Numerical Simulations of 3D Reconnection: rotating footpoints

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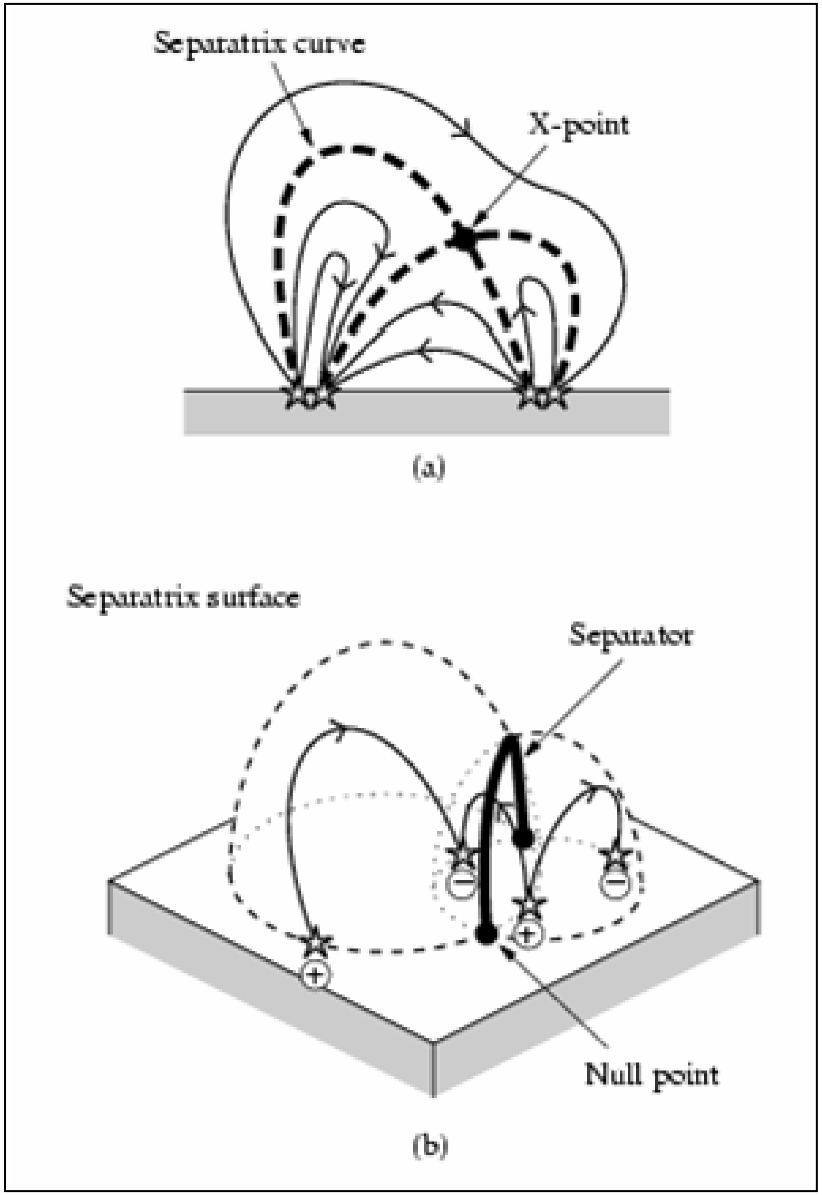
Contents: - numerical setup
- description of results
- reconnection rates
- energetics
- conclusions

3D Reconnection

- 2D magnetic skeleton:
  - X-point (B=0)
  - Separatrix curves
- 3D magnetic skeleton:
  - Null points (B=0)
  - Separatrix surfaces:
    - » Outline connectivity domains
  - Separator:
    - » Intersection of 2 separatrix surfaces



