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Magnetospheric hot ions (H^+ and O^+) behavior in magnetopause reconnection

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Abstract

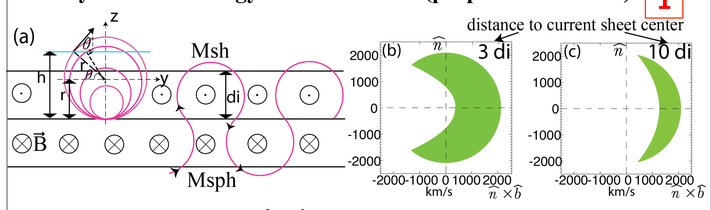
It is still an open question whether and how magnetospheric (Msph) hot ions (H^+ and O^+) are involved in magnetopause (MP) reconnection and how they escape to the magnetosheath (Msh). Heavy ions like O^+ increase the ion mass density, slow the Alfven speed and therefore slow the reconnection rate. However, because of the large gyroradius (R_g), O^+ may not be fully entrained in the flow and its effect depends on kinetic processes. In this study, with MP reconnection events observed by Cluster, we analyse the ion velocity distribution functions (VDFs) to distinguish the behaviours of different ion populations at the MP boundary layer. We suggest with a guide field, higher energy ions may get access further to the Msh side in reconnection outflow. Finite gyroradius effect commonly exists at MP, and helps to determine the depth of ions to arrive on the Msh side. However, there might be mechanisms to retard hot ions entering the reconnection region to maintain the fluid structure, but extremely hot ions can still leak out directly. We also provide models for typical ion VDFs in MP reconnection, especially when there is a guide field.

Introduction

- In reconnection with a guide field, whether the ions undergo a non-adiabatic process to be picked up in the exhaust region depends on their R_g[1][2].
- In the MP reconnection, Msh flow dominates. Magnetospheric hot ions may escape either through reconnection[3] or leakage with finite gyroradius (FG) effect[4].
- In this study, we analyze the motions of Msph hot ions (H^+ and O^+) via VDFs, and discuss possible ways for them to get access to the Msh side.

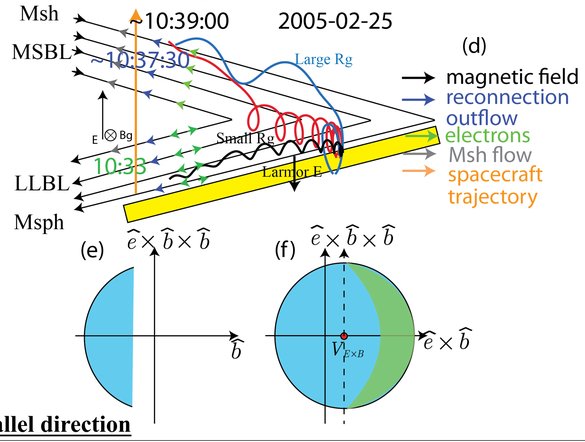
Ion velocity distribution function model

Finite gyroradius effect (FG): Above the boundary, ions show velocity cutoffs in the gyration direction (perpendicular to B) 1



- Increasing V_{cutoff} along $\hat{n}\times\hat{b}$ with increasing depth into the Msh;
- With typical Msh condition, H^+ V_{cutoff} ~1000-2000 km/s, observable;
- VDF shifts with bulk drift velocity;
- V_{cutoff} depends on **guiding center location (l_g) + gyration speed (V_g)**.

Reconnection with a guide field



Parallel direction

- Ions with large R_g: Speiser motion –> picked up, V_{para} reflected in the dHT frame (no E, energy conserved), accelerated in the inertial frame[1]. **V_{para} cutoff** at least $V_{HT,\,para}$;
- **Time-of-flight effect**, (**TOF**): **increasing V_{para} cutoff from the field reversal region to the separatrix**. Trajectories of ions with higher V_{para} can reach closer to the separatrix boundary.

