Estudo observacional da reconexão magnética na magnetosfera terrestre

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Plasmas

99% do espaço observável são plasmas.
Plasmas existem quaisquer lugares

Coroa solar

Aurora

Raios

SDO

Galáxia

Fogo

Laboratório

Plasmas - The 4th State of Matter

sinais de neônio

MRX
Reconexão magnética é um processo que ocorre quando plasmas magnetizados com componente antiparalela do campo magnético se encontram na pequena região.

**Energia magnética**  →  **Energia cinética, térmica e aceleração de partículas**
Evidence Mounts

Dungey's magnetic reconnection idea has gradually seen a move from questionable to highly controversial (owing to the inability at the time to make actual observations to back up the predictions) to universally accepted as the main driver of space storms, which showed conclusively that reconnection is in fact the trigger mechanism. The solar wind carries the interplanetary magnetic field through the bow shock and magnetopause, which reconnects northern and southern fields (which studies how the Earth’s magnetosphere has become overwhelmed. The southward fields were also associated with inward movement of the magnetospheric substorm, as magnetic flux is stripped away. CMEs at the Earth, which reconnect in the distant tail of the magnetosphere, allows energy and charged particles from the solar wind to enter the magnetosphere. Open magnetic field interacts with the solar wind bow shock, which triggers the substorm or is a secondary effect was answered in 2008 when researchers on the Earth's nightside confirmed that reconnection is responsible for driving plasma flow out of the magnetosphere as magnetic flux is stripped away. Computer simulations of electron populations in reconnection regions allow energy and charged particles from the solar wind to enter the magnetosphere. Open magnetic fields from the Sun and the solar wind interconnect, which should be key in deciphering more about how this event unfolds. (Left image is courtesy of the Japanese Space Agency, right image is courtesy of James Drake and Michael Shay, University of Delaware.)

Since then researchers on the Earth's nightside, which were both confirmed by craft data, have been able to witness the process. Computer simulations of electron populations in reconnection regions allow energy and charged particles from the solar wind to enter the magnetosphere. Open magnetic fields from the Sun and the solar wind interconnect, which should be key in deciphering more about how this event unfolds. (Left image is courtesy of the Japanese Space Agency, right image is courtesy of James Drake and Michael Shay, University of Delaware.)

(Left) An x-ray image of a solar coronal structure from Japan’s Hinode spacecraft, Fred Hoyle, in 1948, with whom Dungey's magnetic reconnection idea is overlaid. (Right) CME at the Earth. This figure shows only a noon-to-midnight cross-section of the three-dimensional magnetosphere. (dotted box at left) CME at the Earth. This figure shows only a noon-to-midnight cross-section of the three-dimensional magnetosphere. (dotted box at right). (dotted box)

(b) Computer simulations of electron populations in reconnection regions allow energy and charged particles from the solar wind to enter the magnetosphere. Open magnetic fields from the Sun and the solar wind interconnect, which should be key in deciphering more about how this event unfolds. (Left image is courtesy of the Japanese Space Agency, right image is courtesy of James Drake and Michael Shay, University of Delaware.)

CME at the Earth. This figure shows only a noon-to-midnight cross-section of the three-dimensional magnetosphere. (dotted box at left) CME at the Earth. This figure shows only a noon-to-midnight cross-section of the three-dimensional magnetosphere. (dotted box at right). (dotted box)

Se a tempestade magnética for muito intensa?

Burch e Drake, 2009, American Scientist
On March 13, 1989 the entire province of Quebec, Canada suffered an electrical power blackout. Hundreds of blackouts occur in some part of North America every year. The Quebec Blackout was different, because this one was caused by a solar storm!

http://www.nasa.gov/topics/earth/features/sun_darkness.html
Reconexão magnética na magnetopausa terrestre utilizando dados do satélite POLAR (No ponto de vista da escala macroscópica)

1. As distâncias de linha de reconexão estimada até o local da reconexão observada

2. Condição do modelo do Gonzalez e Mozer 1974

3. Associação de eventos de reconexão com parâmetros do vento solar

4. Dependência de hora local magnética e latitude com a amplificação magnética
Satélite POLAR

De fevereiro até maio de 2001, 2002, e 2003, com 9,5 Re de apogeu, **74 eventos de reconexão magnética** foram obtidos na baixa latitude da parte diurna da magnetopausa.

**Órbitas do satélite POLAR**

x: sol-terra
y: leste-oeste
z: norte-sul
Dados de campo magnético e plasma: Um Exemplo

Polar MFE (6 second resolution)

Polar Fast Plasma Analyzer - HYDRA (13.8 second resolution)

From UCLA/IGPP Polar Magnetometer Interactive Data Server and NASA/GSFC CDAWeb
Modelo do Gonzalez-Mozer 1974

\[
\sin \beta = \frac{B_2 - B_1 \cos \alpha}{(B_1^2 + B_2^2 - 2B_1B_2 \cos \alpha)^{1/2}}
\]

\[
\sin(\alpha - \beta) = \frac{B_1 - B_2 \cos \alpha}{(B_1^2 + B_2^2 - 2B_1B_2 \cos \alpha)^{1/2}}
\]

\(\alpha\): O ângulo entre a bainha magnética (\(B_1\)) e magnetosfera (\(B_2\))