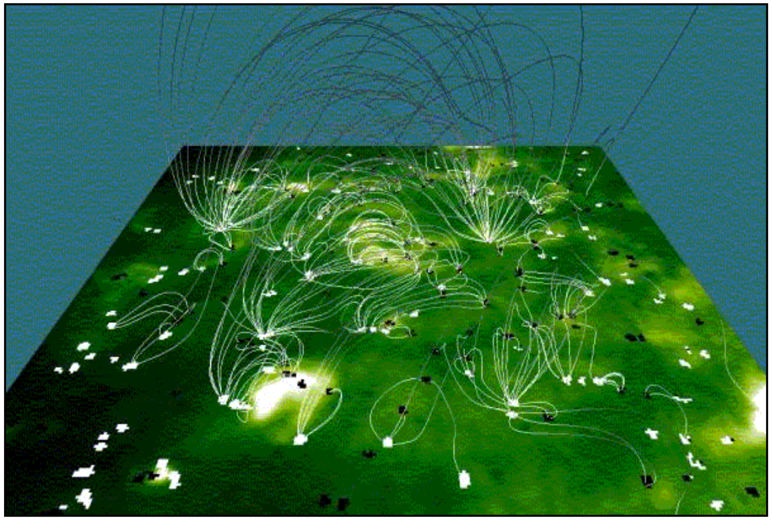
Tectonics

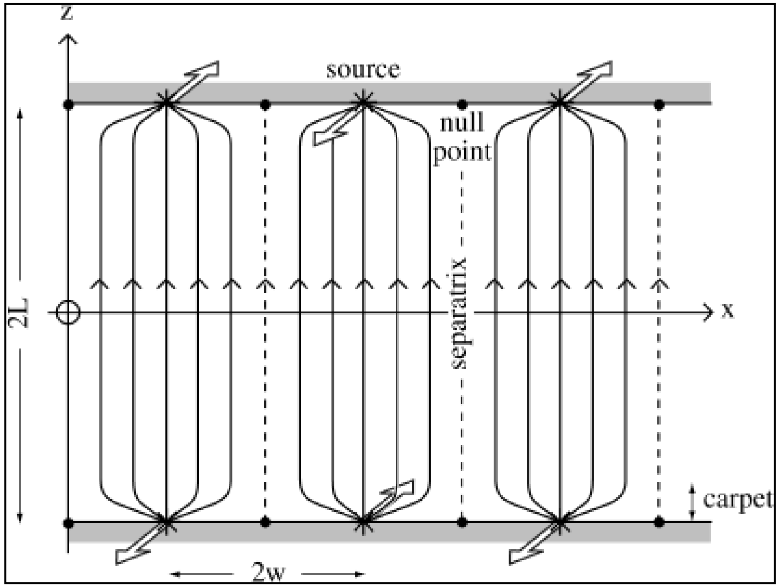
- Flux comes through surface in concentrated sources
  - » Magnetic carpet
- Photospheric flux reprocessed in 8 - 19 hours (Hagenaar *et al* 2003)
  - » Effect on coronal heating?

- Start with array of intense flux tubes ($B \sim 10^3$ G, <100km)
- » Simple motions
- » Very rapid build up of current (Priest *et al* 2002)

- Coronal field recycled much faster in 1.4 hours (Close *et al* 2004)

➢ Investigate elementary heating event, driven by simple photospheric motion



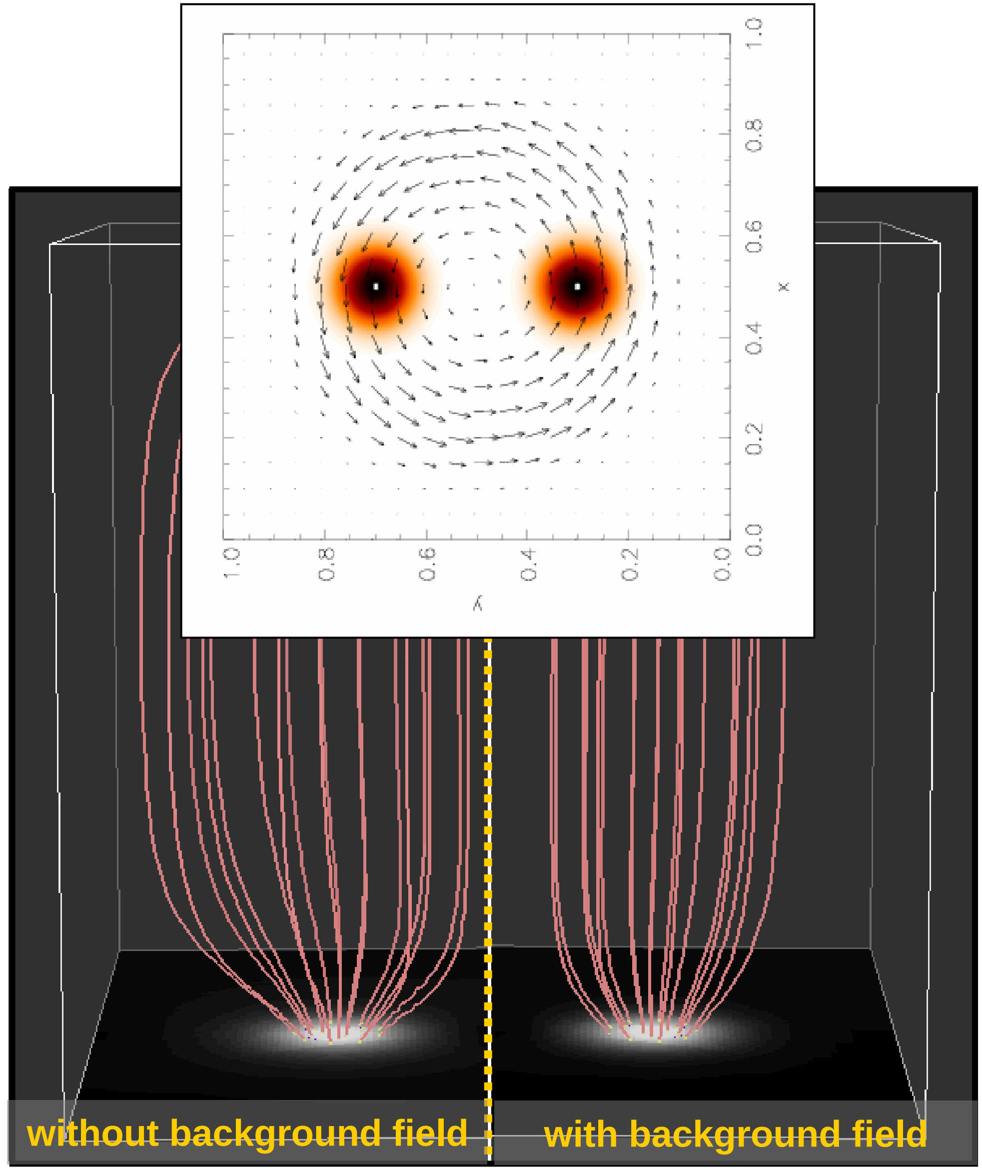


Basic Model

- ➢ **Model reconnection driven by rotating photospheric footpoints**
- ▪ **3D numerical box:**
  - » **z=0: 2 +ve sources**
  - » **z=L: 2 –ve sources**
  - » **counter-rotate**

