Magnetic Trapping Acceleration in Interplanetary Plasmas

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Analogy of MTA

Magnetic field : B

Induced electromotive force : \((q/c)v \times B\)

Electromagnetic induction
Colliding plasmas

Magnetic field: \(-B\)

Electric field: \(E\)

Magnetic field: \(B\)

Electric field: \(E\)
Fields configuration

Center of collision
Basic equations

\[ m \frac{d(\gamma v)}{dt} = q(E + \frac{v}{c} \times B), \]

\[ mc^2 \frac{d\gamma}{dt} = qE \cdot v \]

\[ \nabla \times E = -\frac{1}{c} \frac{\partial B}{\partial t}, \]

\[ \nabla \times B = \frac{4\pi}{c} J \]

Relativistic Equation of motion
Energy equation
Faraday's law
Ampere's law
Numerical calculations

Magnetic field configuration

\[ B_{zi} = \left( B_0 / 2 \right) \left[ \tanh \eta_i + (-1)^i \right] \]

\[ \eta_i \equiv k(y + \nu_{pi} t) + h_i(ky) + \phi_i \]

Phase parameters

Attainable gain of particle around the center of collision

\[ \gamma \approx 2 (qE_x / mc) t \approx 2\Omega \beta_p t \]
Attainable gains

\[ \gamma \approx 2(qE_x / mc)t \approx 2\Omega \beta_p t \]

saturation
Attainable gain

\[ \gamma_a = \frac{C_1 \beta_p^3}{\alpha^2 \zeta_0} \]  
( theoretical )

\[ \gamma_a = \frac{C_2 \beta_p^{2.19}}{\alpha^{1.22} \zeta_0^{0.28}} \]  
( numerical )

- Phase velocity
- Initial position of particle
- Radius of curvature of magnetic field
- Initial position of particle
Particle trajectories & distributions (yz-plane)

- Magnetic neutral sheet
- Plasma inflow
- Spiral motion on plasma surface
- Particle acceleration
- Plasmoid

$\gamma > 2$
Particle trajectories & distributions (xy-plane)

\( \gamma > 2 \)

- Plasma inflow
- Magnetic neutral sheet
- Acceleration
- Spiral motion
Particle trajectories & distributions (xz-plane)

\( \gamma > 2 \)

Spiral motion

Particle acceleration

Plasmoid
Current flow along wave front

Wave front

Drifting motion

First collision

Induced magnetic field

\[ \nabla \times \mathbf{B} = \frac{4\pi}{c} \mathbf{J} \]
Electron-Positron Acceleration

Magnetic pulse

Restoring force

Electron trapping

Positron trapping

Magnetic neutral sheets
Particle simulation

“Current Sheet” Shock Surfing

Hoshino PTP 2001, Nagata 2005

Magnetic neutral sheet

High energy particles by MTA

Magnetic pulse

This can provide unlimited acceleration
Magnetic Trapping Acceleration

- magnetic neutral sheet
- magnetic field reconnection
- plasmoid
- electron-positron plasma

Simultaneous acceleration of electron and positron, in principle, unlimited acceleration