Perpendicular direction

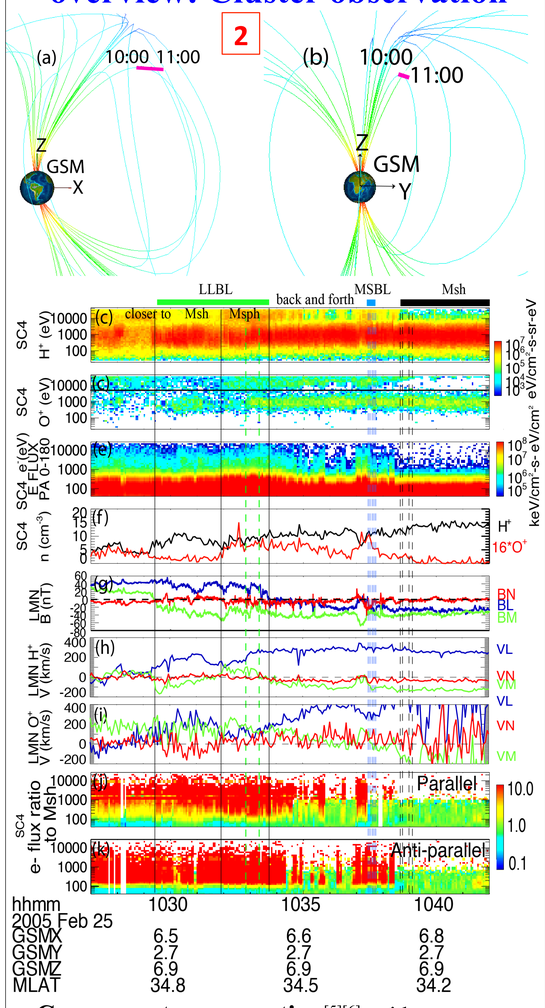
- Ions gyrate around the guide field
- Small R_g ions with adiabatic motion cannot go deep to Msh;
- E_N leads demagnetized ions towards Msh.

Gyration + *Difference in l_g and V_g*

Similar to FG effect: V_{perp} cutoff (Fig. 1c on top of Fig. 1f)

Reconnection on Feb. 25, 2005 overview: Cluster observation

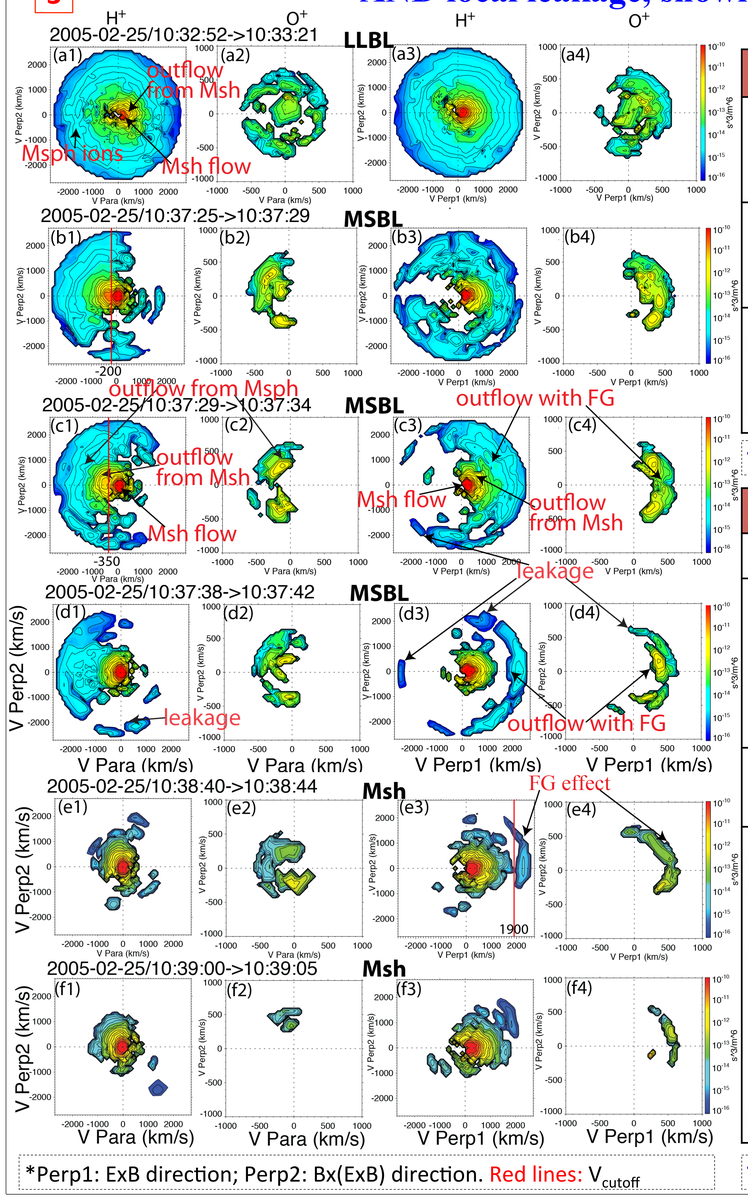
2



- **Component reconnection**[5][6] evidence:
  - Electron flux[6]:
    - LLBL bi-directional
    - MSBL uni-directional;
  - Main change in B_L is at a different time with the change in B_M: guide field;

