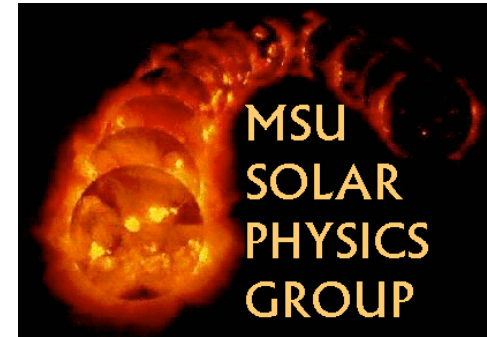# Separators: Fault Lines in the Magnetic Field

Dana Longcope

Montana State University

Acknowledgments

Graham Barnes
Colin Beveridge
Steve Cowley
Charles Kankelborg
Isaac Klapper
KD Leka

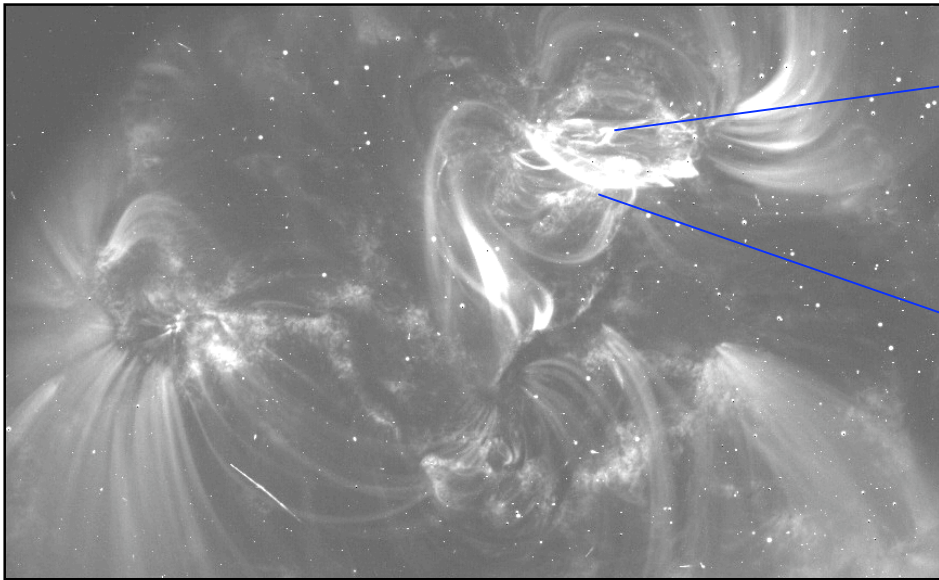Tetsuya Magara
Eric Priest
Aad van Ballegooijen
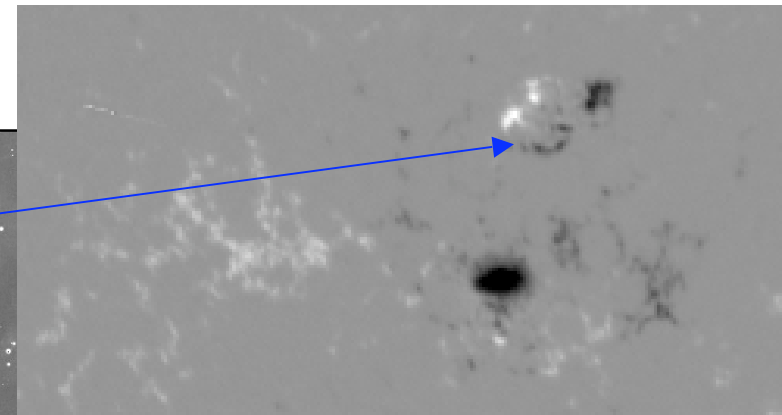Brian Welsch

The Changing Magnetic Field

PHOTOSPHERE

THE CORONA

TRACE 171A
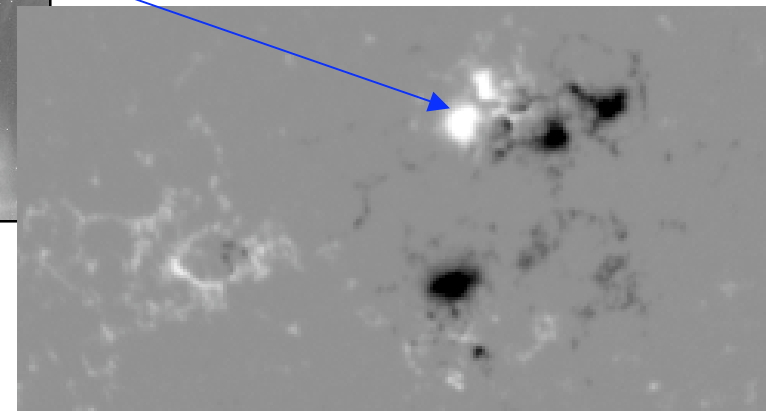
SoHO MDI

8/11/01 9:25 UT (movie)

8/10/01 12:51 UT

8/11/01 17:39 UT

Is this Reconnection?

PHOTOSPHERE

THE CORONA

SoHO MDI

TRACE 171A
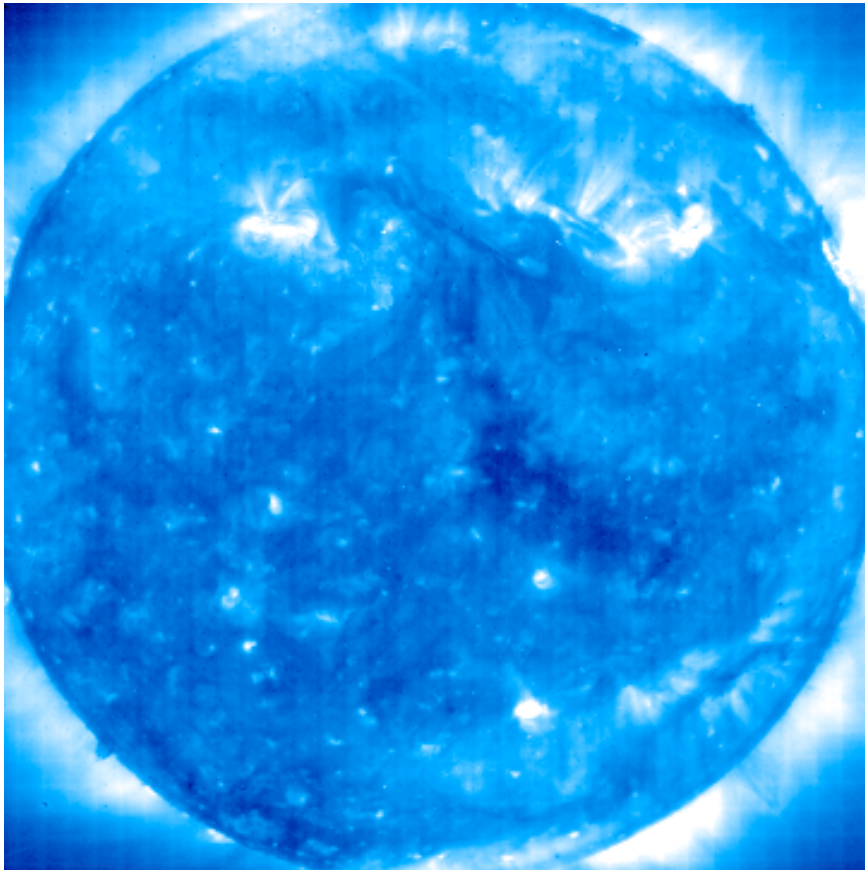

8/10/01 12:51 UT

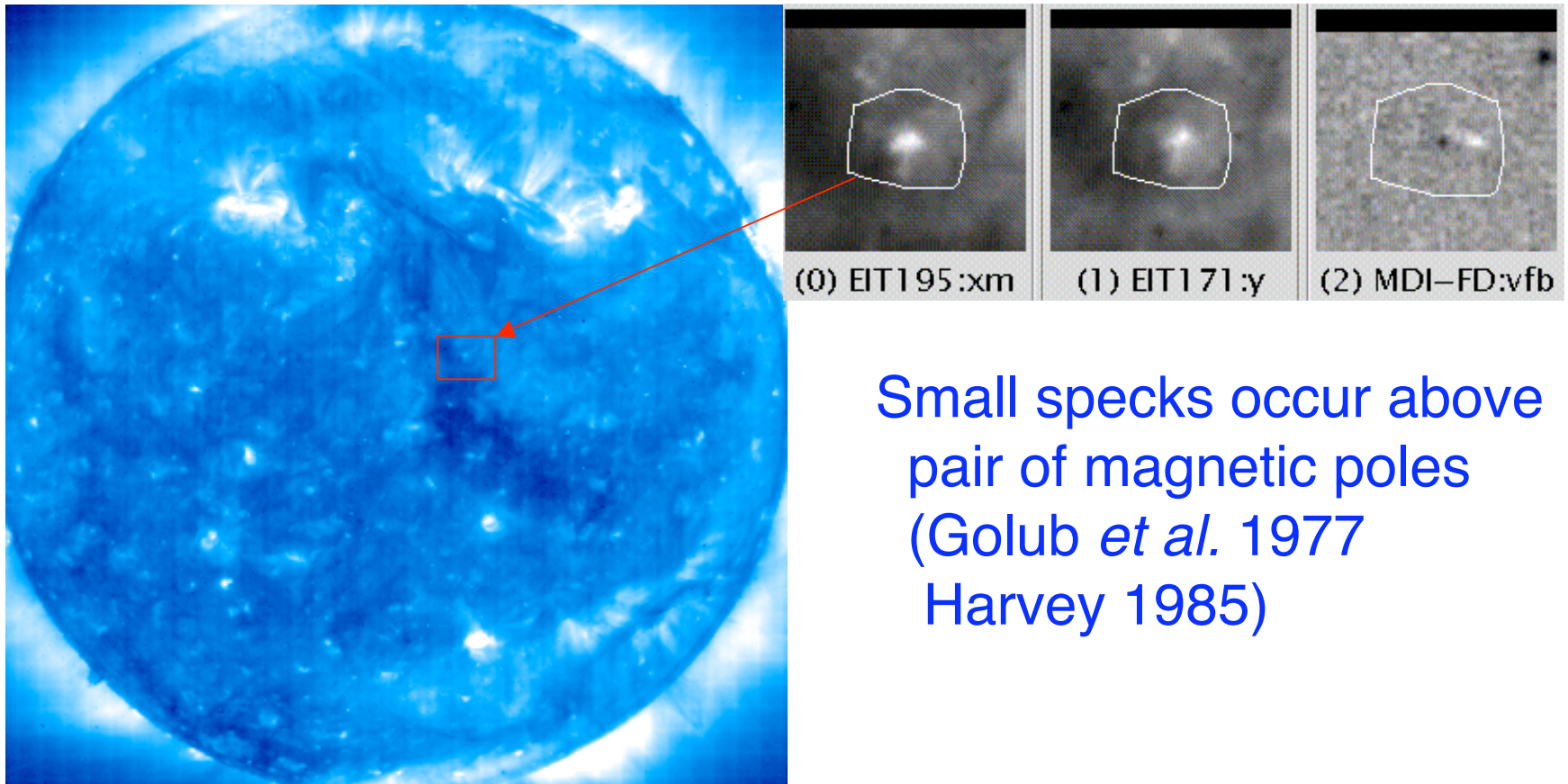8/11/01 9:25 UT (movie)
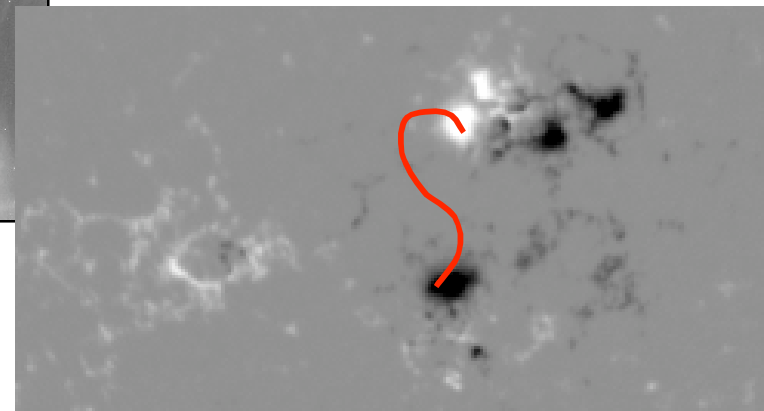
8/11/01 17:39 UT

