Three-dimensional non-steady magnetic reconnection signatures
Model and observation

A. Alexandrova[1], V. Semenov[2], R. Nakamura[1], H. Biernat[1]
[1] IWF/ÖAW, Graz/Austria,
[2] St.Petersburg State University, St.Petersburg, Russia

IWF Space Research Institute — ÖAW Austrian Academy of Sciences

Abstract

In current work we consider magnetic reconnection process in the Earth magnetotail current sheet.
-As reconnection is a locally initiated process, its onset characteristics are difficult to be measured in-situ. However, signatures of reconnection are frequently observed in the Earth magnetotail.

-One consequence of the reconnection is the appearance of fast plasma flows. These flows result in specific disturbances of the plasma parameters in the ambient medium.

-We develop a method to estimate the reconnected magnetic flux, the location of the ion diffusion region and the length of the X-line from the properties of magnetic field and plasma velocity fluctuations in the surrounding regions of this plasma flow.

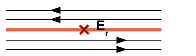
-The analysis is based on a 3D time dependent reconnection model where the X-line has a finite length. In this framework, we obtain a system of equations connecting the fluctuations of the magnetic field and plasma flow with the reconnection characteristics.

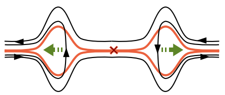
-We show here the theoretical result and its application on the THEMIS data in the distant magnetotail.

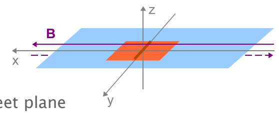
Model background

Approach

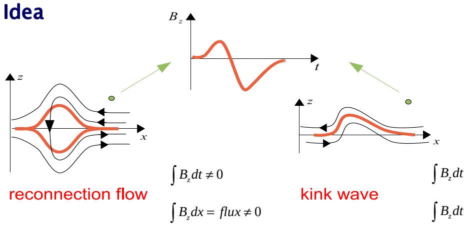
- Plasma -MHD [ideal, collisionless, infinitely conducting, incompressible]
- Current sheet
  - ∞, uniform, thin
  - separates oppositely orientated magnetic field
- Reconnection
  - time-dependent Petchek-type model
  - diffusion region =line in the current sheet plane







Idea

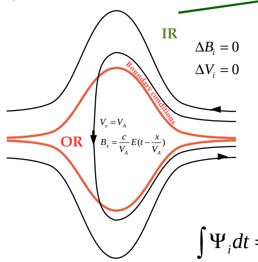


Plasma disturbances of the reconnection fast flows contain direct information about reconnection

MODEL

Plasma parameters in the Outflow (OR) and Inflow (IR) regions

MHD equations linearized under the small $\varepsilon = E_r / E_A$ = reconnection rate
(E_r-reconnection electric field
$E_A = B_0 V_A / c$,
B_0 – characteristic magnetic field value
V_A – Alfvenic velocity)
give:



Laplace equation

$$\Delta \Psi_i = 0$$

Standart solution

$$\Psi_i = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} dxdy\,\psi K(x,y,z)$$

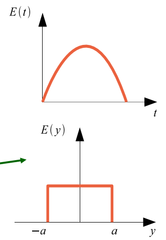
with boundary condition

$$\psi = \psi(E_r)$$

where

$$\Psi_i = B_i, V_i \qquad i = x, y, z$$

Electric field assumption



$$E(y) = \Theta(a-y)\Theta(a+y)$$

$$\int \Psi_i dt = ?$$

(1) $\int V_x dt = 0$

(2) $\int V_y dt = \frac{F}{B_0 2\pi} \ln \frac{(y-a)^2 + z^2}{(y+a)^2 + z^2}$

(3) $\int V_z dt = \frac{F}{B_0 \pi}\left(arctg\frac{(y-a)}{z} - arctg\frac{(y+a)}{z} \right)$

(4) $\int B_x dt = \frac{2F}{V_A \pi} \ln \frac{y - a + \sqrt{x^2 + (y-a)^2 + z^2}}{y + a + \sqrt{x^2 + (y+a)^2 + z^2}}$