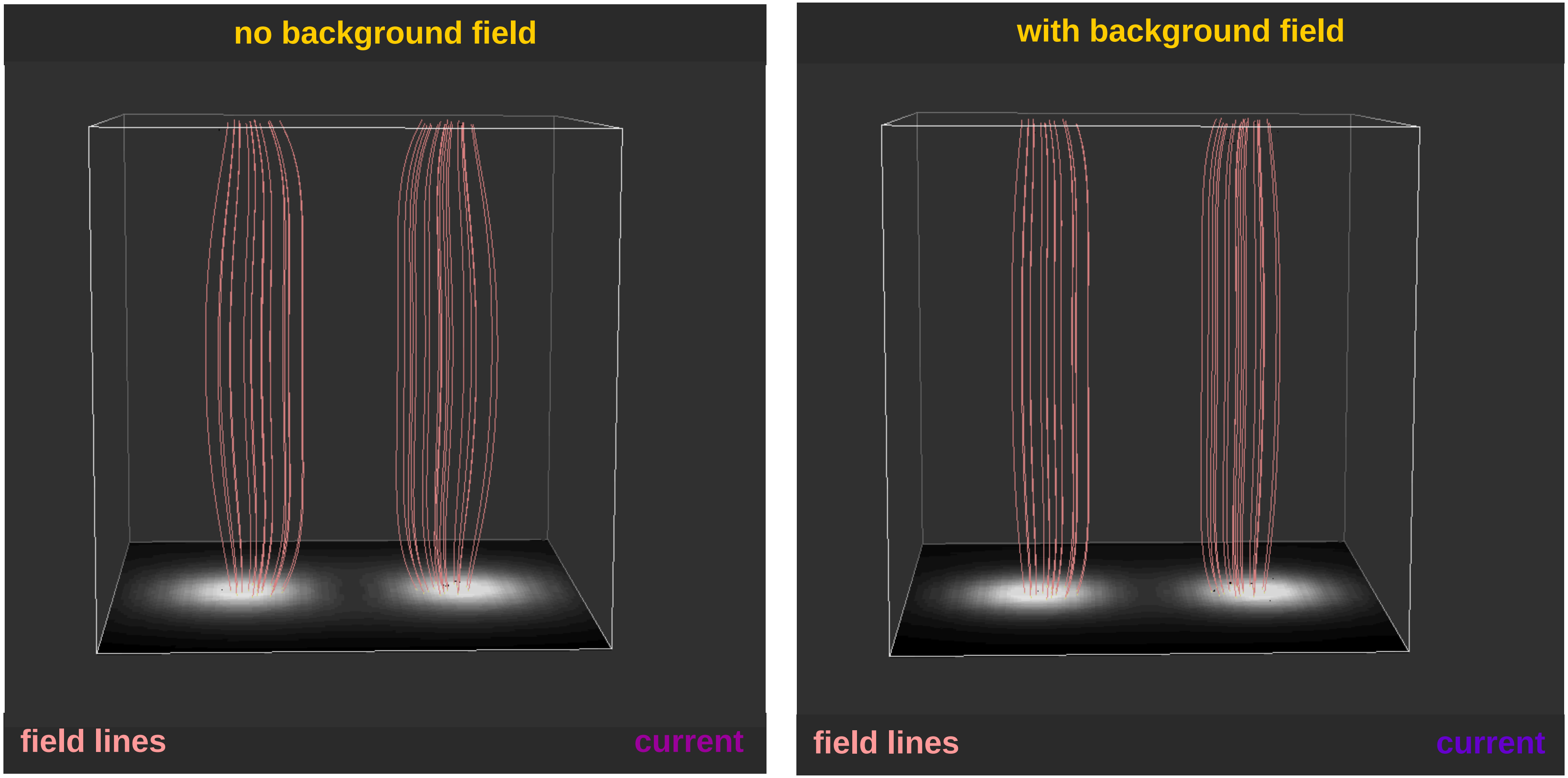
- ➢ **Consider 2 variations of setup:**
- ▪ **Without background field**
  - » **flux tubes fan out quickly**
  - » **separtrix surfaces**

- ▪ **With (vertical) background field**
  - » **flux tubes confined**
  - » **“fluxtube-separatrix” surfaces**



Dynamical Evolution (1)

- Flux ‘domains’ are forced to interact
- Twisted current sheets form along separatrix surfaces
- Field lines reconnect to other sources + (periodic) domain outside box