Outline

1. The XBP: A simple example of 3d reconnection
2. Quantifying Reconnection
3. Numerical simulation
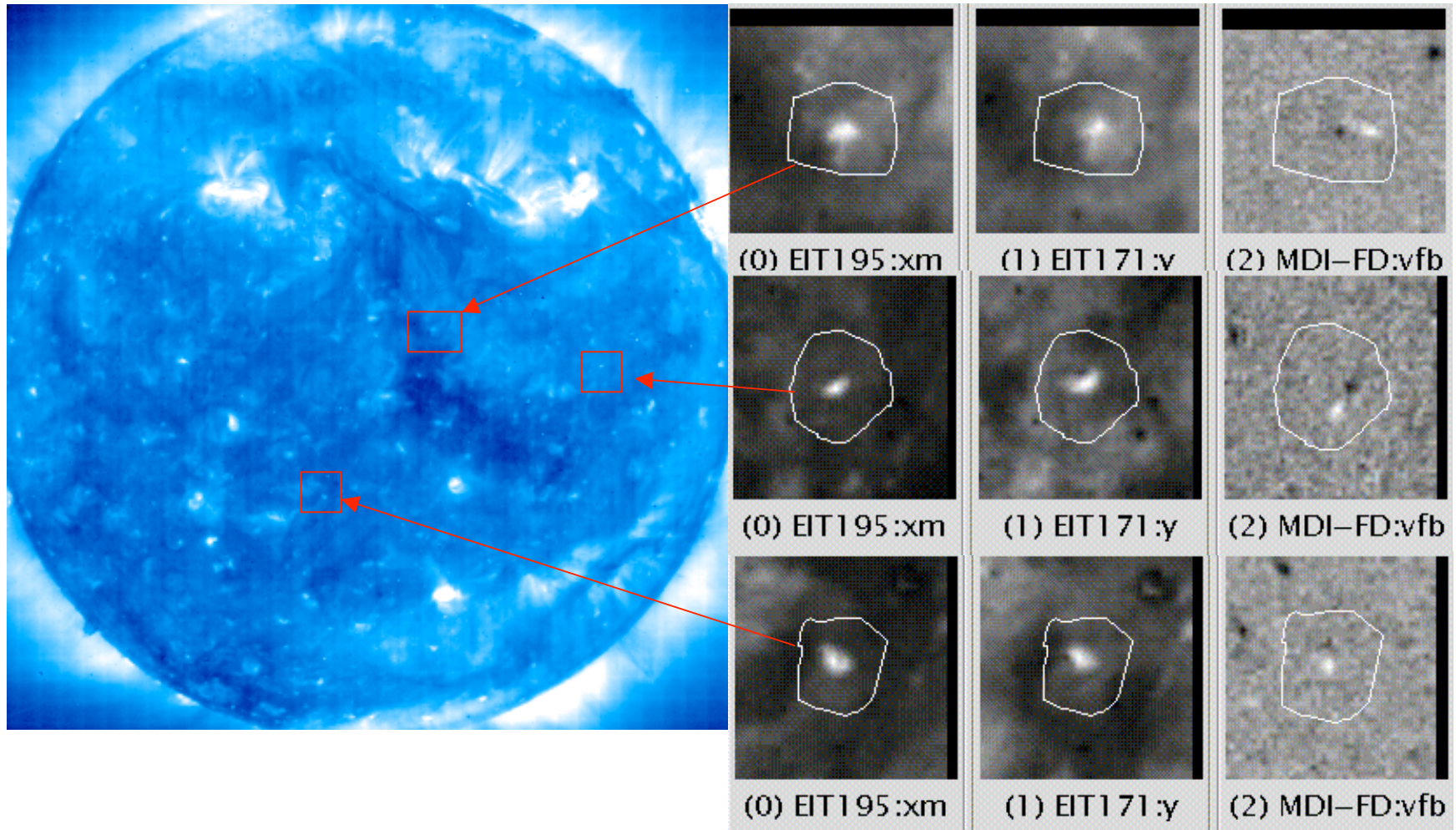4. A more complex example

Example: X-ray bright points

EIT 195A image of
"quiet" solar corona

Example: X-ray bright points

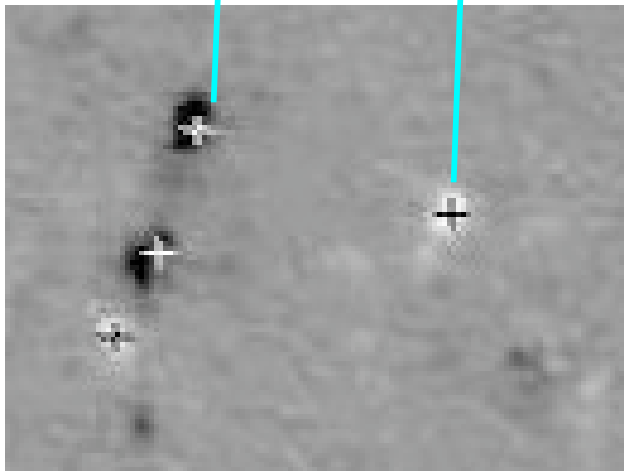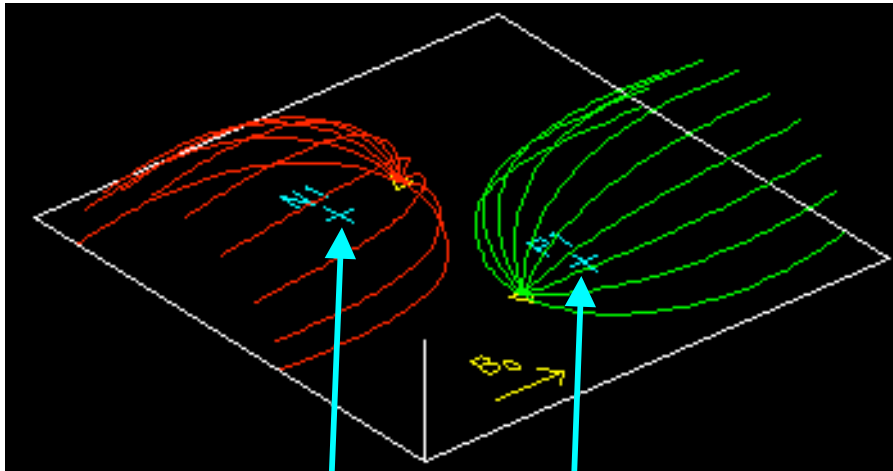(0) EIT195:xm   (1) EIT171:y   (2) MDI-FD:vfb

Small specks occur above
pair of magnetic poles
(Golub *et al.* 1977
Harvey 1985)
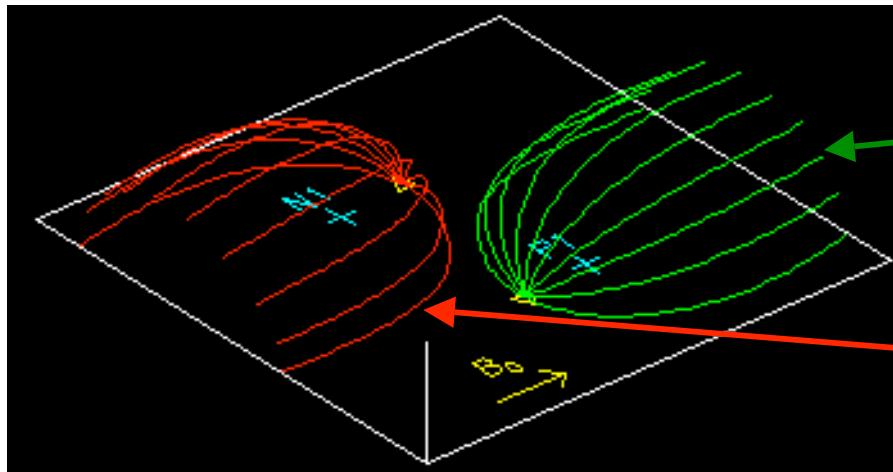
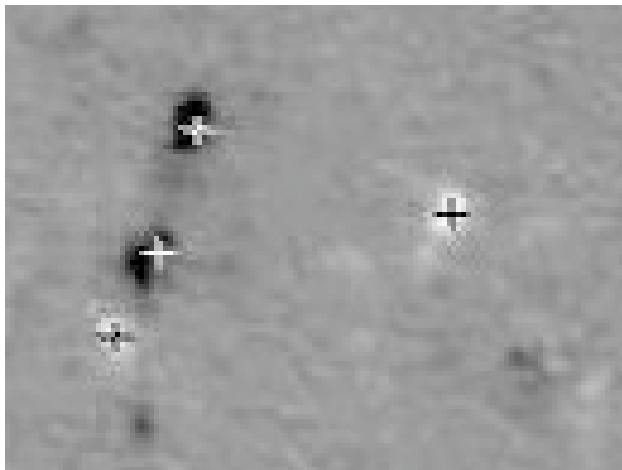# Example: X-ray bright points

When 2 Poles Collide

Photospheric flux concentrations sources of coronal field
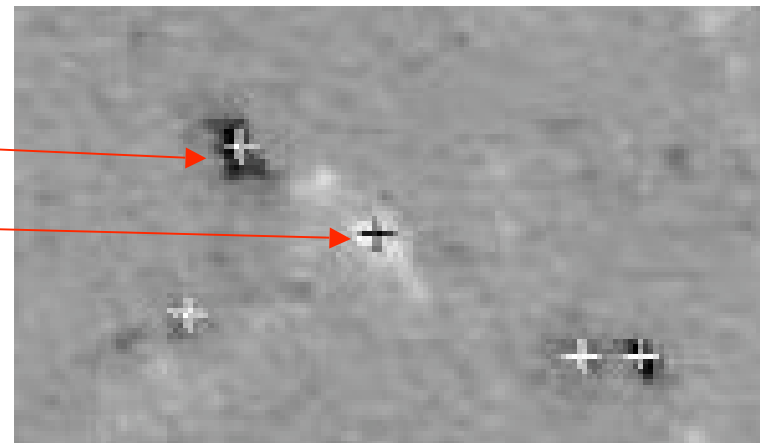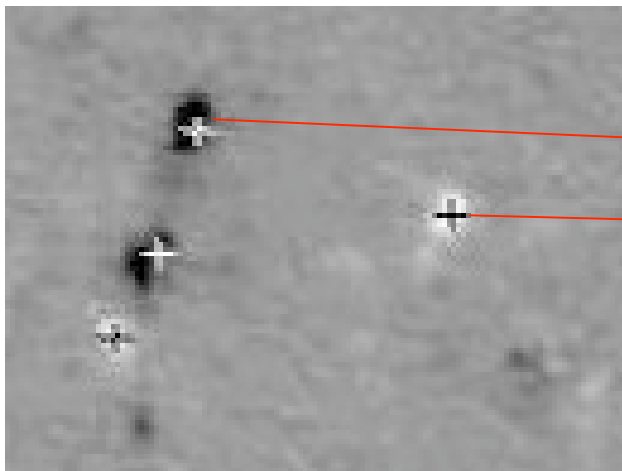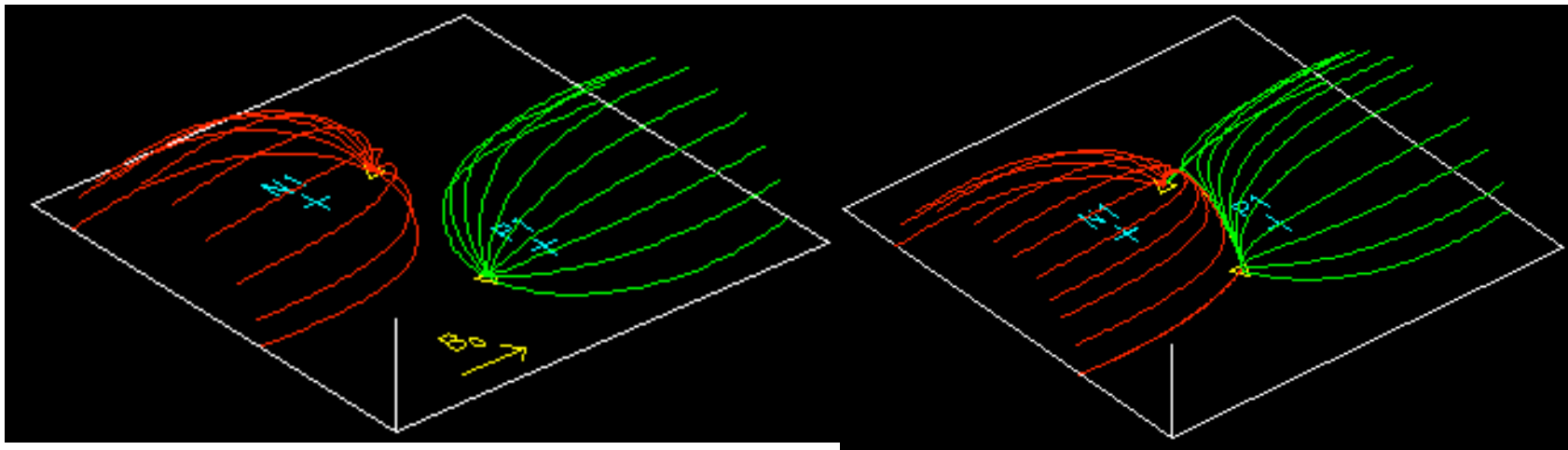
When 2 Poles Collide

All field lines from
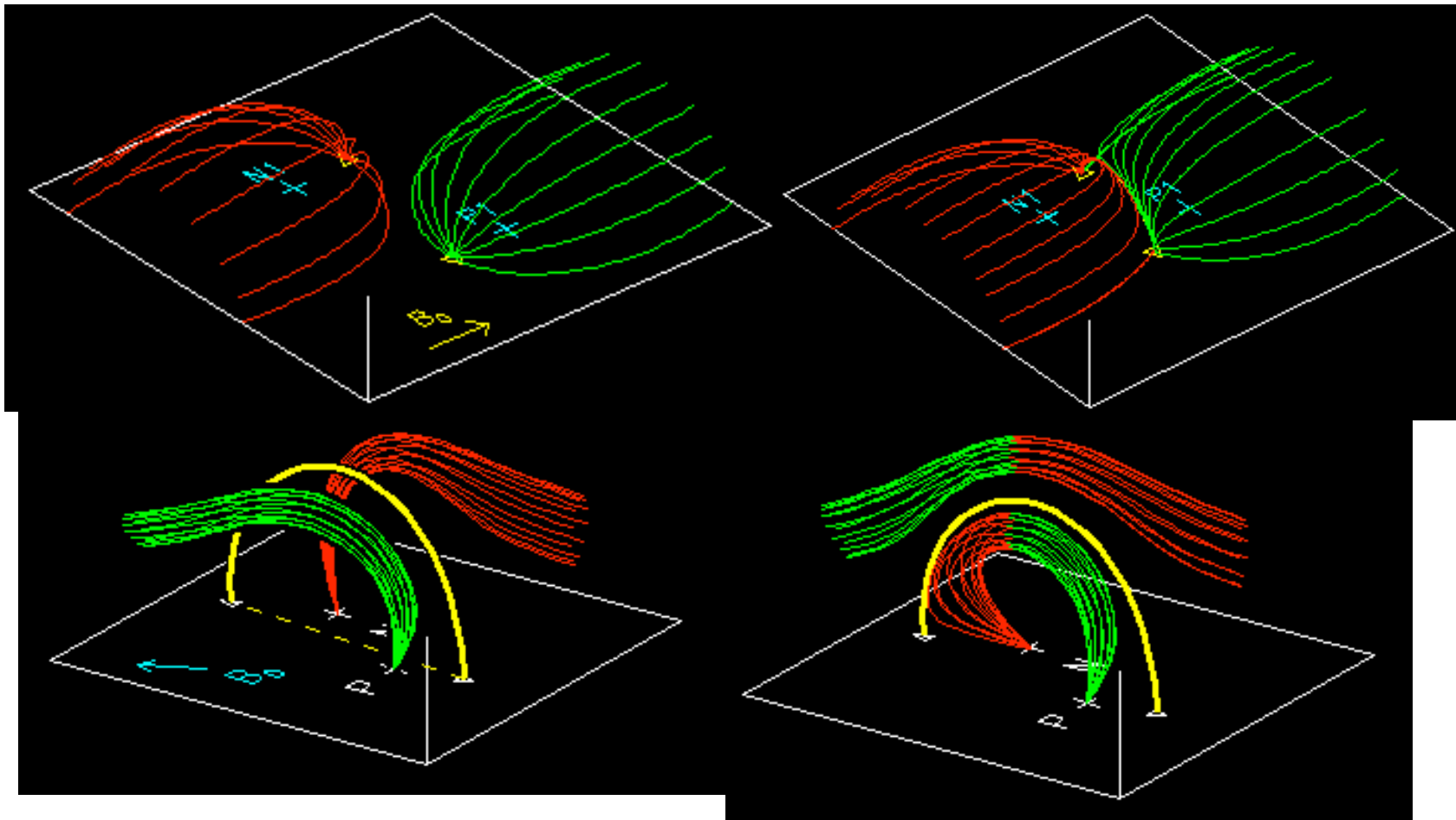   positive source P1

