Small-scale reconnection events on the Sun

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Reconnection

Breaking and rejoining of magnetic fields. In space plasma it is accompanied by rapid conversion of magnetic energy into plasma kinetic and thermal energy, and intense particle acceleration.
Regimes of reconnection

Lundquist Number
Resistive diffusion time/Alfven time)

\[ S = \mu_0 L_{cs} V_A / \eta \]
\[ \approx 2 \times 10^{10} \text{ in the TR} \]

Resistivity
\[ \eta \approx 5 \times 10^{-7} \text{ ohm-m (Spitzer)} \]

Width of current sheet
\[ L_{cs} \approx 1 \times 10^5 \text{ m} \]

Alfven speed
\[ V_A \approx 1 \times 10^5 \text{ m/s} \]

Vacuum permeability
\[ \mu_0 \approx 1 \times 10^{-6} \text{ Ohm-s/m} \]

Plasma size
\[ L \approx 10^6 \text{ m} \]

Skin depth
\[ d_i \approx 0.1 \text{ m} \]
Reconnection configurations

Single X-line

Petschek reconnection

(a) Flow velocity along x at t=145

(b) Density145

Rate \sim \frac{1}{\ln (S)}

Multiple X-line

Sweet-Parker current sheet

(a) Flow velocity along x at t=200

(b) Density200

Rate \sim \frac{1}{S^{1/2}}

2D plasmoid instability

(a) Flow velocity along x at t=301

(b) Density301

Rate \sim S^{1/4}

Aim is to use IRIS to study line profiles from reconnecting regions in the transition region and to compare with simulations.
Sites of reconnection
Explosive events

Explosive events coincide with flux emergence and cancellation at supergranular cell junctions.

Innes & Teriaca 2012
Sites of reconnection

Explosive events

Explosive events sites on the edge of strong field and between opposite polarity flux concentrations.

(Dere, Bartoe, Brueckner, Ewing & Lund 1991)

Velocity 100 km/s comparable to Alfven speed in plasma with magnetic field strength 20 G and density $7 \times 10^{10}$ cm$^{-3}$

(Dere, Bartoe & Brueckner 1989)
Characteristics in Si IV:

- Blue often starts before Red
- Center does not move across Sun
- Blue often longer than Red
- Blue often faster than Red

Innes, Inhester, Axford & Wilhelm 1997
IRIS UV spectral observations

IRIS is a ultraviolet spectrometer and slit-jaw camera
Spatial resolution about 0.2”, slit width 0.33”
4 times better spectral resolution than SUMER
Step cadence 3.5s

AIA 171
HMI Line-of-sight field

IRIS Si IV
IRIS Jet from explosive event

IRIS 1400 A

SDO/AIA 171 A

Intensity Running difference Magnetic field
What caused the jet?

‘Jet’ velocity 2000 km/s

Supra-thermal (10 keV) particles from a reconnection site?

Why only in one direction and perpendicular to high line-of-sight velocities?
Line profiles

Symmetric red and blue wings.

Note core brightening later in event.
Line profiles

Asymmetric with red and blue off-set along the slit.

Plateau indicating multiple velocity components

High velocity red component
Quieter region

Cadence 5.6s

Explosive events at three positions on the edge of strong field regions.
Evolution and line profiles
Observation Summary

Survey of 15 events

1. Enhanced red and/or blue non-Gaussian wings out to 300 km/s
   => acceleration up to Alfven speed
   => multiple acceleration sites

2. Sometimes red and blue wings are off-set along the slit
   => up and down flows not on the same path
   => not due to turbulence

3. The sites do not move along the slit
   => Stationary flow

4. Often see narrow core brightening, later in event
   => Emission from low-velocity, high-density region
Profiles from reconnection simulations

Single X-point

Petschek reconnection

(a) Flow velocity along x at t=145

(b) Density145

Sweet-Parker current sheet

(a) Flow velocity along x at t=200

(b) Density200

Multiple X-point

2D plasmoid instability

(a) Flow velocity along x at t=301

(b) Density301
Plasmoid instability

Huang & Bhattacharjee 2012

S = 10^7, plasma beta = 6
Plasmoid instability profiles

S = 10^5, plasma beta = 0.5

Solution at middle time
Summary

The line profiles cannot be explained by single X-point reconnection.

Plasmoid formation provides the necessary line core enhancement.

Multiple X-lines provide multiple acceleration regions required for plateau in the wings.

Asymmetric profiles possible from non-steady flows/asymmetric boundary conditions/angle to line-of-sight.

Outflow from the ends of the current sheet explains more prominent red and blue off-sets along the slit, similar to single X-point reconnection.