\(\beta\): O ângulo entre magnetosfera e linha-X

Quando \(\alpha < \beta\), não acontecerá reconexão!
As distâncias de linha de reconexão estimada até o local da reconexão observada

Existem os eventos mais próximos à linha-X na região equatorial.
Condição do modelo de Gonzalez e Mozer 1974

\[ B_{sh} > B_{sp} \cos \alpha \]

\[ B_{sh} = B_{sp} \cos \alpha \]
A lei de Ampère

\[ \nabla \times \mathbf{B} = \mu_0 \mathbf{J} \]

\[ - \frac{\partial B_z}{\partial x} = \mu_0 J_y \]

\[ \frac{\Delta B}{L} = -\mu_0 J_y \]

\[ \Delta B = B_{sh} \sin(\beta - \alpha) - B_{sp} \sin \beta \]

\[ B_{sh} = B_{sp} \cos \alpha \]

\[ \Delta B = -B_{sp} \sin \alpha \cos(\beta - \alpha) \]

\[ J_y = \frac{B_{sp} \sin \alpha \cos(\beta - \alpha)}{\mu_0 L} \]

\[ J_y = B_{sp} \sin \alpha \mu_0 L \]

Maximização de corrente elétrica ao longo da linha-X!
Associação de eventos de reconexão com parâmetros do vento solar

![Diagrama mostrando o ângulo X-line e a magnitude IMF, com pontos distribuídos em diferentes regiões representando ICMEs+MCs, CIRs e pós-CIRs, além da pressão dinâmica. O texto na imagem indica grande dispersão.]
Dependência de hora local magnética e latitude com a amplificação magnética

![Graphical representation](image)

Alta frequência de ocorrência

90 ~ 180°

Ecliptic azimuthal Angle (degree)

Magnetic Local Time (hour)

Amplification Factor

Frequency of occurrence

Dependência de hora local magnética e latitude com a amplificação magnética
Dependência de hora local magnética e latitude com a amplificação magnética
Taxa de reconexão
(No ponto de vista da escala microscópica)

Na fronteira das duas regiões, a componente tangencial do campo elétrico é contínua.

$$E_{tan} = V_i B_L = V_A B_N$$

Então, a taxa de reconexão é dada por

$$R = \frac{V_i}{V_A} = \frac{B_N}{B_L}$$
Taxa de reconexão

\[ \beta = \frac{n k_B T}{B^2 / 2 \mu_o} \]
Taxa de reconexão

<table>
<thead>
<tr>
<th>Date</th>
<th>Reconnection Rate: R</th>
<th>Beta</th>
<th>Correlation coefficient between R and Beta</th>
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<tr>
<td>05/04/1998</td>
<td>0.19</td>
<td>0.04</td>
<td>-0.50</td>
</tr>
<tr>
<td>05/04/1998</td>
<td>0.10</td>
<td>0.30</td>
<td>-0.23</td>
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<td>04/01/2001</td>
<td>0.11</td>
<td>0.12</td>
<td>-0.14</td>
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<td>05/03/2001</td>
<td>0.18</td>
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<td>05/12/2001</td>
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<td>0.15</td>
<td>-0.67</td>
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<td>04/14/2003</td>
<td>0.08</td>
<td>0.44</td>
<td>-0.77</td>
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<tr>
<td>The 6 events' average</td>
<td>0.14</td>
<td>0.21</td>
<td>-0.45</td>
</tr>
</tbody>
</table>

\[ \beta = \frac{nk_B T}{B^2/2\mu_o} \]

\[ y = -0.26x + 0.19 \]
Efeito do termo Hall
(estudo em andamento)

A lei de Ohm generalizada

\[ \mathbf{E} + \mathbf{V} \times \mathbf{B} = \eta \mathbf{J} + \frac{1}{ne} \mathbf{J} \times \mathbf{B} - \frac{1}{ne} \nabla \cdot \mathbf{P}_e + \frac{m_e}{ne^2} \frac{\partial \mathbf{J}}{\partial t} \]
POLAR observation March 27, 2001

Graph showing time series data with labels Bz +, Ex +, By +, Bz -, Ex -, By -, and N. The x-axis represents UT (Universal Time) ranging from 16:25:06 to 16:30, and the y-axis represents nT. The graph also includes a legend for Ex', N, Bz', and By'.
Depêndencia de parâmetros de plasma
Comparação com teoria de reconexão

Mozer et al. 2002 PRL
Colaboração nacional/internacional

**GSFC/NASA:** Dr. David G. Sibeck
**Univ. West Virginia:** Dr. Paul Cassak
**UC Berkeley:** Prof. Forrest S. Mozer

**USP:** Dra. Flavia R. Cardoso

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Dra. Cristiane Loesch
Dr. Arian Ojeda Gonzalez
Marcos V. D. Silveira
Vitor Souza (GSFC/NASA)
Paulo Ricardo Jauer
German Farinas Perez
Introduction

Workshop in honor of Eugene N. Parker to be held at the National Institute of Space Research, INPE, São José dos Campos, SP, Brazil, during March 18-21, 2014.

Objectives

The meeting’s objective is the presentation of recent advances in the area of Magnetic Reconnection. The speakers to be invited are scientists with recognized performance in this area, abroad as well as on the country. The targets of the presentations are post-grad students and young doctors in this area of expertise.