All field lines to
   negative source N1
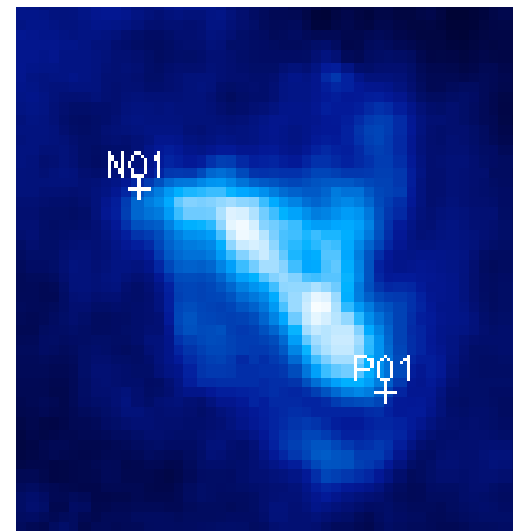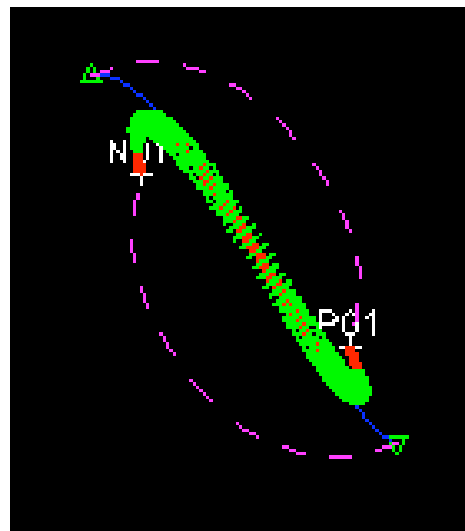
When 2 Poles Collide
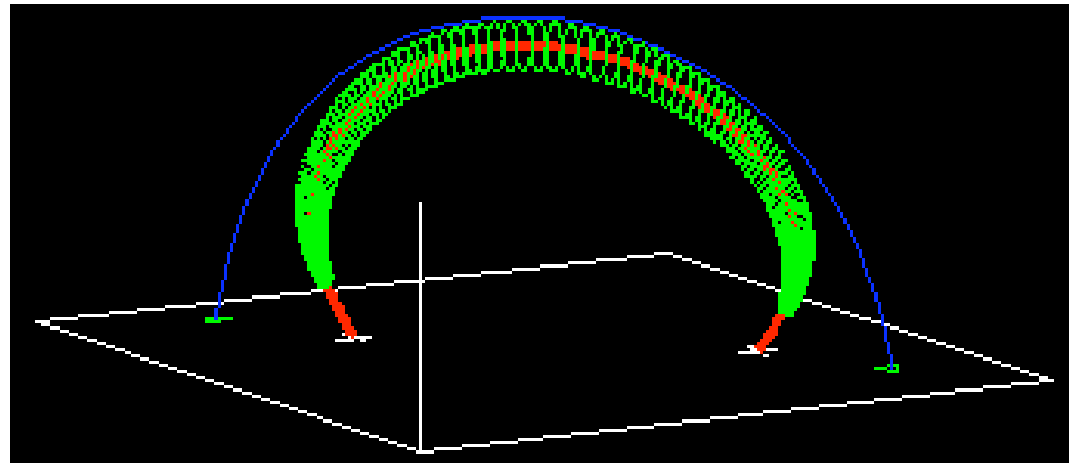

Poles approach: domains intersect

When 2 Poles Collide

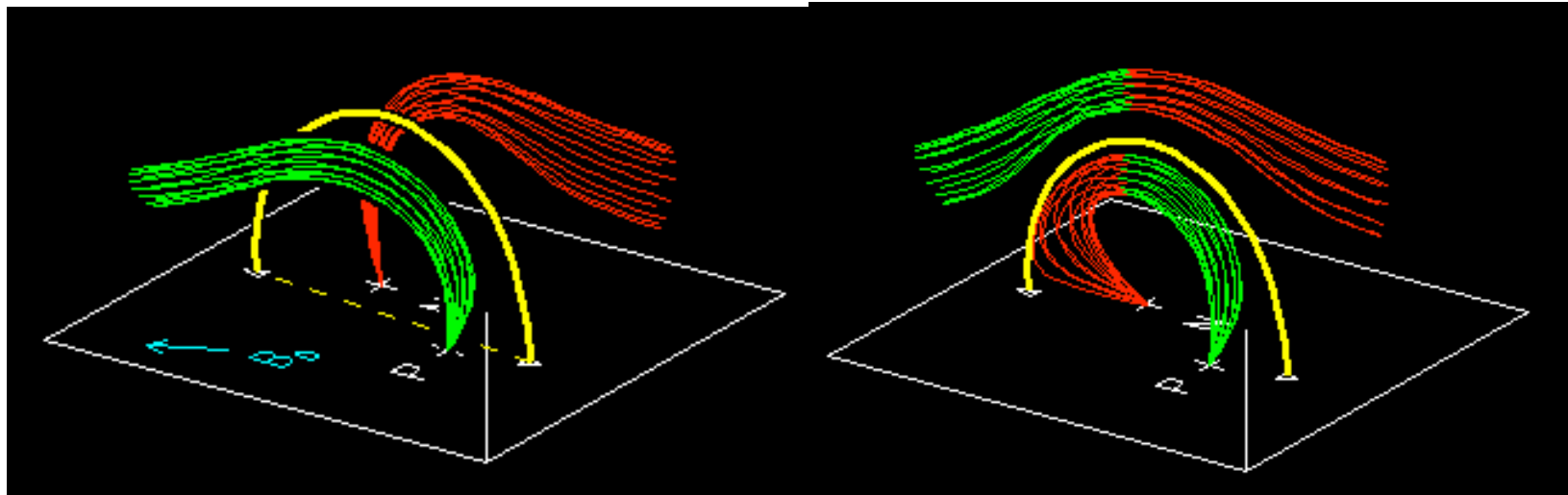Reconnection = new field lines

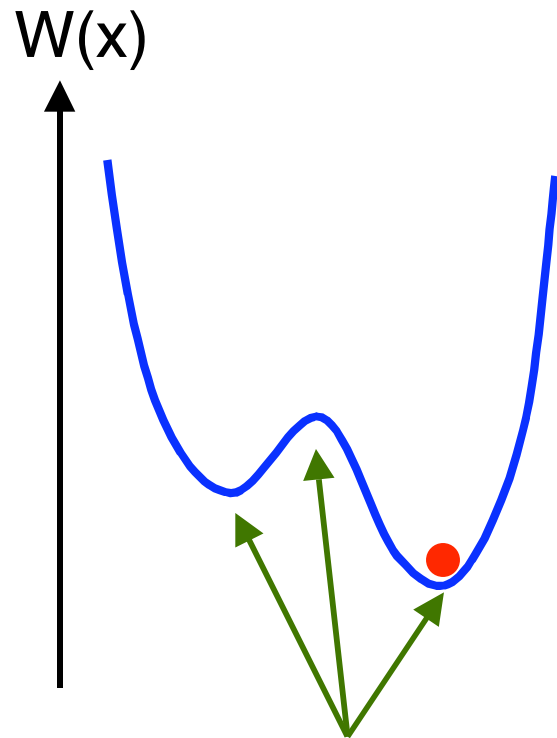# Post-reconnection Flux Tube

TRACE observations 6/17/98 (Kankelborg & Longcope 1999)

Quantifying Reconnection

- Why does it release energy?
- How much energy can it release?
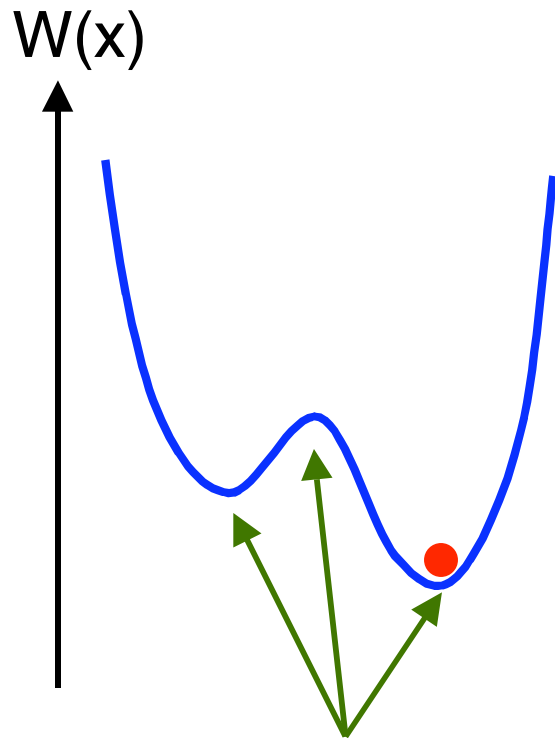- What about reconnection in complex magnetic fields?

Quasi-static Evolution

W(x)
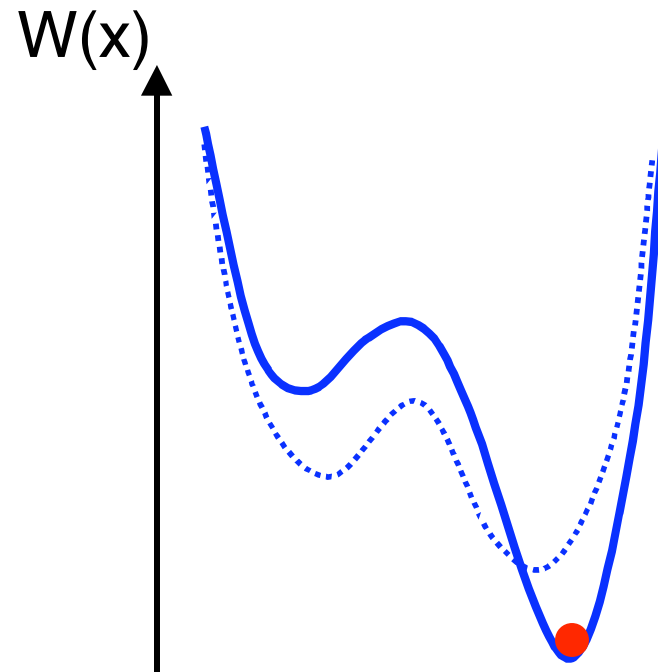
Equilibrium: W'(x)=0

Quasi-static Evolution
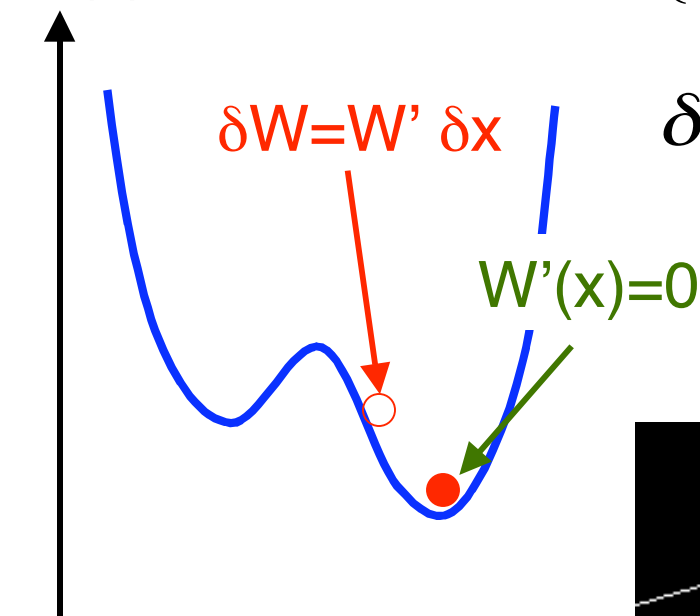

Equilibrium: W'(x)=0

W(x) evolves … **SLOWLY**
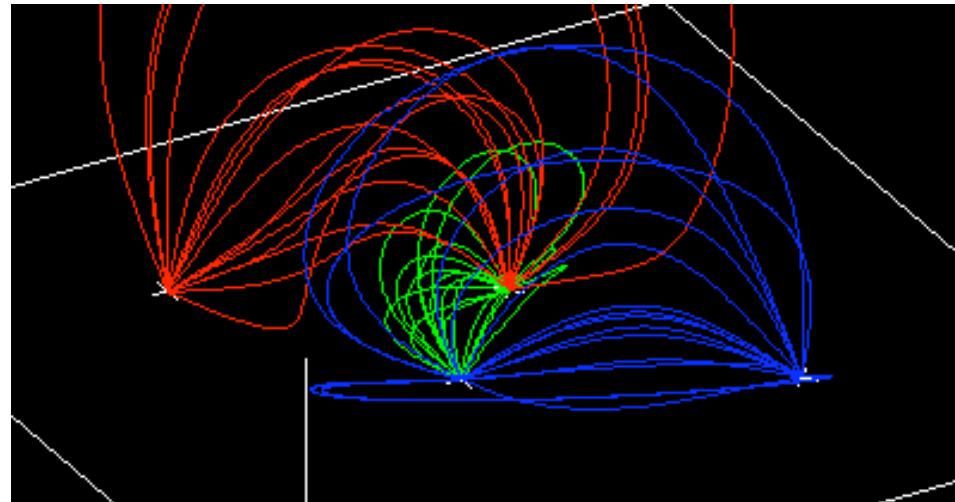
Equilibrium: Minimum Energy

$$W\{\mathbf{A}(x)\} = \frac{1}{8\pi}\int |\nabla \times \mathbf{A}|^2 \, d^3x$$

$$\delta W = \frac{1}{4\pi}\int (\nabla \times \mathbf{B})\cdot \delta\mathbf{A} \, d^3x$$