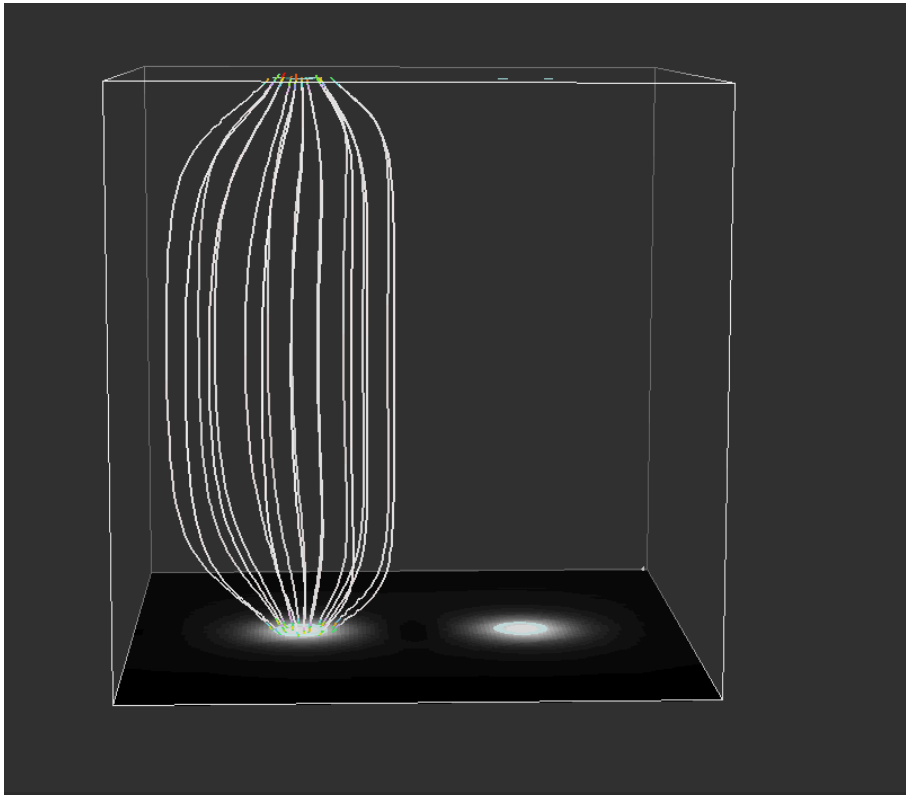


Dynamical Evolution (2)

- Component of electric field along field lines (E_{par}) is a good indicator of reconnection

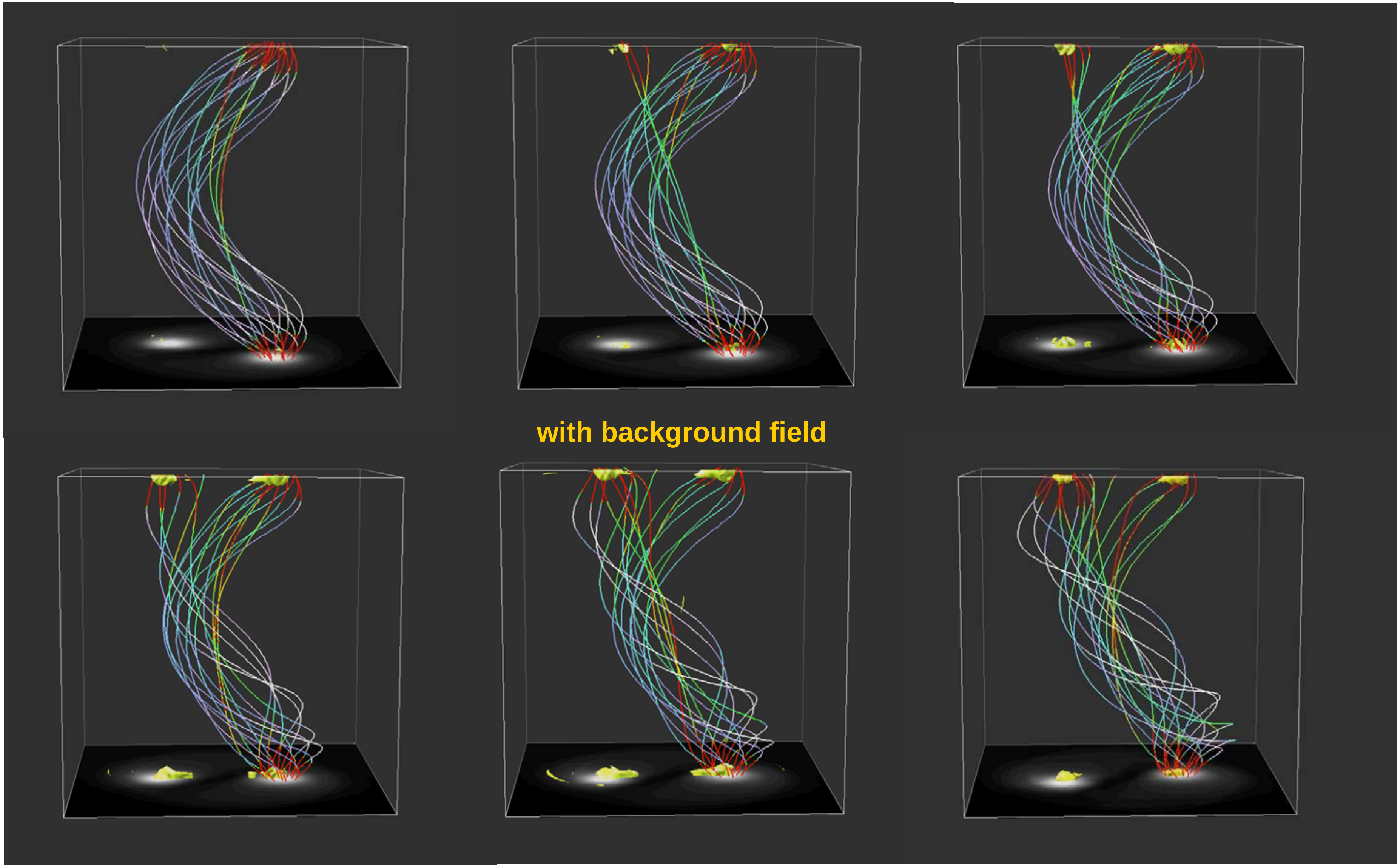
» Build up of E_{par} along field lines close to current sheets

