Observational test of the dayside magnetopause reconnection rate

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Abstract

In asymmetric reconnection at the dayside magnetopause, the rate (R) is expected to follow Cassak-Shay formula with an aspect ratio around 0.1[1,2]. We perform a statistical study of 13 magnetopause reconnection events observed by Cluster. Our results show that the measured R generally follows the asymmetric prediction. However, the predicted rate only considering the magnetosheath (Msh) contribution also correlates well with the measured R. Cold ions commonly exist near the reconnection region. For individual events, cold ions can make a comparable contribution to the Msh H^+ when there are plasmaspheric drainage plumes; the contribution of magnetospheric hot O^+ can be up to ~30%. However, the variation of solar wind conditions has a larger effect on the variation in the reconnection rate. The aspect ratio does not vary systematically with the O+ content, and 0.1 is a reasonable estimation. The outflow velocity is around the hybrid Alfven speed, but there is not a strong correlation. This may be due to motion of the x-line, or effects of the magnetosheath shear flow.

Motivation

- In asymmetric reconnection like dayside magnetopause, the local reconnection rate (R) is expected to follow Cassak-Shay formula[1]
  $R = \frac{2\delta}{L}(B_{ph}B_{sh})^{3/2}(\mu_0\rho_{ph}B_{sh}+\mu_0\rho_{sh}B_{ph})^{-1/2}(B_{sh}+B_{ph})^{-1/2}$
  where δ/L is the aspect ratio of the diffusion region, usually ρ_{sh} is dominant.

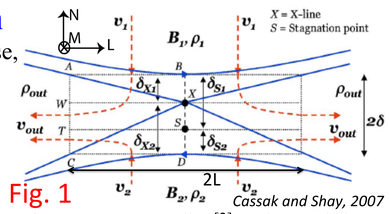
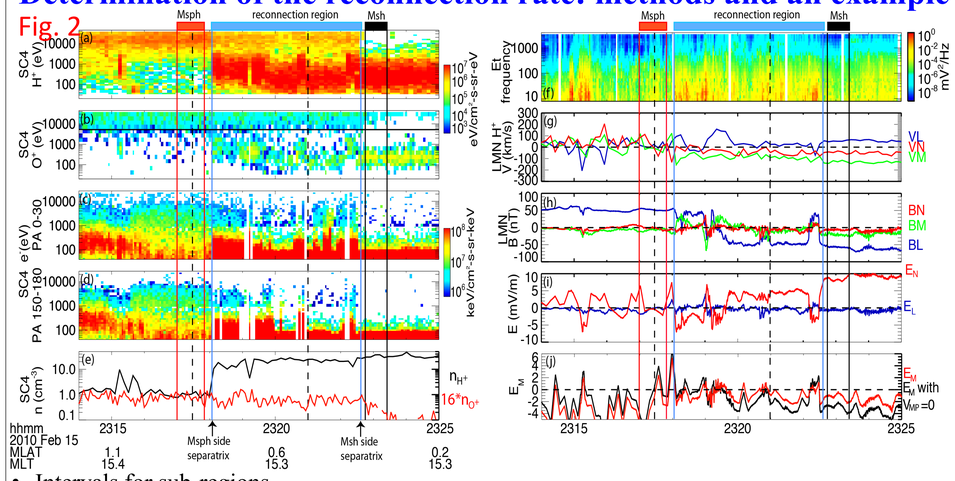


Fig. 1 Cassak and Shay, 2007

- Assuming the Cassak-Shay formula and an aspect ratio of 0.1, recent studies[2] estimated that the plasmaspheric plume can reduce R up to tens of percents; an observational case[3] showed that the reconnection outflow follows the hybrid V_A and is reduced by the plume density.
- O^+, with 16 times the H^+ mass, may be more efficient in reducing R; on the other hand, it may also increase the aspect ratio[4,5] which increases R.
- We present a **statistical study with Cluster** to examine
  - whether the reconnection rate follows the prediction;
  - the contribution of O^+ and cold ions.