W(x)

$\delta W = W'\,\delta x$

W'(x)=0

$$\boxed{\nabla \times \mathbf{B} = 0}$$ potential

Mimimum w/ Constraints

Constrained min. –195'
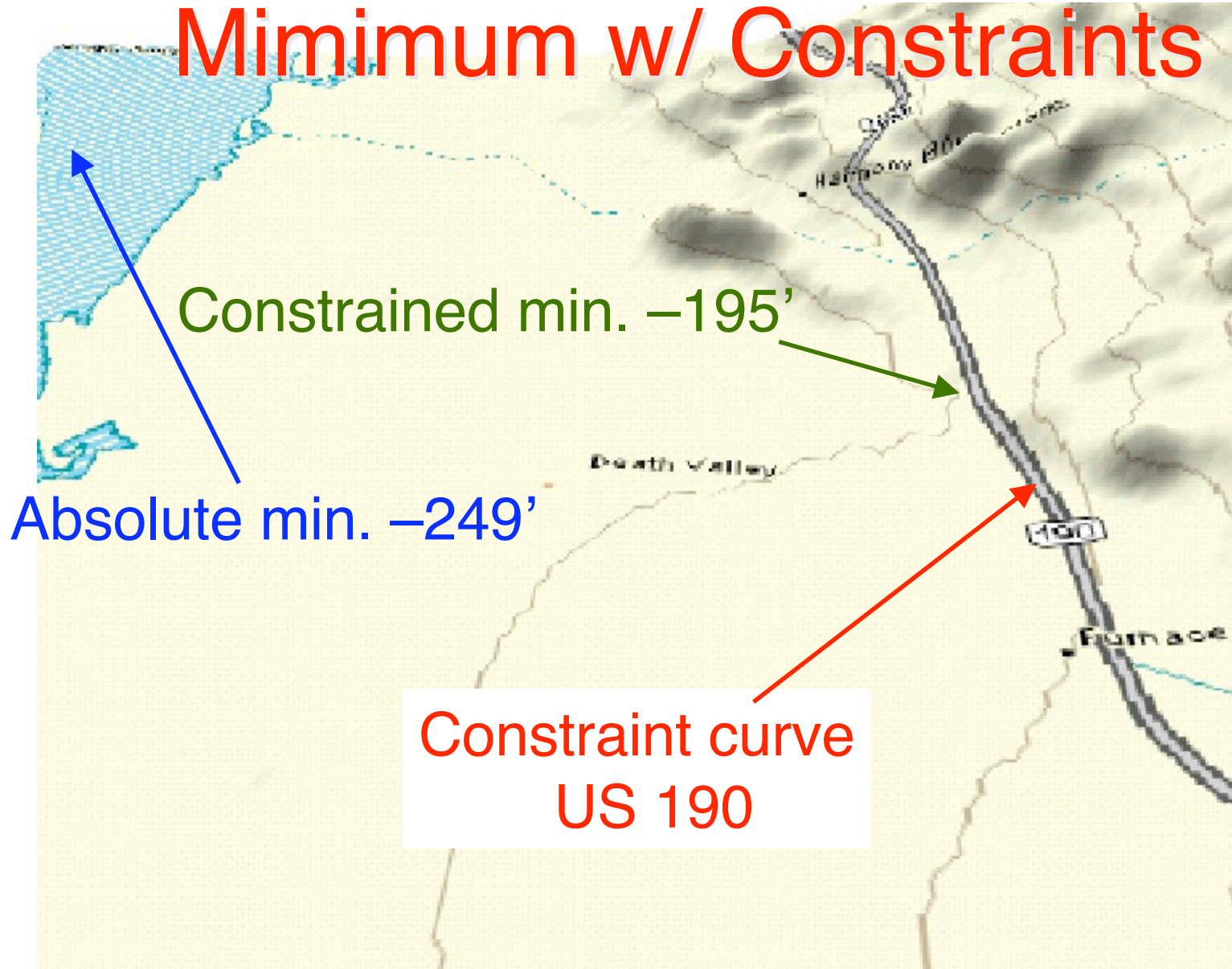
Absolute min. –249'

Constraint curve
US 190

A new type of constraint…
(Longcope 2001, Longcope & Klapper 2002)

Photospheric sources move

Number of field lines linking
each pair remains constant
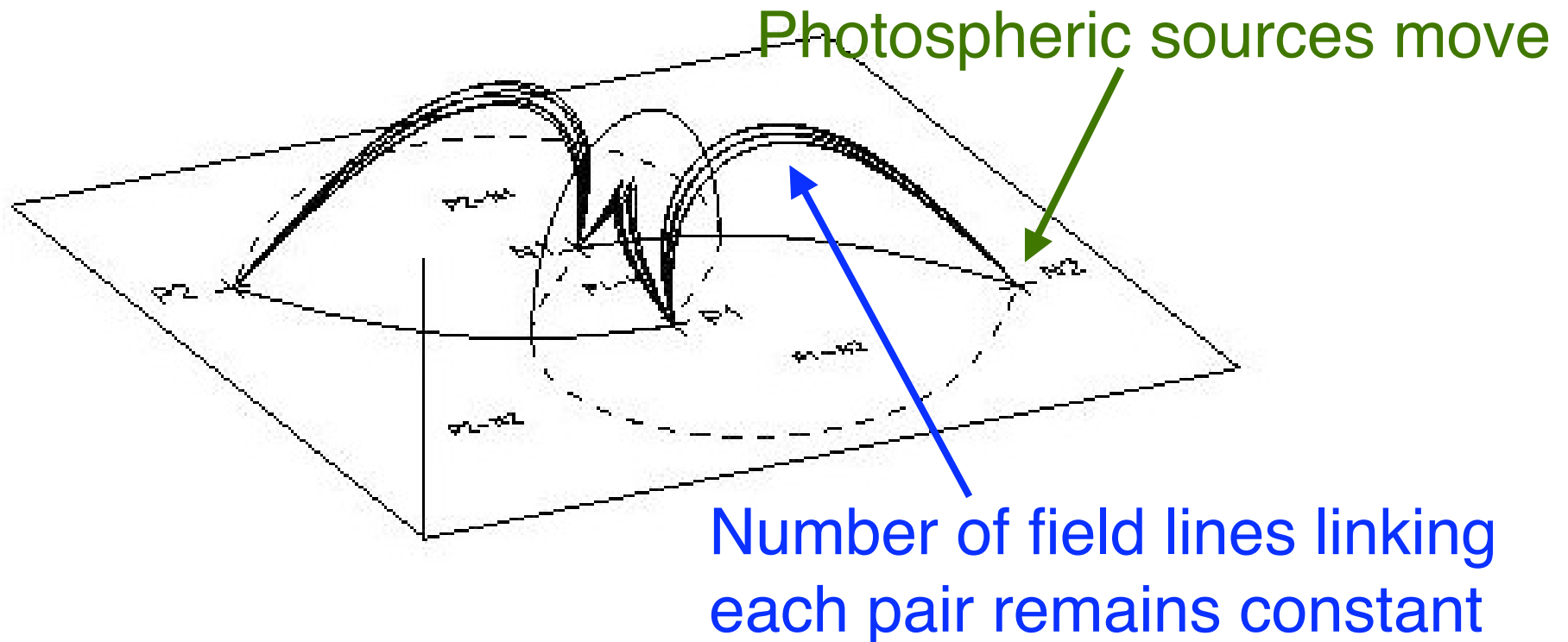
No reconnection

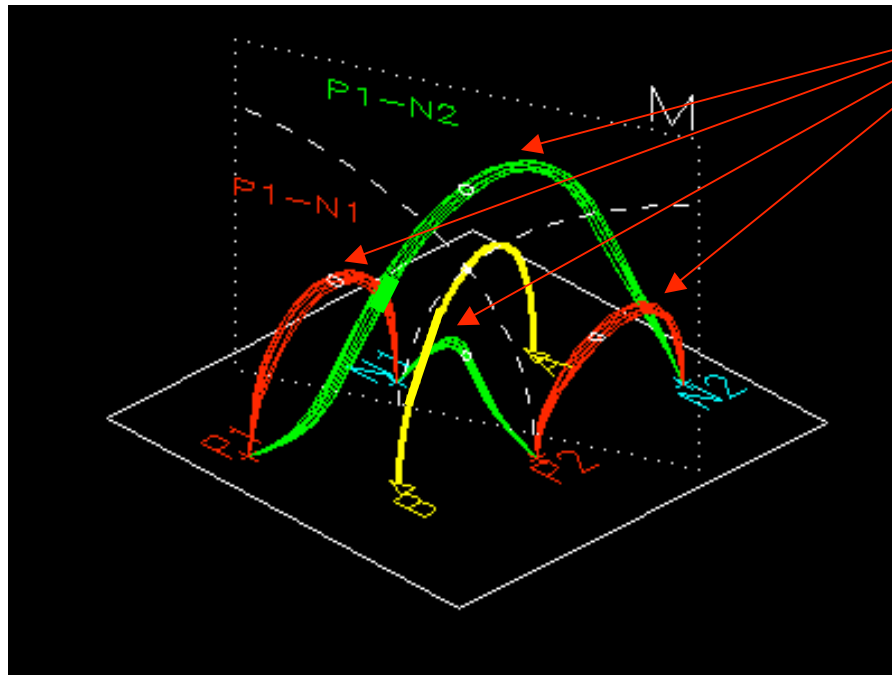# A new type of constraint…
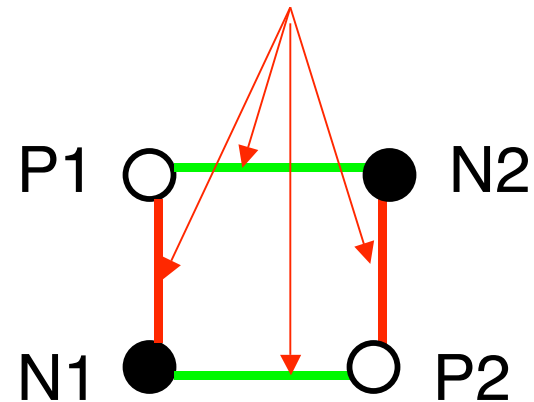
(Longcope 2001, Longcope & Klapper 2002)
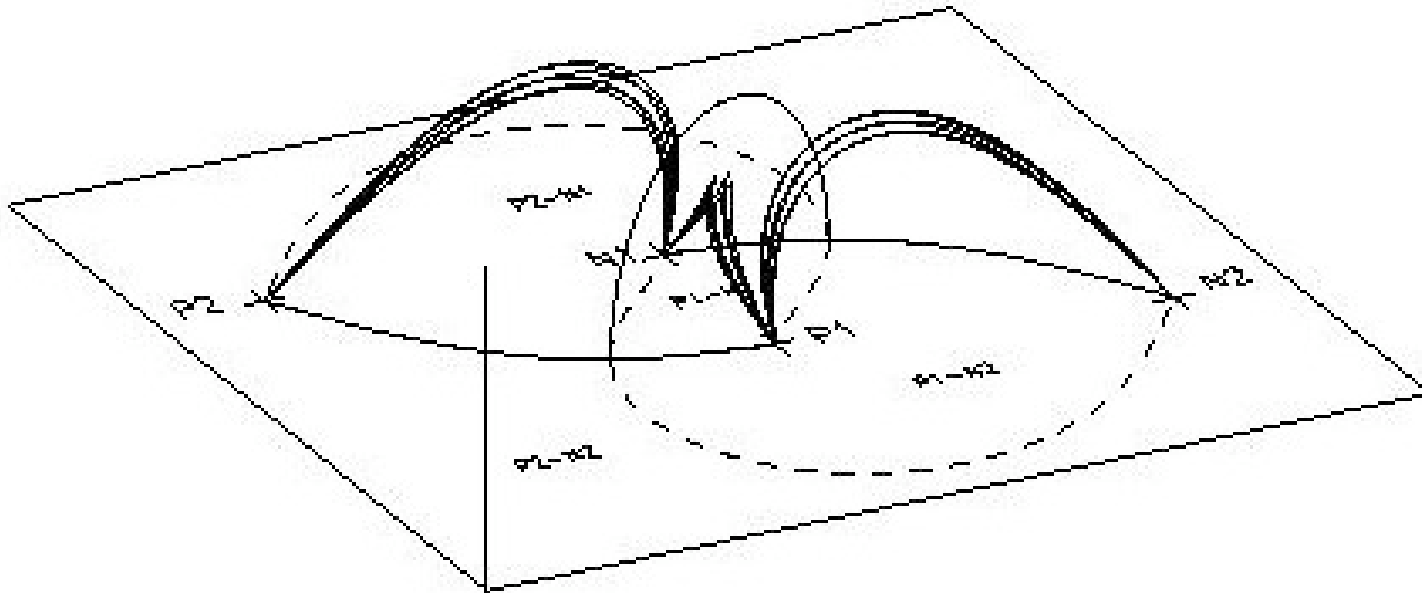
Minimize: $W\{\mathbf{A}(x)\} = \frac{1}{8\pi}\int|\nabla \times \mathbf{A}|^2\, d^3x$