» Field lines with high E_{par} reconnect in subsequent snapshot



no background field

Dynamical Evolution (3)



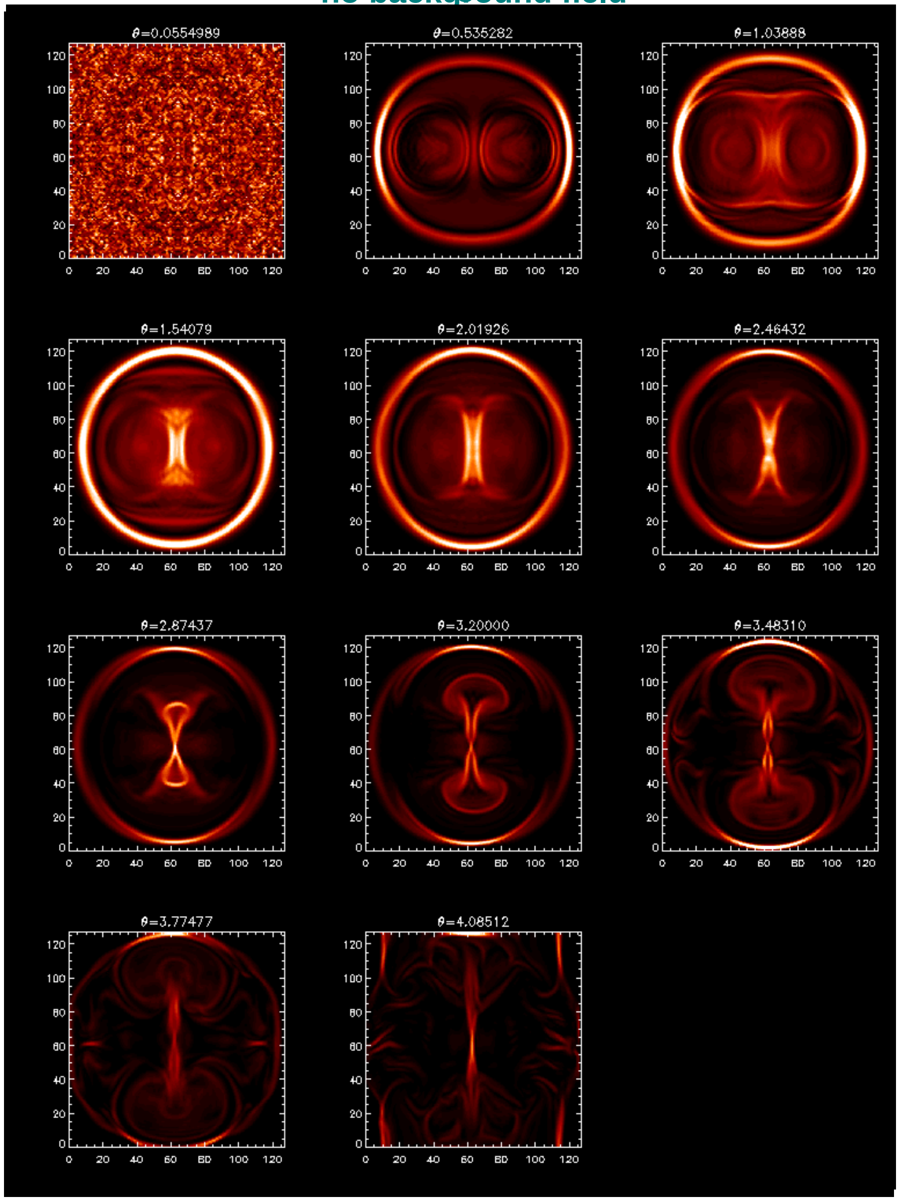
Current at z=0.5

- **No background field:**
  - » **current sheet along coinciding separatrix surfaces**
  - » **as sources rotate, develops into x-type configuration**

- **With background field:**
  - » **ring of current at edge of domain due to velocity shear**
  - » **“fluxtube-separatrix” surfaces initially apart**
  - » **development of x-type configuration**
  - » **strong outflow velocities cause ‘bowshock’ currents**

