-Helmholtz instability can be one of the candidates. By using two-dimensional MHD simulations, we study FTE signatures observed by virtual satellites as they pass through K-H vortex along different trajectories. While the satellites encountered well-developed KH vortex and spine region, the signatures, when detected by a spacecraft in the magnetosphere, would be easily misidentified as FTEs.

► Figure 3. In the bottom panel, the normal component distribution are shown in 2D plane with color map. The vector field denotes the plasma velocity, and the gray contour lines denote the total in-plane magnetic field. In the top panel, the black and red lines represent time variation of normal b_n and total magnetic field b_{tot}, which are observed by virtual satellite.

SIMULATION

A full set of MHD equations are solved to study the Kelvin-Helmholtz behavior temporally and spatially.

$$\frac{\partial \rho}{\partial t} = -\nabla \cdot (\rho \boldsymbol{v}), \quad (1)$$

$$\frac{\partial \rho \boldsymbol{v}}{\partial t} = -\nabla \cdot \left(\rho \boldsymbol{v}\boldsymbol{v} + \frac{1}{2}(p + b^2)\bar{\bar{I}} - \boldsymbol{b}\boldsymbol{b} \right), \quad (2)$$

$$\frac{\partial \boldsymbol{b}}{\partial t} = -\nabla \times (\boldsymbol{v} \times \boldsymbol{b} - \eta \boldsymbol{j}), \quad (3)$$

$$\frac{\partial h}{\partial t} = -\nabla \cdot (h\boldsymbol{v}) + \frac{\gamma - 1}{\gamma} h^{1-\gamma} \eta j^2, \quad (4)$$

$$\boldsymbol{j} = -\nabla \times \boldsymbol{b}, \quad (5)$$

where ρ is the density, $\boldsymbol{v}$ is the plasma velocity, $\boldsymbol{b}$ is the magnetic field, p is the plasma pressure, η is the anomalous resistivity, and $\boldsymbol{j}$ is the current density. Totally 12 sets of numerical parameter are applied in the simulation. As categorized in Table 1, each of the three density groups includes the combinations of plasma pressure and magnetic field. For the same plasma parameters across the magnetosphere and magnetosheath, we slightly adjusting the projection angle of the magnetic field in order to discuss how in-plain field affect the evolution of KHI.

Table 1. The list of plasma pressure and magnetic field in 12 cases

Density	$\rho_{msp} = 1.00, \rho_{msh} = 1.00$							
Case No.	Case 01		Case 02		Case 03		Case 04	
	MSP	MSH	MSP	MSH	MSP	MSH	MSP	MSH
Plasma Pressure P	1	1	2	2	1	4	4	1
Magnetic Field B	1	1	1	1	2	1	1	2
Plasma Beta	1	1	2	2	0.25	4	4	0.25

Density	$\rho_{msp} = 1.75, \rho_{msh} = 0.25$							
Case No.	Case 05		Case 06		Case 07		Case 08	
	MSP	MSH	MSP	MSH	MSP	MSH	MSP	MSH
Plasma Pressure P	1	1	2	2	1	4	4	1
Magnetic Field B	1	1	1	1	2	1	1	2
Plasma Beta	1	1	2	2	0.25	4	4	0.25

Density	$\rho_{msp} = 0.25, \rho_{msh} = 1.75$							
Case No.	Case 09		Case 10		Case 11		Case 12	
	MSP	MSH	MSP	MSH	MSP	MSH	MSP	MSH
Plasma Pressure P	1	1	2	2	1	4	4	1
Magnetic Field B	1	1	1	1	2	1	1	2
Plasma Beta	1	1	2	2	0.25	4	4	0.25

Table 2. The in-plane projection angle applied for each cases

	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	No.11	No.12
φ_1	3	3	3	3	10	10	-3	-3	-3	-3	-10	-10
φ_2	3	10	-3	-10	3	-3	3	10	-3	-10	3	-3

RESULTS and CONCLUSION

The formation of b_n reversal can be made up of spine region and leading edge, as shown in Fig. 3a . Besides, an alternative reversal satellite can observed locate at the trailing edge (Fig 3b & 3c). Particularly, the bipolar signature in Fig 3b at $t_A \sim 100$ is accompanied by a local minimum in b_{tot}, while the signature in Fig 3c is accompanied by a b_{tot} local maximum. These features, which named M-shape and W-shape FTE respectively, are commonly interpreted as evidence for magnetic reconnection. In Fig 3d and 3e, the projection angles which determine the orientation and magnitude of in-plane magnetic field make the vortex more diffusive and turbulent during the KHI, the satellite thus observed more small scale bipolar signatures in the nonlinear phase. These analysis examines and categorizes these observed signatures that are clearly generated by the KHI. These results can be used as diagnostic when analyzing spacecraft data to help distinguish KHI created signatures from FTEs.