Subject to **flux constraints**

Separators: where domains meet
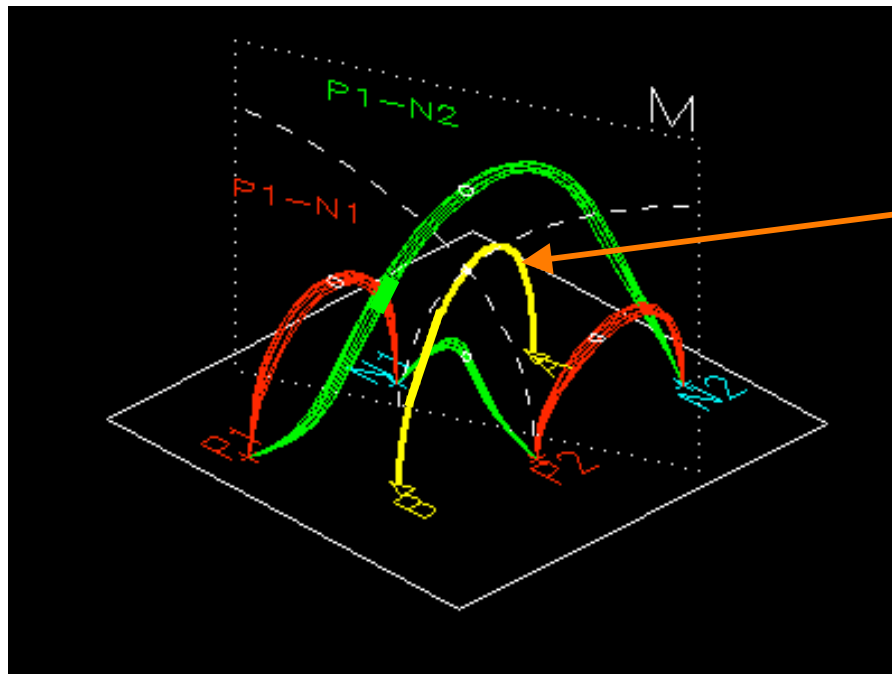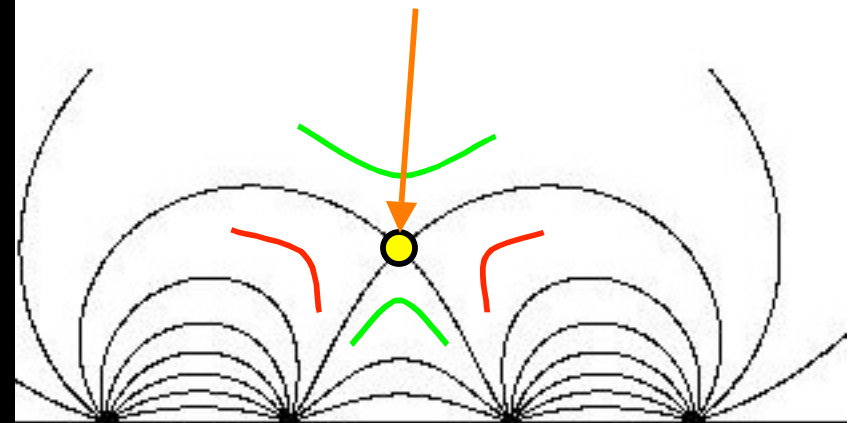
Distinct flux domains
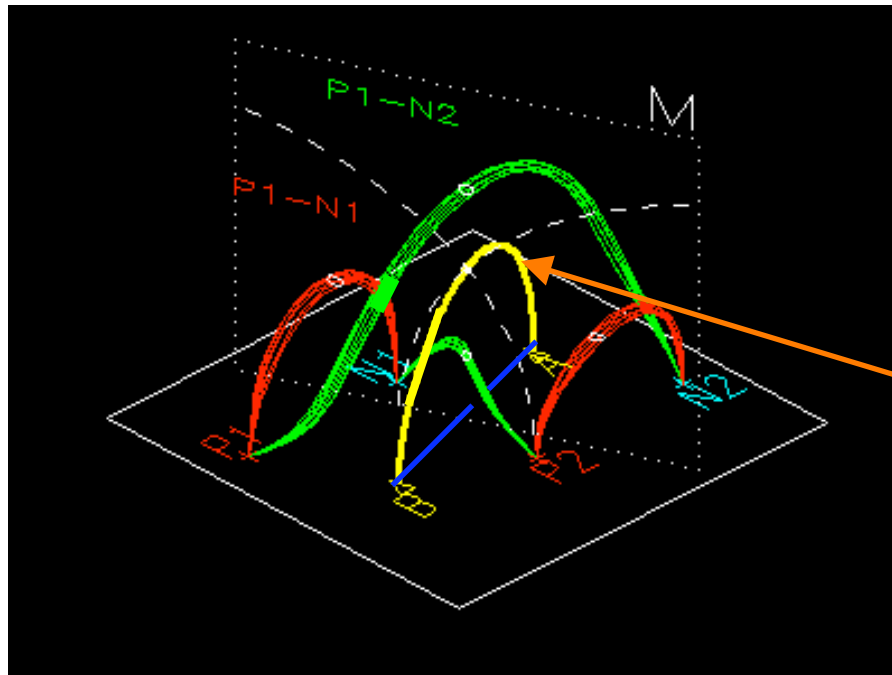
Separators: where domains meet

Distinct flux domains

Separator at interface
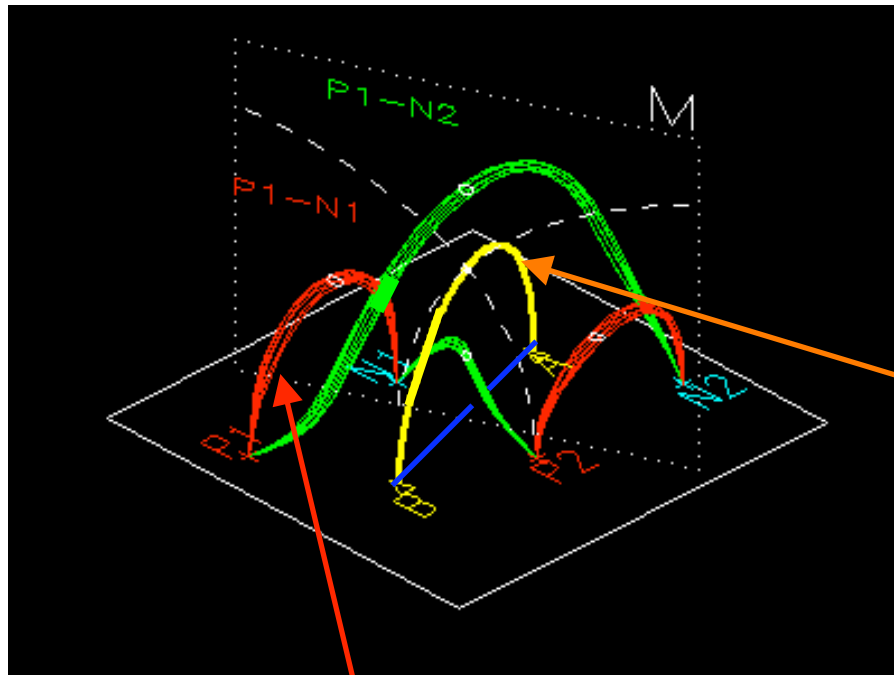
Separators: where domains meet

Distinct flux domains

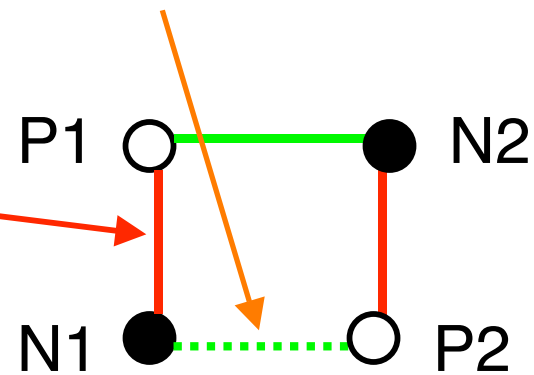Separator at interface

Closed loop encloses all flux linking P2-N1

The Separator Constraint

**Constraint
only at separator**

Closed loop encloses
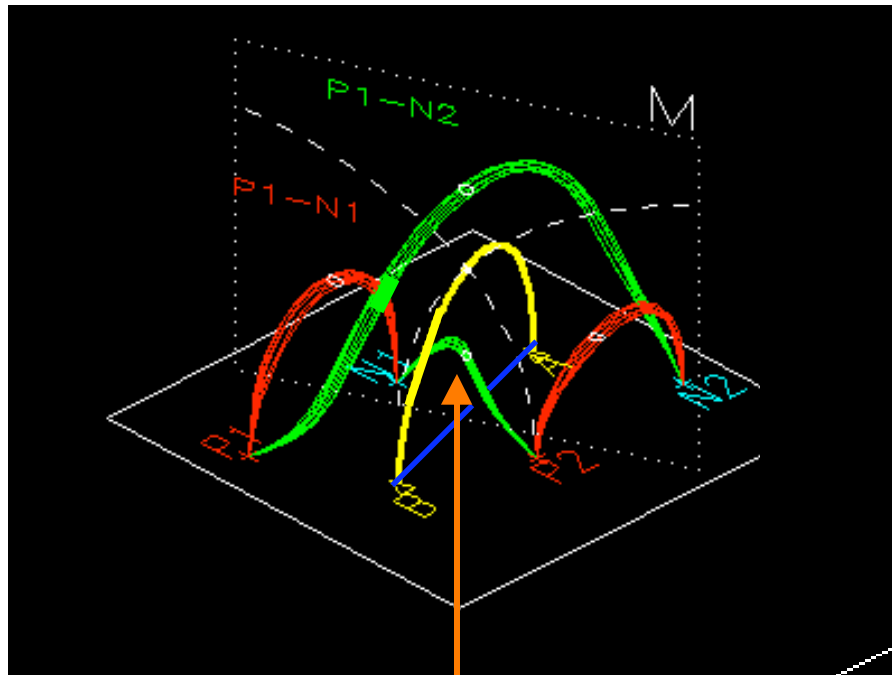all flux linking
P2-N1

Fluxes in remaining
domains: set by BC

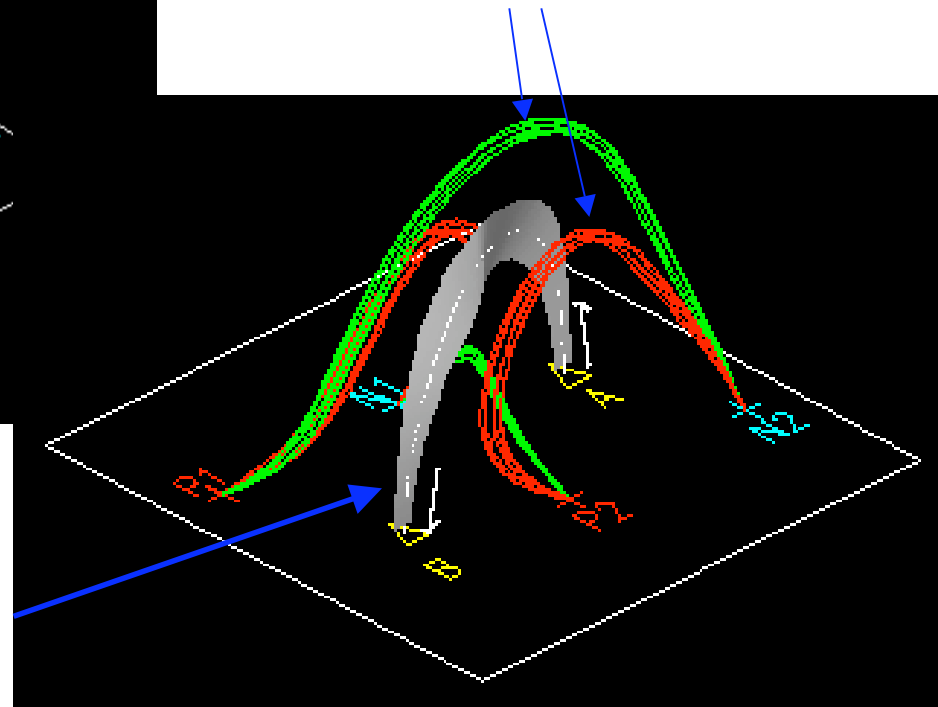P1 ○ ━━━ ● N2

N1 ● ┄┄┄ ○ P2

Minimum W subj. to constraint

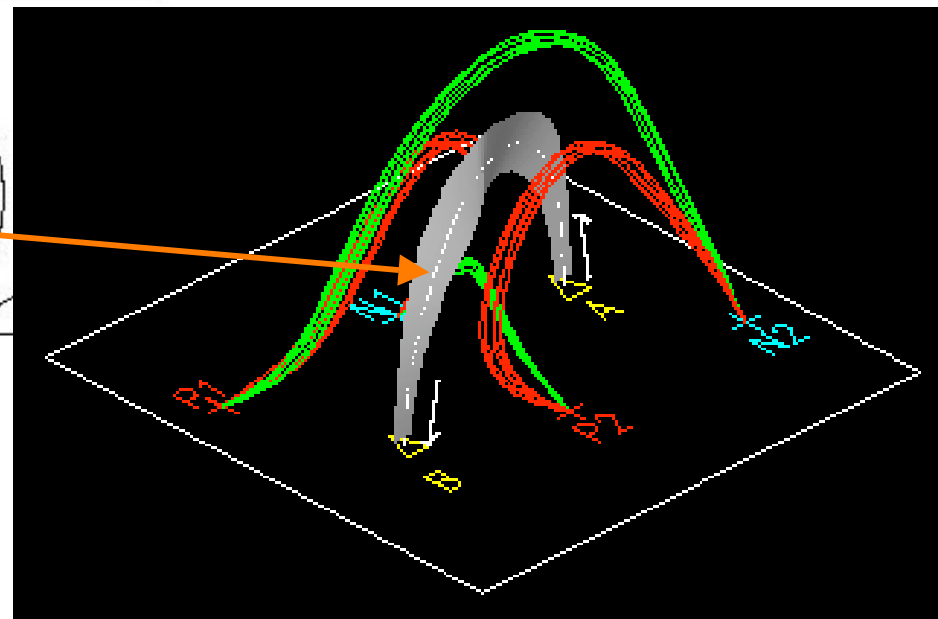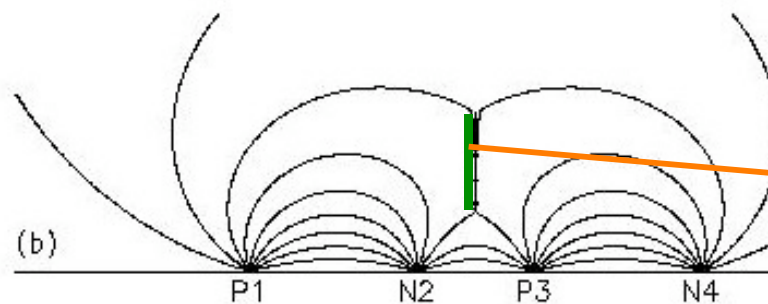
$$\nabla \times \mathbf{B} = 0$$