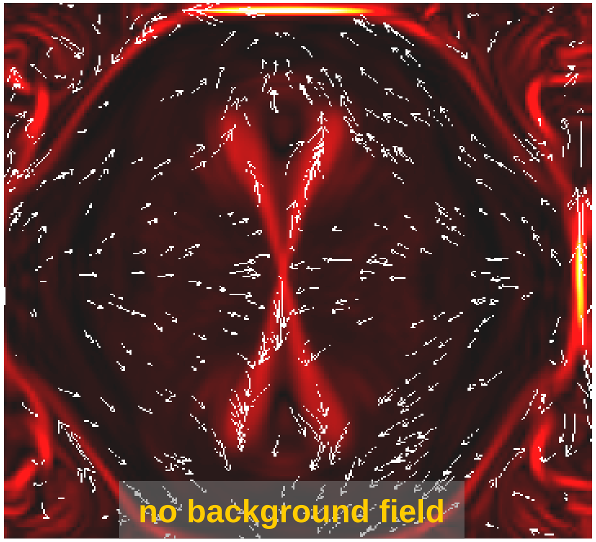
with background field

no background field

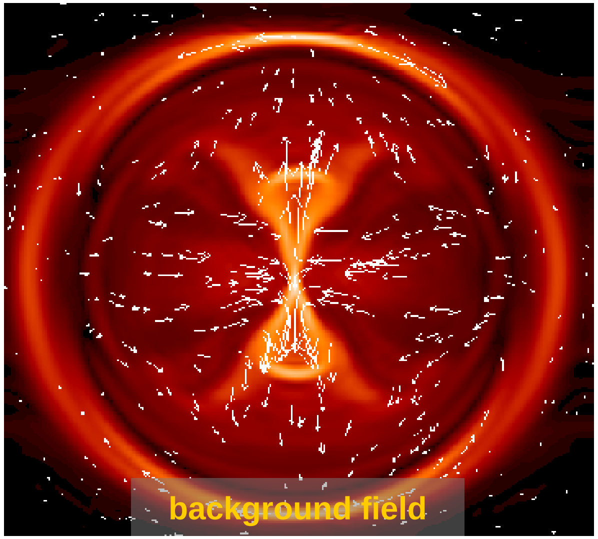


Current + Velocity at z=0.5

- **No background field:**
  - » **stagnation point flow**
  - » **outflow velocities comparable to inflow**
    - » **(slow) shock along separatrices**

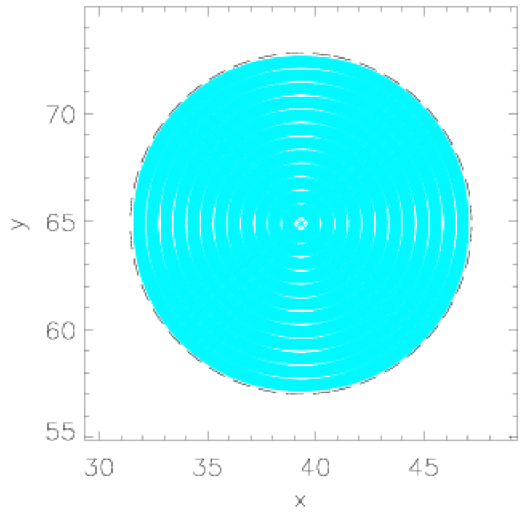


- **With background field:**
  - » **velocity shear at edge of domain**
  - » **stagnation point flow**
  - » **fast outflow velocities**
    - » **fast (bow)shock**



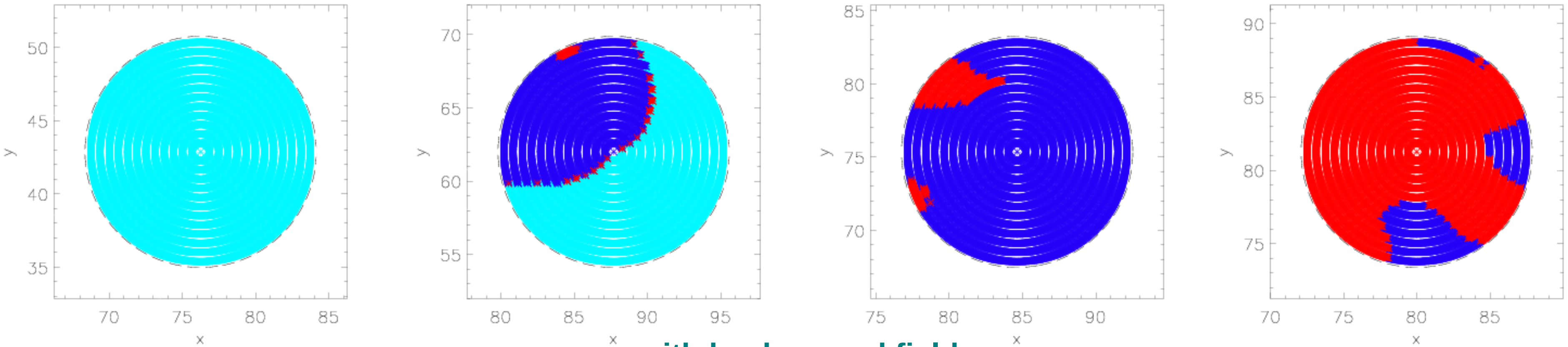
Connectivity Structure

- **Dynamical evolution of connectivity is complex!**
- **No background field (confining): substantial number of field lines reconnect to neighbouring domain**
- **With background field: most field lines connect to neighbouring domain when ‘bowshock’ currents collide with edge current**



no background field

Original connection
reconnected to other source
reconnected to neighbouring domain