Magnetospheric hot ions transport to magnetosheath: via reconnection outflow AND local leakage, showing FG effect

3



*Perp1: ExB direction; Perp2: Bx(ExB) direction. Red lines: V_{cutoff}

Region	Direction	Source
LLBL	Parallel, low V	Msh flow
	Parallel high V	Reconnection outflow
MSBL	Parallel(1)	Msh flow
	Antiparallel(2)	Reconnection outflow

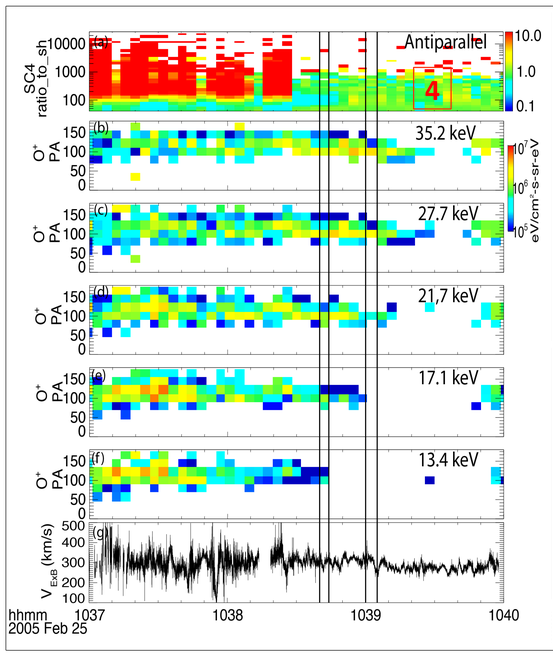
(1)Component along guide field does not change directions in Vpara;
(2)V_{cutoff} increases towards Msh separatrix, TOF.

Table 1. *Msh* origin ions in VDFs

Region	Direction	Source
LLBL	Isotropic	
MSBL	(1) Antiparallel V_{cutoff}	Reconnection outflow
	(2) Perp1 V_{cutoff}	
	(3) High V_{perp}, low V_{para}, gyrotropic	Local leakage.
Msh	(4) Perp1 V_{cutoff}	RX outflow & leakage

(1)V_{cutoff} increases towards Msh separatrix, TOF.
(2)V_{cutoff} increases towards Msh separatrix, high-E ions go further; FG.
(3)There should be mechanisms to retard ions with larger R_g than current sheet scale to maintain the fluid structure, e.g., Larmor electric field[7], so leakage only appears in very high-E ions.
(4)V_{cutoff} increases towards Msh, FG.

Table 2. *Msph* origin hot ions in VDFs.



Estimation for finite gyroradius effect in H^+ and O^+ (Table 3)

- O^+ E_c from PA distribution (Fig. 4b-4f);
- Calculate O^+ V_c ($E = 1/2mv^2$);
- $V_c=V_g+V_d$, drift velocity (V_d) ~ 300 km/s (Fig. 4g), same for H^+ and O^+;
- Estimate H^+ V_g with same R_g ($V_{g,\,H}/V_{g,\,O}=m_O/m_H=16$);
- Calculate H^+ $V_c=V_g+V_d$;
- Compare with VDF (Fig. 3e-3f).

Time	10:38:40	10:39:00
O^+ E_c (keV)	**13.4**	**17.1**
O^+ V_c (km/s)	400	451
O^+ V_g (km/s)	100	151
H^+ V_g (km/s)	1600	2400
H^+ V_c (km/s)	**1900** (Fig. 3e3)	**2700** (~upper limit Fig. 3f3)

Table 3 Subscripts: c - cutoff; g - gyration

Discussions and summary

- **Typical ion VDFs for Msph origin hot ions in the reconnection MSBL with a guide field have been identified and explained with a simple model**:
  - The **Parallel V_{cutoff}**, increasing towards Msh separatrix, is due to TOF effect;
  - The **Perpendicular V_{cutoff}** (with component along outflow), increasing towards Msh separatrix and continuing to increase outside separatrix, is due to FG effect;
  - A **High energy gyrotropic** population (not existing in general), is due to local leakage.
- In MP reconnection, **Msph hot ions (both H^+ and O^+) are involved in outflow**. Thus the heavy ions may affect the outflow speed and reconnection rate.
- **Finite gyroradius effects widely exist at MP**, and determine how far ions can penetrate on the Msh side as a function of the ions' energy.
- **With reconnection, only ions with very high energies can leak out directly.**
- Future work: (1) to look for consistency in more events in the behavior of hot ions in reconnection; (2) to compare with asymmetric reconnection simulations.

References and Acknowledgement

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