Determination of the reconnection rate: methods and an example

Fig. 2



- Intervals for sub-regions
  - Inside reconnection region: waves (Fig. 2f); mixture of plasmas from both sides (Fig. 2a-2d)
  - Msph side separatrix: ion density gradient and cavity (Fig. 2e);
  - Msh side separatrix: boundary of high energy field-aligned e^- (Fig. 2c-2d);
  - Msph (red), Msh (solid black) intervals close to separatrices (blue) with steady n, V and B.
- Measured reconnection rate
  - $R_{measure}=V_{in,sh}*B_{sh}$
  - B_{sh}: average in the Msh interval;
  - Magnetopause motion $V_{MP}=V_{HT,N}$
    - deHoffmann-Teller analysis performed throughout the crossing (dashed black lines);
    - Adjusting E_M to be constant on both side (Fig. 2j);
    - Changes of $V_{HT,N}$ is used as the error bar for R.
  - $V_{in,sh}=V_{N,sh}-V_{MP}$
- Predicted reconnection rate
  - Cassak-Shay formula with parameters evaluated in Msph and Msh intervals, assuming aspect ratio 0.1;
  - O^+ and cold ions (assumed to be H^+) mass densities are included and the fractions of their contributions are evaluated.
- Outflow velocity
  - Choose maximum measured V_L
  - Subtract the shear flow: $V_{L,max}-V_{L,sh}$
  - Compare with the hybrid Alfven speed $V_A=\sqrt{\frac{B_{sh}B_{ph}}{\mu_0}}\sqrt{\frac{B_{sh}+B_{ph}}{\rho_{sh}B_{ph}+\rho_{ph}B_{sh}}}$

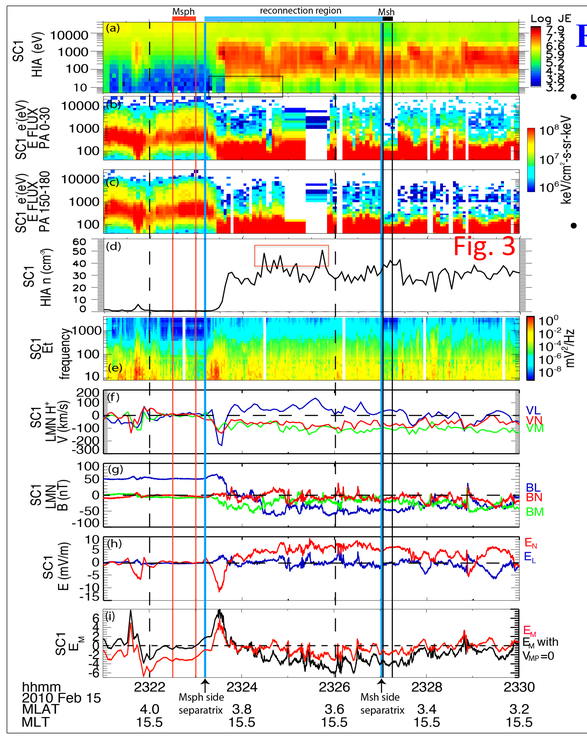
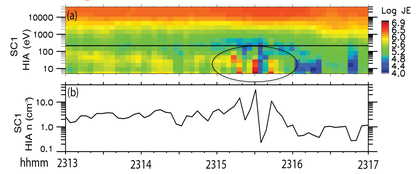


Fig. 3

Evaluation of the cold ion density

- Indications of cold ions
  - Low energy part of the ion spectra close to the separatrix (Fig. 3a);
  - $n>n_{sh}$ inside the reconnection region (Fig.3d);
  - Distribution function (not shown).
- **Density: HIA 5-216 eV**
  - 32.2 cm^{-3} for this event (Fig.4)
  - In order to participate in the reconnection, cold ions need to gain at least the ExB drift velocity at the separatrix
    - E~1 mV/m
    - B~40 nT
    - Energy for ExB drift ~ 3eV (assuming H^+)
    - HIA below 200 eV is likely to capture most of the cold ions near the reconnection region – used for statistical study, angular restriction if needed.

Fig. 4



- **Cold ions clearly appear in 10 out of 13 events**
  - High density (>5cm^{-3}) mainly in the afternoon sector: plume drainage;
  - Low density more scattered in MLT: local cold population.
  - A common population to participate in reconnection