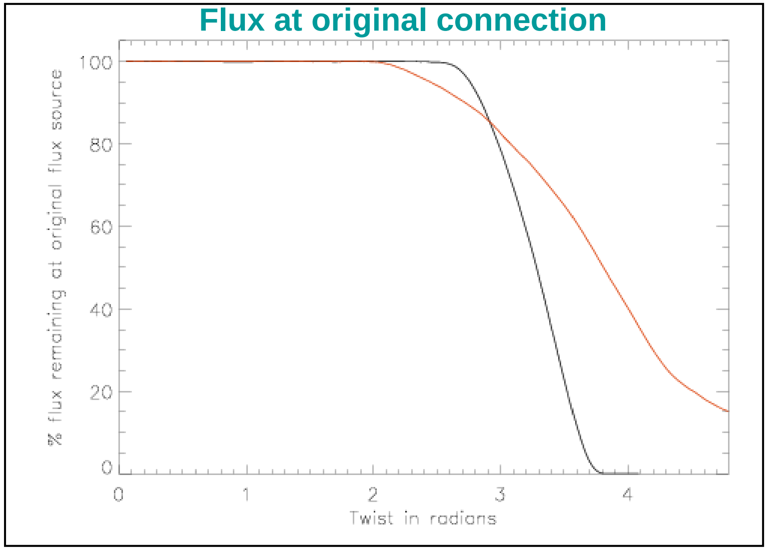
with background field

Reconnection rate

- Fixed amount of flux associated with each field line
- Work out amount of reconnected flux as field lines change connectivity

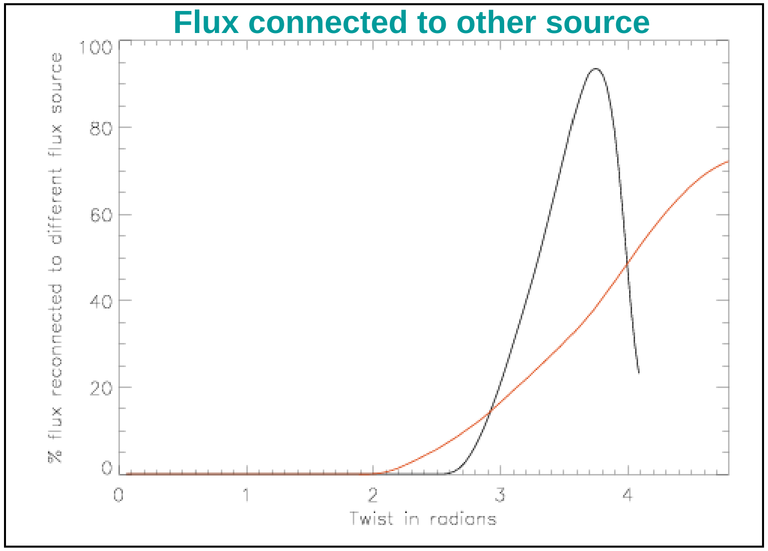
» Reconnection starts later (at larger angle) with background field

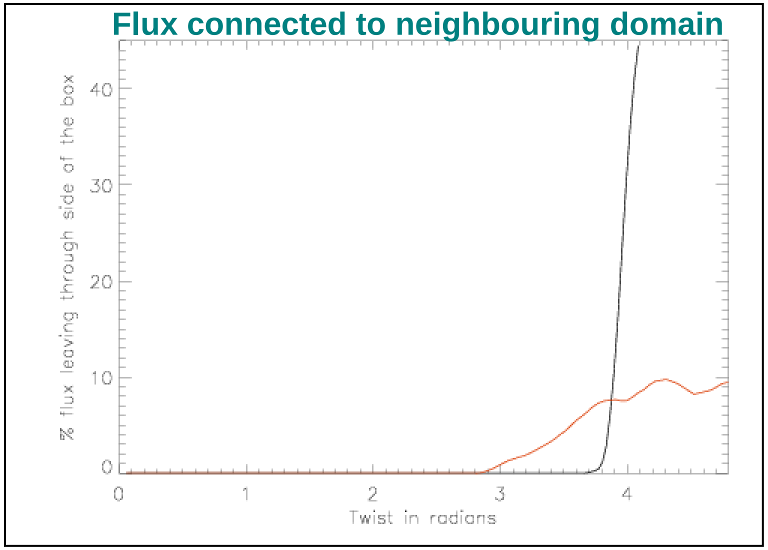
» Amount of reconnected flux increases faster with background field