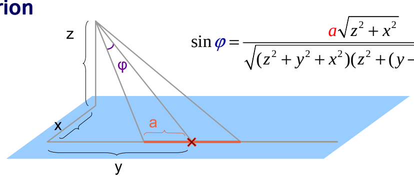
(5) $\int B_y dt = \frac{F}{V_A \pi} \ln \frac{\left(\sqrt{x^2+(y-a)^2+z^2}+x\right)\left(\sqrt{x^2+(y+a)^2+z^2}-x\right)}{\left(\sqrt{x^2+(y-a)^2+z^2}-x\right)\left(\sqrt{x^2+(y+a)^2+z^2}+x\right)}$

(6) $\int B_z dt = \frac{2F}{V_A \pi}\left(arctg\frac{(y+a)x}{z\sqrt{x^2+(y+a)^2+z^2}} - arctg\frac{(y-a)x}{z\sqrt{x^2+(y-a)^2+z^2}} \right)$

F – **reconnected magnetic flux**
a – **half length of reconnection line**
(x,y,z) – **distance from observational point to X-line**

MODEL SOLUTION

3D criterion



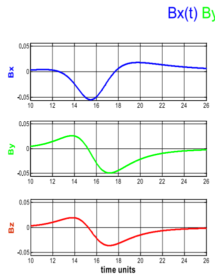
$$\sin\varphi = \frac{a\sqrt{z^2 + x^2}}{\sqrt{(z^2 + y^2 + x^2)(z^2 + (y-a)^2 + x^2)}} \xrightarrow{3D} \varphi$$

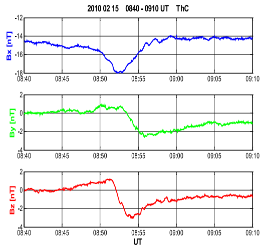
Linearization on the small φ is possible

OBSERVATION

Event 2010 02 15 08:40 - 09:10
THEMIS probe C
(-43.0, -11.2, -6.8) R_E GSM

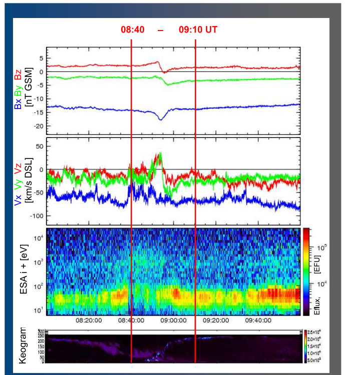
Bx(t) By(t) Bz(t)

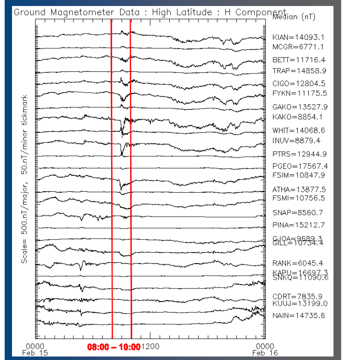




Prediction of the model at (x<0,y<0,z<0) while X-line is (0,0,0)

Experimental evidence of characteristic variations by ThC spacecraft



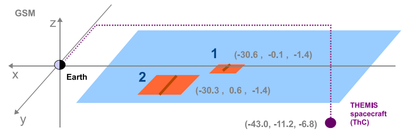


Event background

Solution

Numerical solution from (4)-(6) only using magnetic field data, with fixed z = distance from spacecraft to neutral sheet (from Tsyganenko model)

2 branches of solution:



	1	2
X-line location [R_E GSM]	(-30.6 , -0.1 , -1.4)	(-30.3 , 0.6 , -1.4)
X-line length [R_E]	0.8 - 1.3	6.2-7.0
Reconnected flux [nT m]	8.2 - 8.6·10^7	1.3-1.5·10^7

Summary and discussion

- 3D model solution is applied to the THEMIS spacecraft, probe C observations on 2010-02-15, 08:40-09:10 UT
- Due to problems in velocity data, only magnetic field is used. Therefore, the system of equations is underdetermined. Nevertheless, under the parametrical search, two branches of solution are found. Downtail distance of the X-line in both cases agreed within ~ 1R_E
- Using 3D criterion the linearization of the system (4)-(6) gives the certain result of X-line length and reconnected flux: 1 R_E and 8.5 ·10^7 nT m respectively, which is close to the numerical solution **1**.

Acknowledgments

We acknowledge NASA contract NAS5-02099 and V. Angelopoulos for use of data from the THEMIS Mission. Specifically: K. H. Glassmeier, U. Auster and W. Baumjohann for the use of FGM data .

We acknowledge V. A. Sergeev, O. Alexandrova, E. Panov, V. Sazonov for useful discussions.