Current-free within
each domain

Constraint on P2-N1 flux
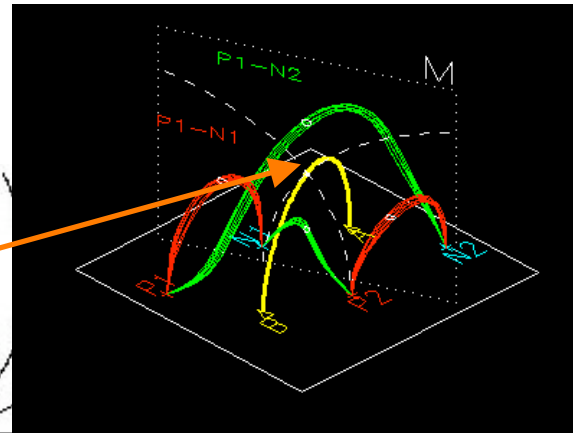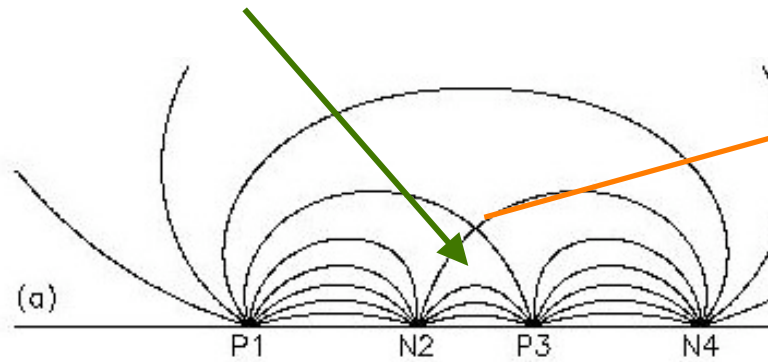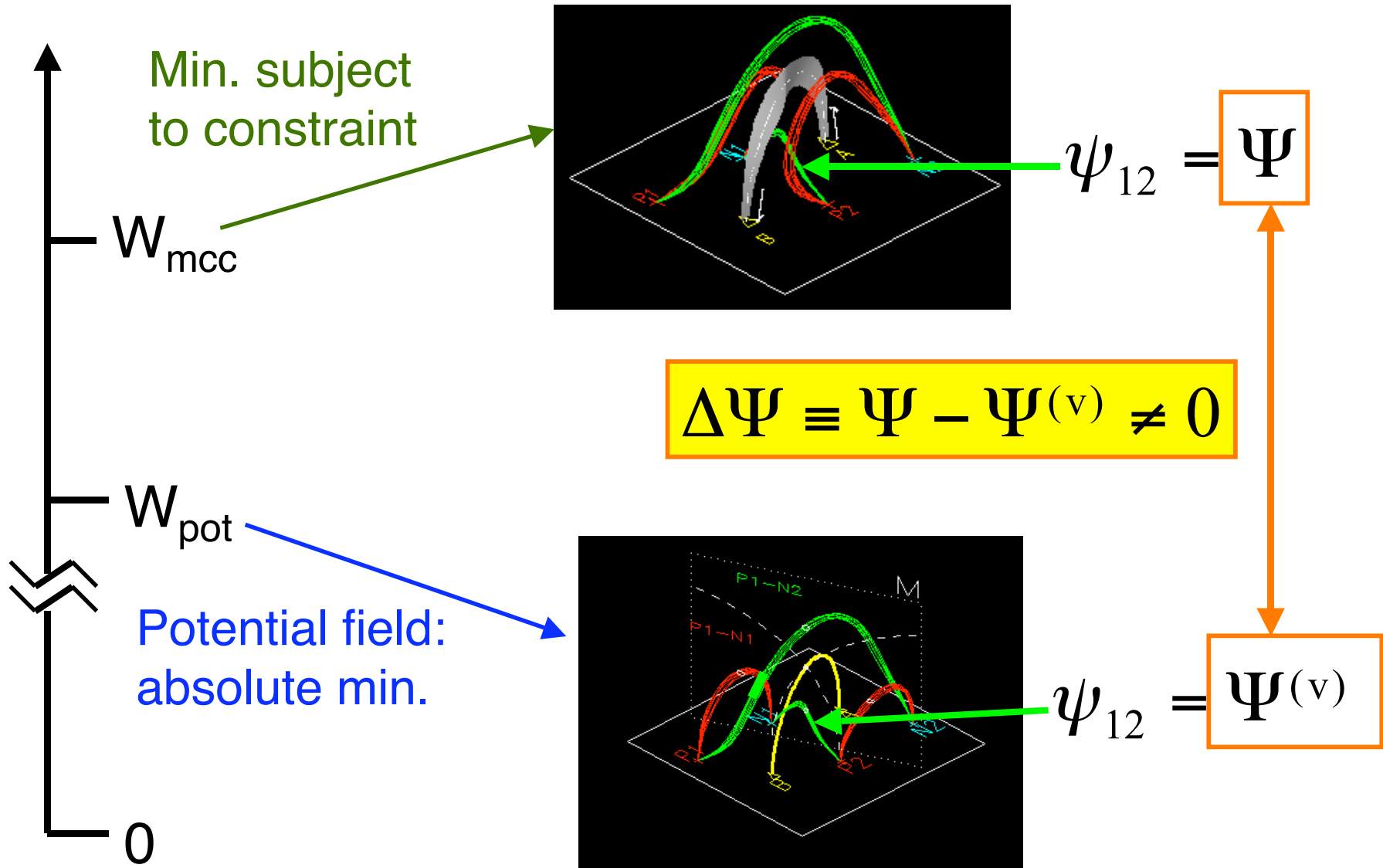
current sheet at separator

Minimum W subj. to constraint

Constraint on P3-N2 flux

2d version: X-point
 @ boundary of 4 domains
becomes current sheet

Constrained Miniumum

Min. subject
to constraint

$$\psi_{12} = \boxed{\Psi}$$

W_{mcc}

$$\boxed{\Delta\Psi \equiv \Psi - \Psi^{(v)} \neq 0}$$

W_{pot}

Potential field:
absolute min.

$$\psi_{12} = \boxed{\Psi^{(v)}}$$

0

Constrained Miniumum

Min. subject
to constraint

W$_{mcc}$

Current

$$I_{cs} = \frac{\Delta\Psi}{L}$$

$$\Delta\Psi \equiv \Psi - \Psi^{(v)} \neq 0$$

W$_{pot}$

Potential field:
absolute min.

0

$$\psi_{12} = \boxed{\Psi}$$

$$\psi_{12} = \boxed{\Psi^{(v)}}$$

Constrained Miniumum

Min. subject
to constraint

W_{mcc}

Free energy

W_{pot}

Potential field:
absolute min.

0

$$\Delta W = \tfrac{1}{2} I_{cs} \Delta \Psi \approx \frac{(\Delta \Psi)^2}{2L}$$

Reconnection

$$\oint \mathbf{E} \cdot d\mathbf{l} \neq 0$$

W_{mcc}

Min. Energy Drops

Eliminate constraint

$$\psi_{12} \to \Psi^{(v)}$$
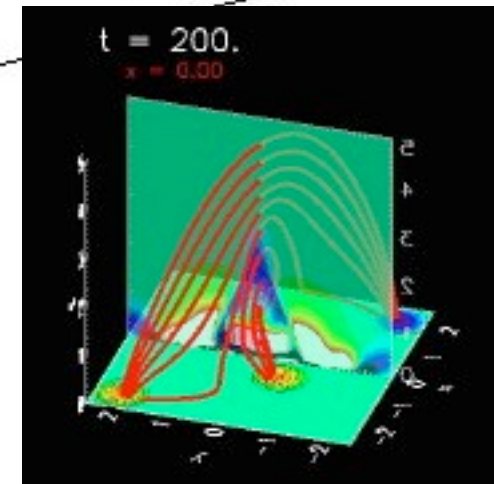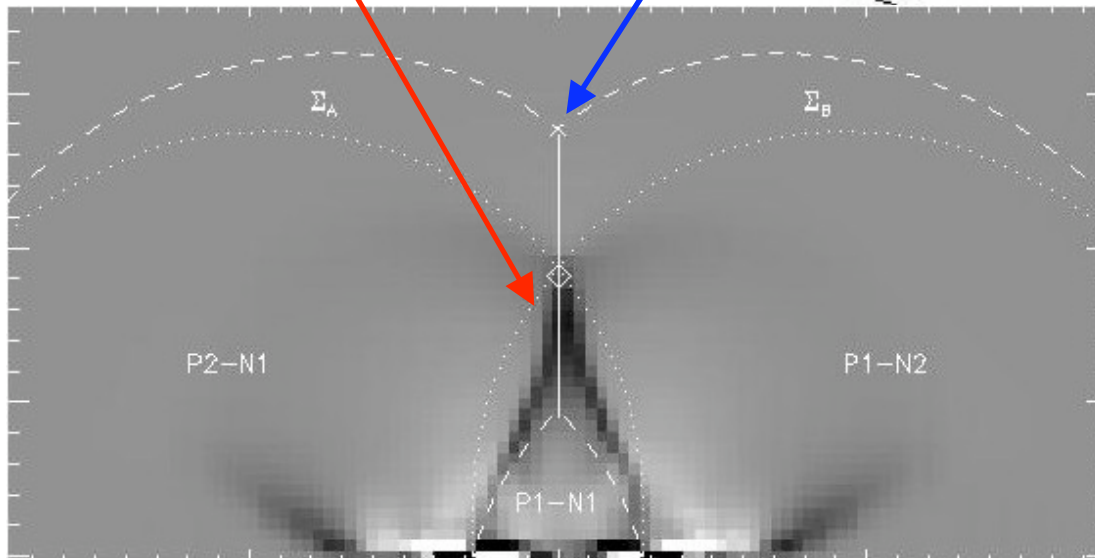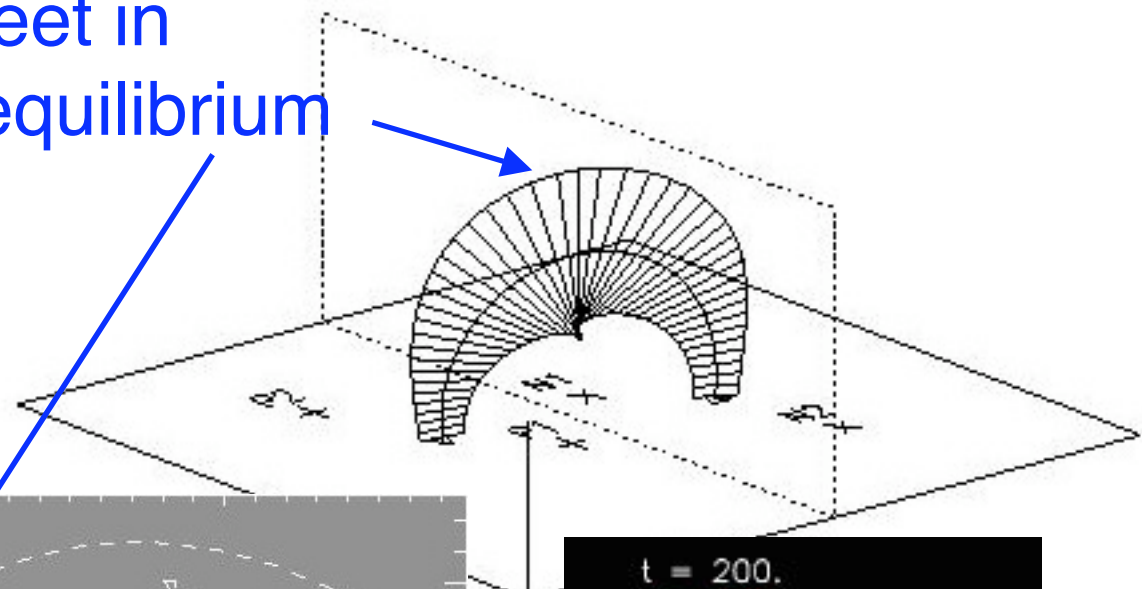
W_{pot}