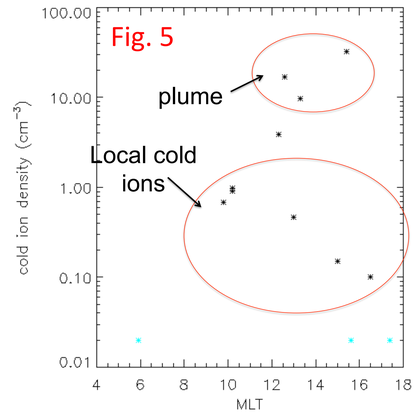
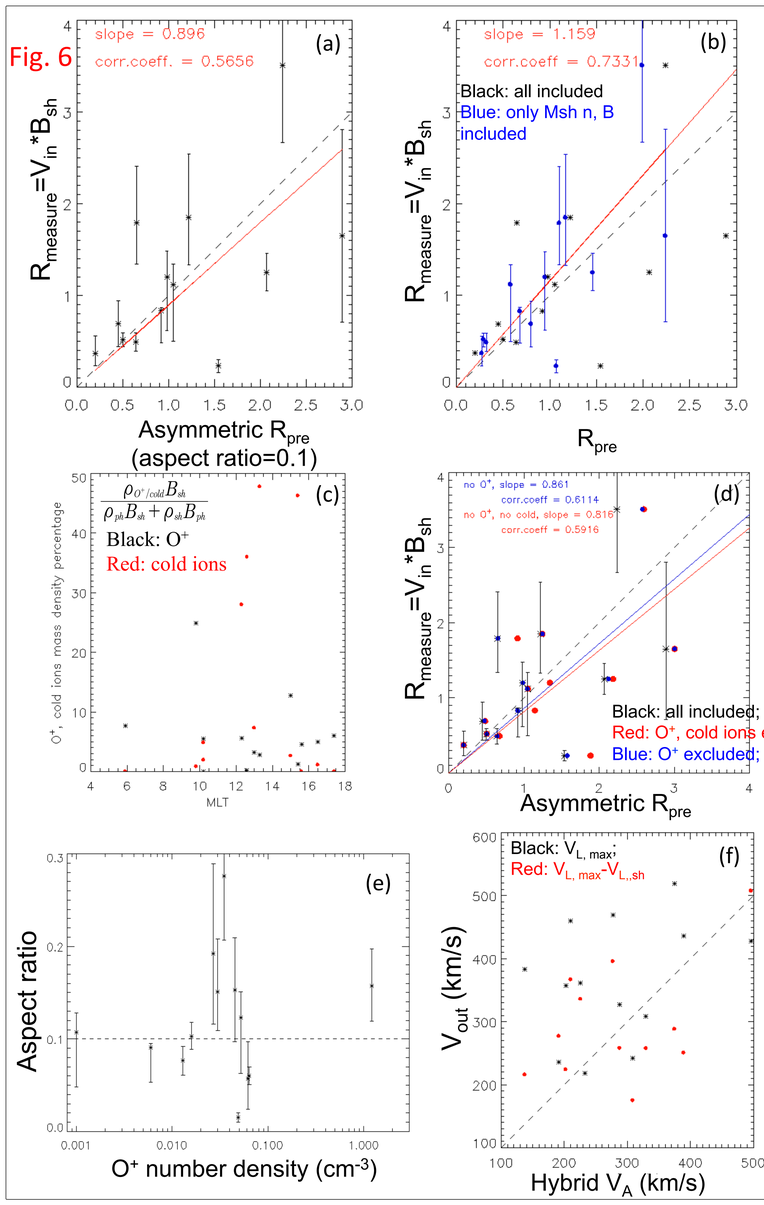


Fig. 6



Statistical results and discussions

We investigate the reconnection rate for 13 magnetopause reconnection events with different geomagnetic activity levels (Kp 1-5)

- Reconnection rate (R)
  - R generally follows the prediction of Cassak-Shay formula (Fig. 6a);
  - Predicted R considering only the contribution from the Msh also correlates well with the measured R (Fig. 6b)
    - Msph n and B can correct R in both directions;
    - The reconnection fluid structure may be dominated by the Msh parameters.
- O^+ and cold ion contribution
  - The contribution (Fig. 6c) to the Cassak-Shay formula is usually small; cold ions in plume can have a comparable (~50%) contributions to Msh H^+; O^+ contribution can be up to ~30%.
  - The variation of Msh (SW) conditions is more dominant than the modification of Msph contribution for R (Fig. 6d).
- Aspect ratio (Fig. 6e)
  - Around 0.1 with large deviations, but not correlated with n_{O+};
  - The effect of O^+ may be smaller than the present error bars.
- Outflow velocity (Fig. 6f)
  - Around hybrid Alfven speed, but does not correlate well;
  - Velocities after the subtraction of Msh flow (red) better correlates with V_A;
    - Shear flow may decrease the outflow velocity[5];
    - X point motion needs to be considered.

Conclusions:

- Dayside magnetopause reconnection rate can be estimated by either the 2D asymmetric (C-S) formula or the formula only considering Msh contribution, with the aspect ratio of 0.1.
- For individual events, the contribution of cold ions and O^+ can be comparable to Msh H^+, but statistically, the variation of Msh/SW conditions dominate the effect on reconnection rate.

References and Acknowledgements

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