Potential field:
absolute min.
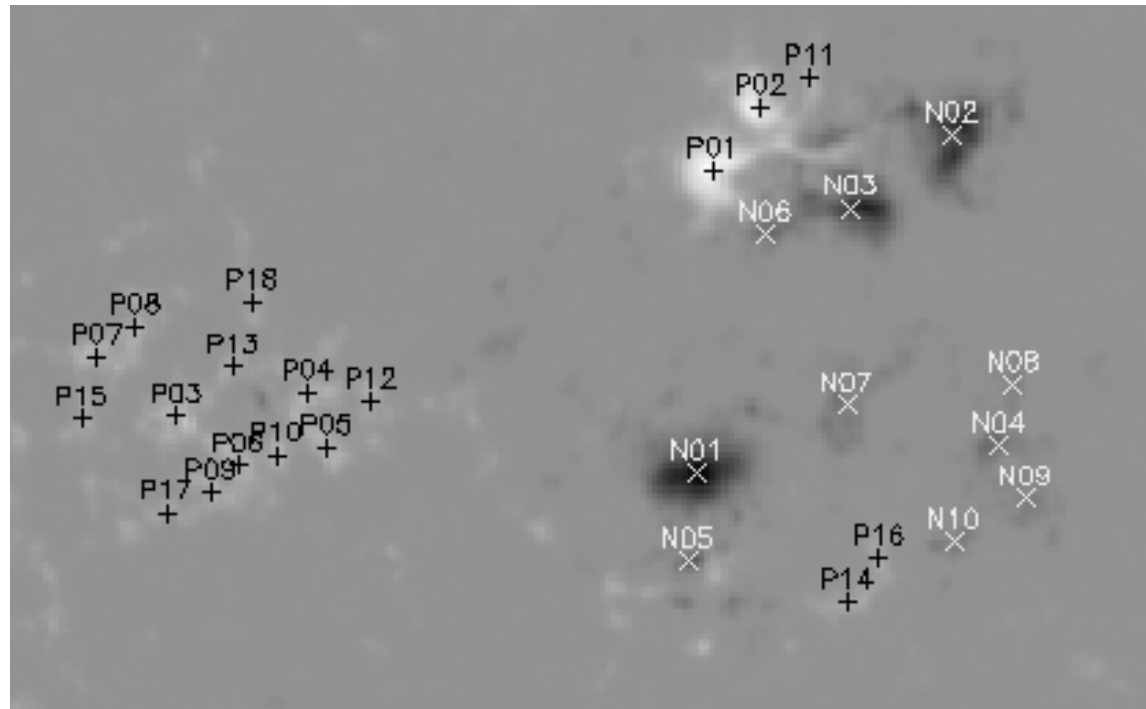
0
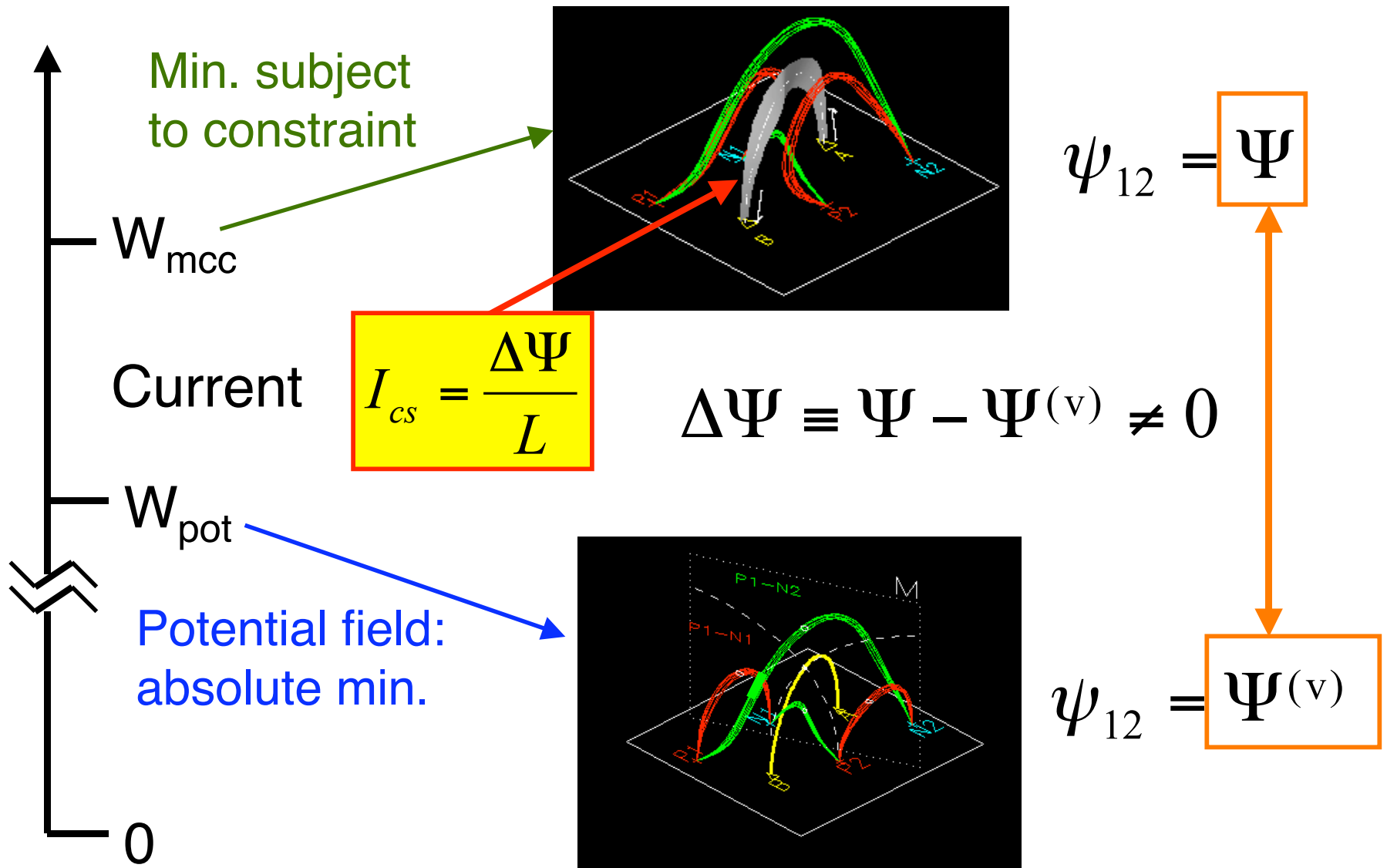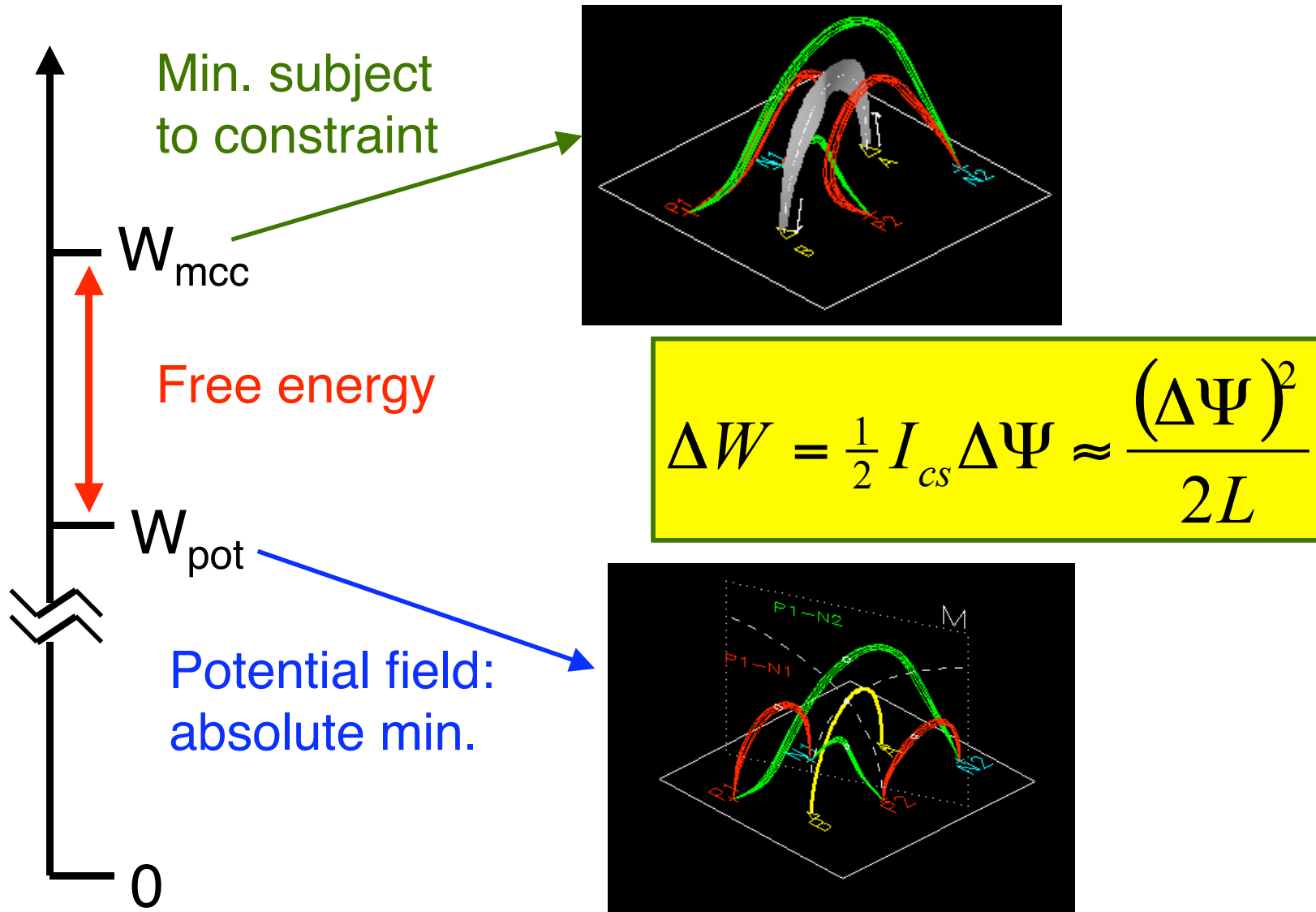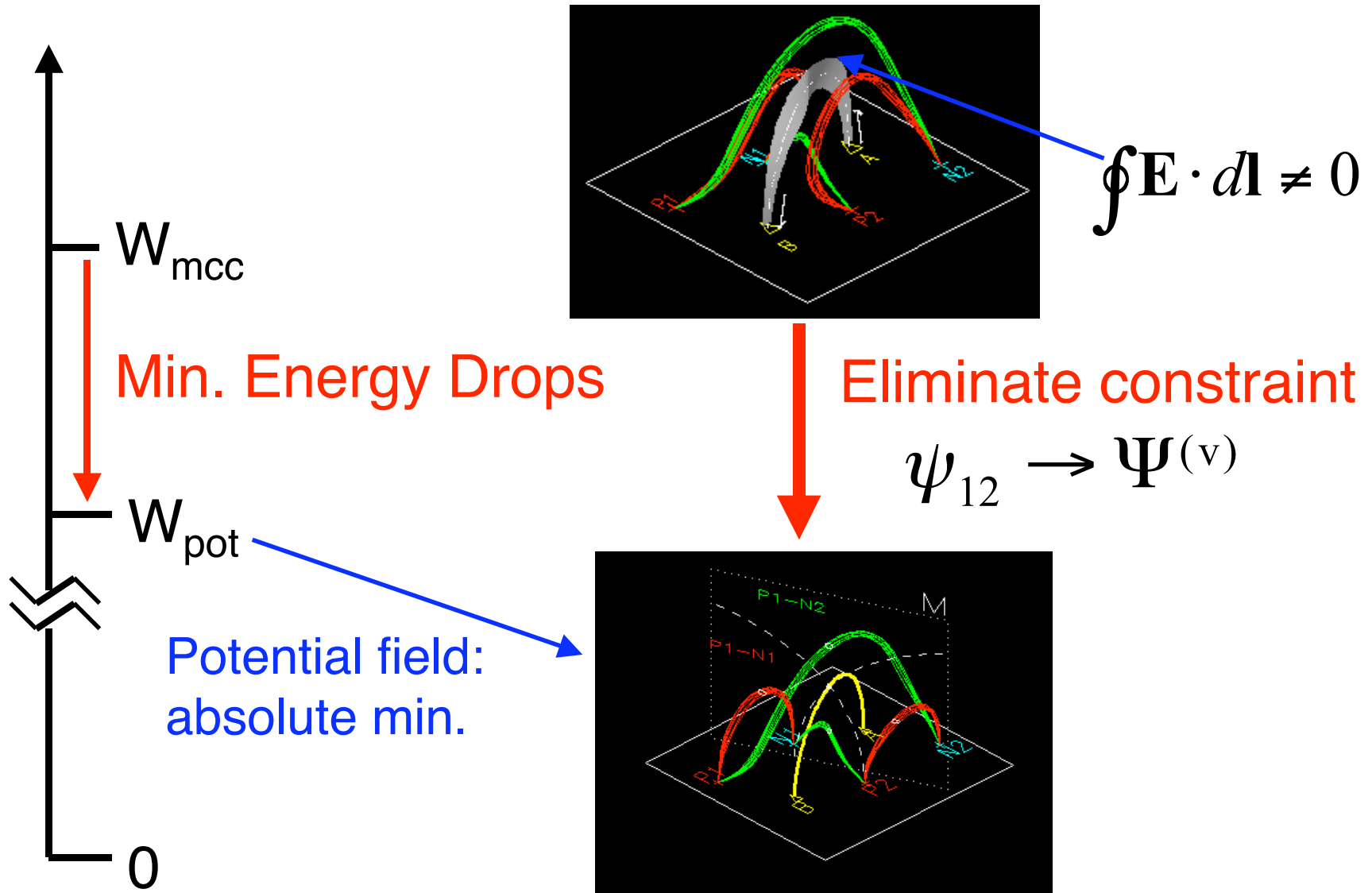
Numerical Test

(Longcope & Magara 2003)

Model: Current sheet in flux-constrained equilibrium

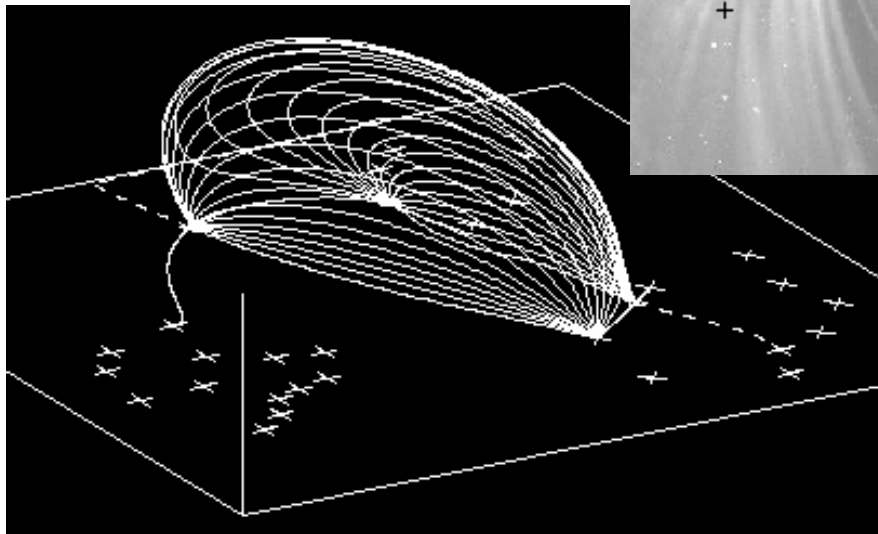**Simulation**: J/B @ midplane
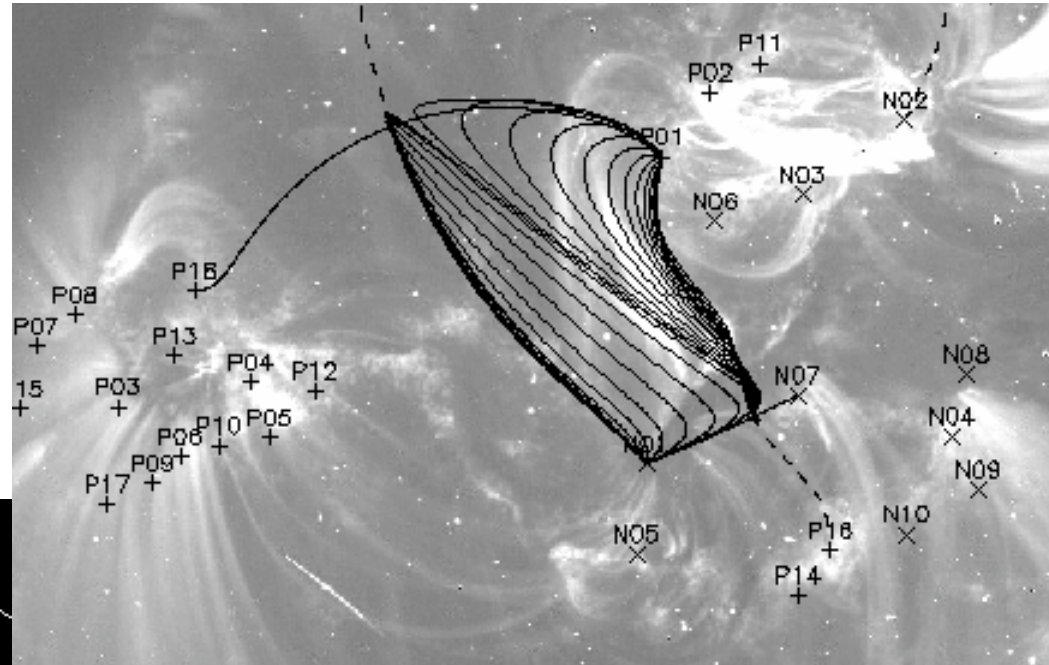
A complex Example

Approximate p-spheric field using discrete sources

The domain of new flux
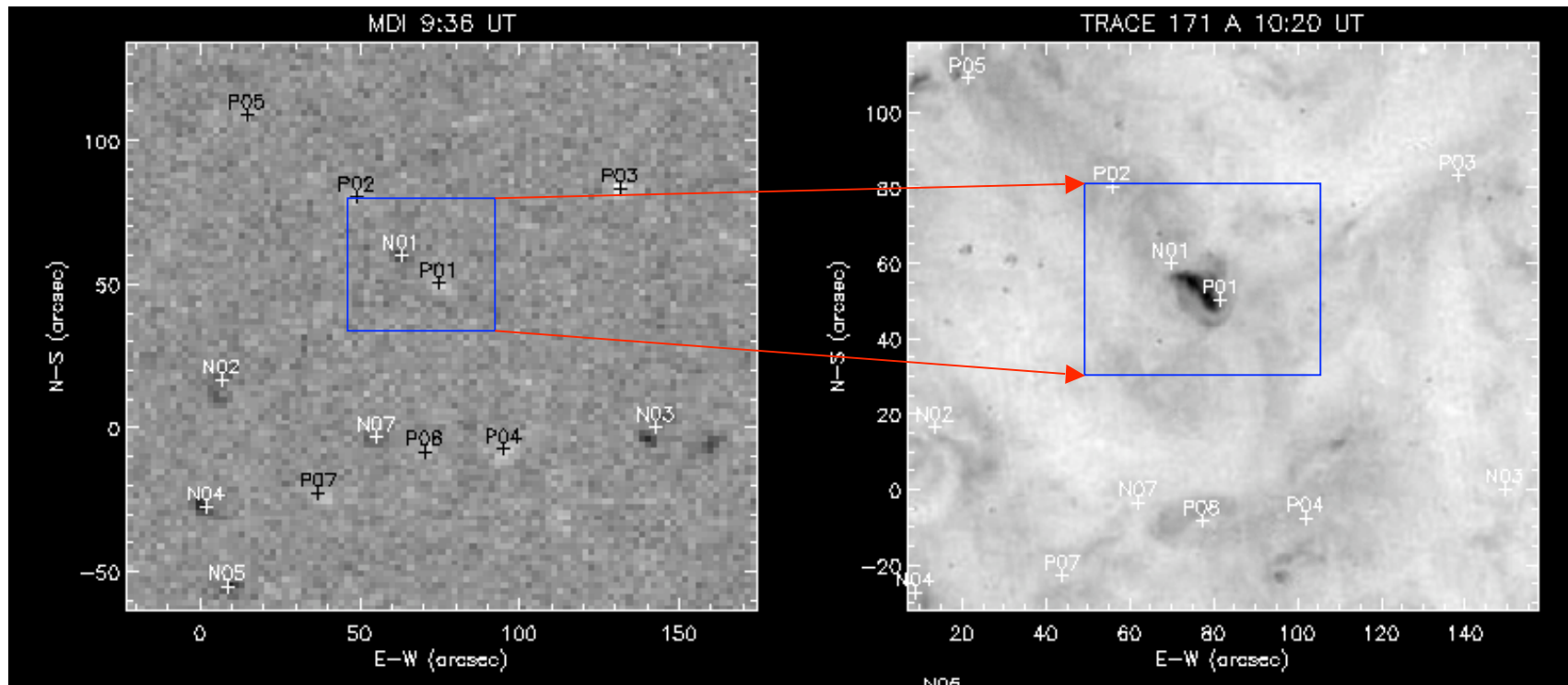
Emerging bipole
P01-N03

New flux connects
P01-N07

Summary

- 3d reconnection occurs at separators
- Currents accumulate at separators
    - ➔ store magnetic energy
- Reconnection there releases energy
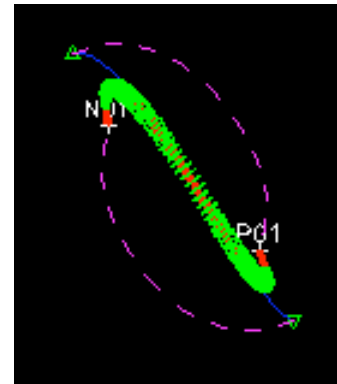
A Case Study

TRACE & SOI/MDI observations 6/17/98
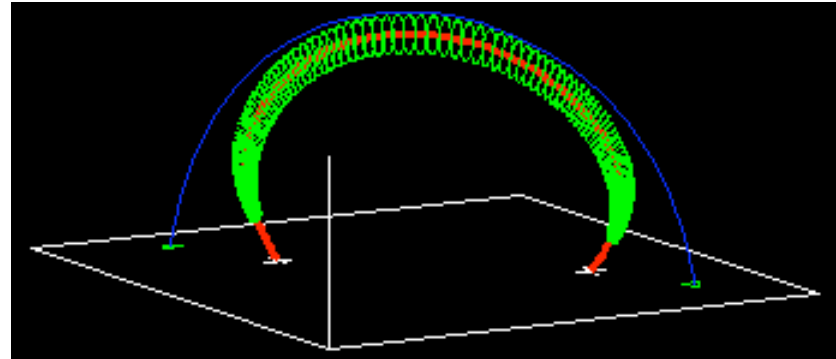
(Kankelborg & Longcope 1999)

Post-reconnection Flux Tube

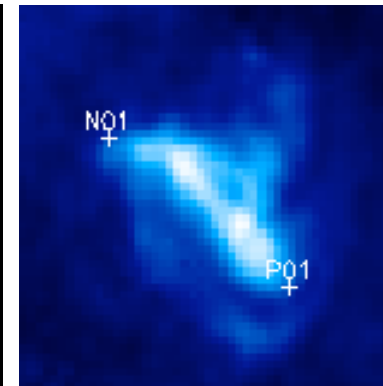
Flux $\Delta\Phi = 1.8 \times 10^{17}$ Mx
Accumulated over

$$\Delta t = 20 \text{ min}.$$
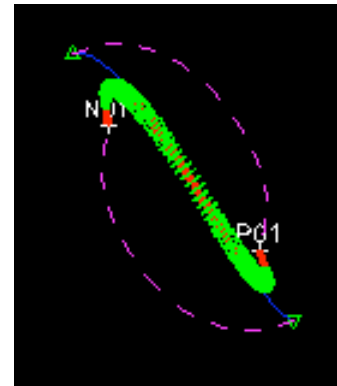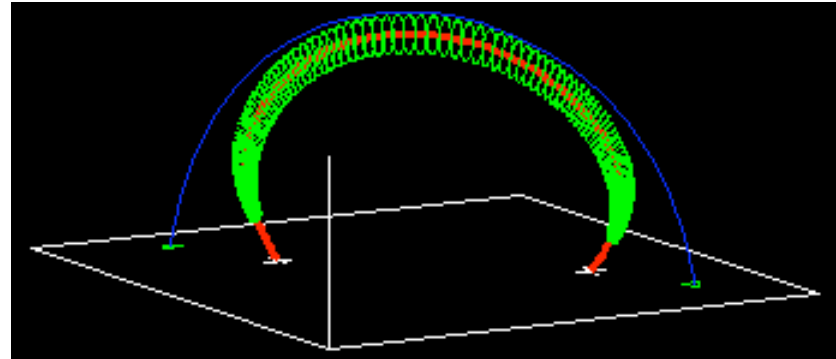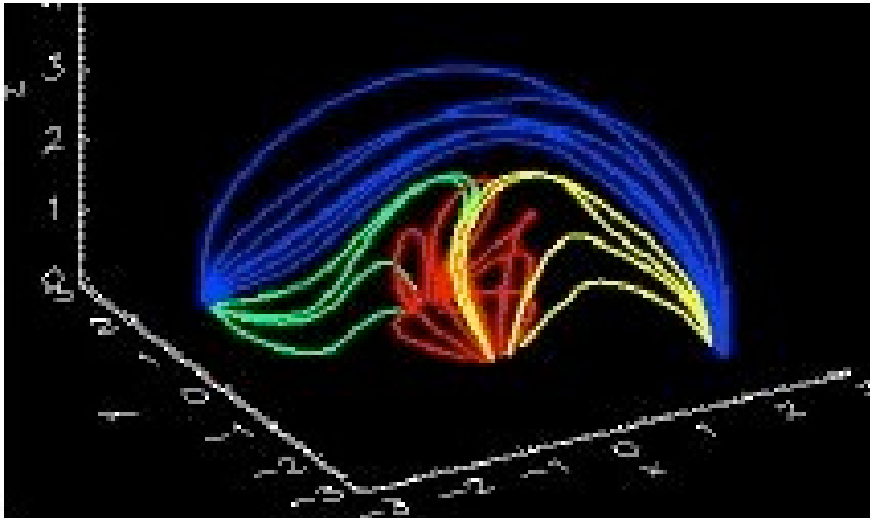

Projected to bipole location

Post-reconnection Flux Tube

Flux $\Delta\Phi = 1.8 \times 10^{17}$ Mx
Accumulated over
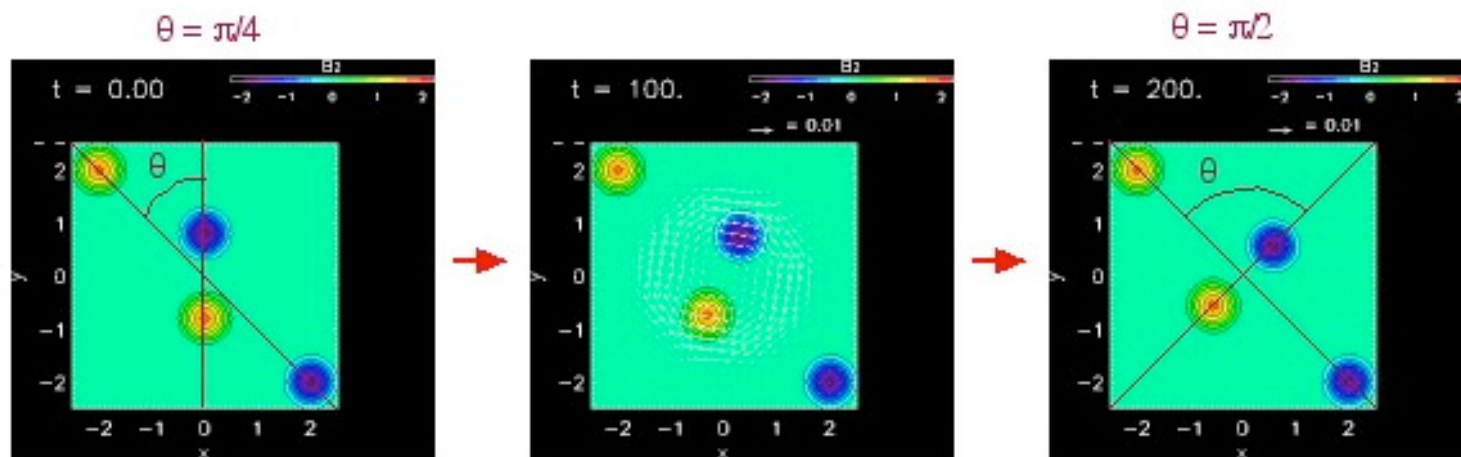
$$\Delta t = 20 \text{ min.}$$

Numerical Test

(Longcope & Magara 2003)

- Initially: potential field
- Move 2 inner sources **slowly**
- Solve 3d MHD eqns. (inside box)

Numerical Test

(Longcope & Magara 2003)