no background field

background field





Poynting flux

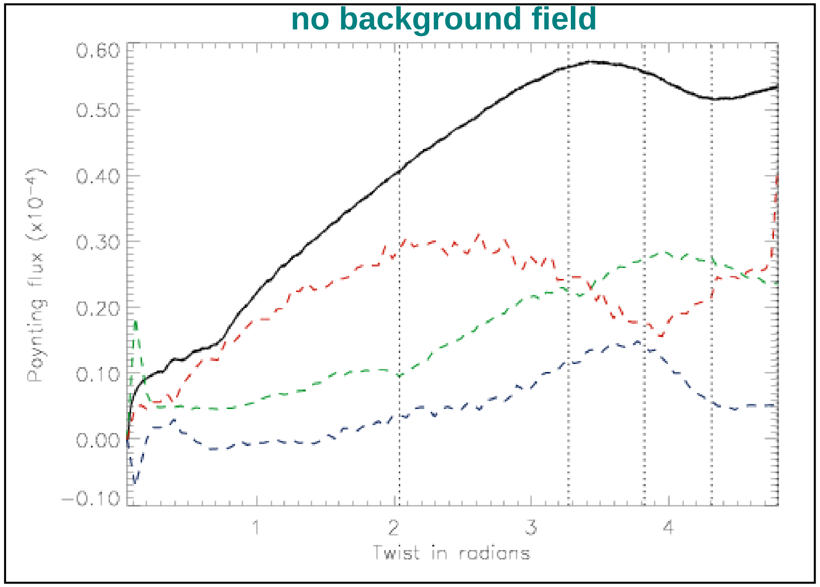
» **Poynting flux describes flow of energy through the boundaries:**

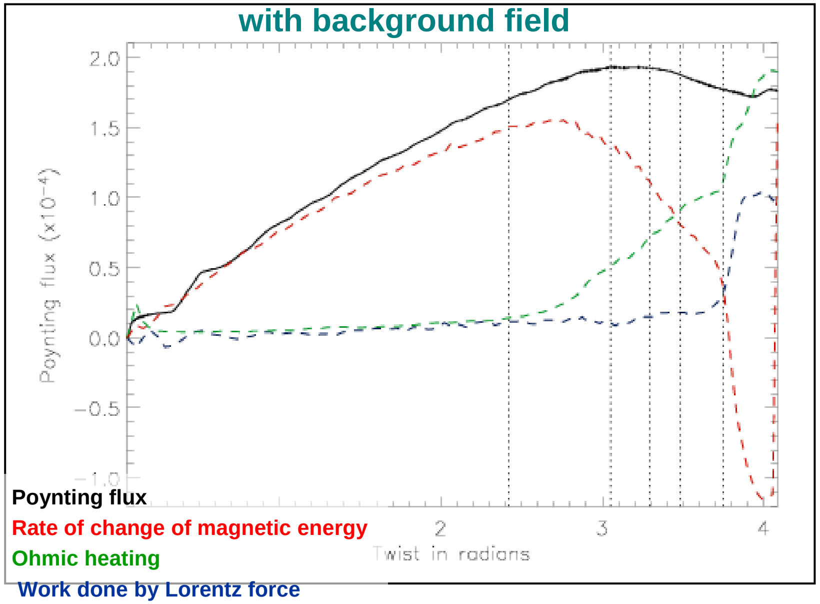
$$-\int (\mathbf{E}\times\mathbf{B})/\mu_0 . dS = \int \frac{\partial}{\partial t}\left(\frac{B^2}{2\mu_0}\right) dV + \int j^2/\sigma dV + \int v.(\mathbf{j}\times\mathbf{B}) dV$$

Inflow of electromagnetic energy = rise in magnetic energy + Ohmic heating + work done by Lorentz force

Energetics

- Start of driving:
  - » magnetic energy increases
- Onset of reconnection:
  - » tension in magn field is reduced:
  - • build up magn energy slows down
  - » strong currents + outflow:
  - • Ohmic dissipation increases
  - • Work done by Lorentz force increases (+ kin energy & visc diss)
- Later stages:
  - » No background field: reconnection slows down
  - » Background field: reconnection of fieldlines to neighbouring domain





Conclusions

- Numerical simulation of 3D reconnection driven by rotation of flux sources
  - » Very efficient build up of current sheets ~ tectonics model
  - » No background field: separatrix surfaces present
  - » With background field: quasi-separatrix surfaces created by driving
- Comparison of setup with and without background field:
  - » reconnection along twisted current sheet
  - » complex evolution of connectivity structure
  - » different reconnection rates
  - » large differences in final stages of experiments
- Further comparisons with:
  - » potential evolution – free magnetic energy?
  - » reconnection rate of standard reconnection models
  - » different types of photospheric motions (e.g. twisting, shearing)

Numerical Code

- **3D MHD Code:**
  - » **finite difference method.**
  - » **third order predictor-corrector method.**
  - » **sixth order spacial partial derivatives.**
  - » **fifth order spacial interpolation.**
  - » **fourth order viscosity and resistivity**
- **Numerical box (1,1,1) with grid resolution (129,128,128)**

$$\frac{\partial \rho}{\partial t} = -\nabla \cdot \rho \underline{v}$$

$$\frac{\partial \rho \underline{v}}{\partial t} = -\nabla \cdot (\rho \underline{v}\,\underline{v} + \underline{\underline{\tau}}) - \nabla P + \underline{j} \times \underline{B}$$

$$\frac{\partial e}{\partial t} = -\nabla \cdot (e \underline{v}) - P \nabla \cdot \underline{v} + Q_{joule} + Q_{visc}$$

$$\frac{\partial \underline{B}}{\partial t} = -\nabla \times \underline{E}$$

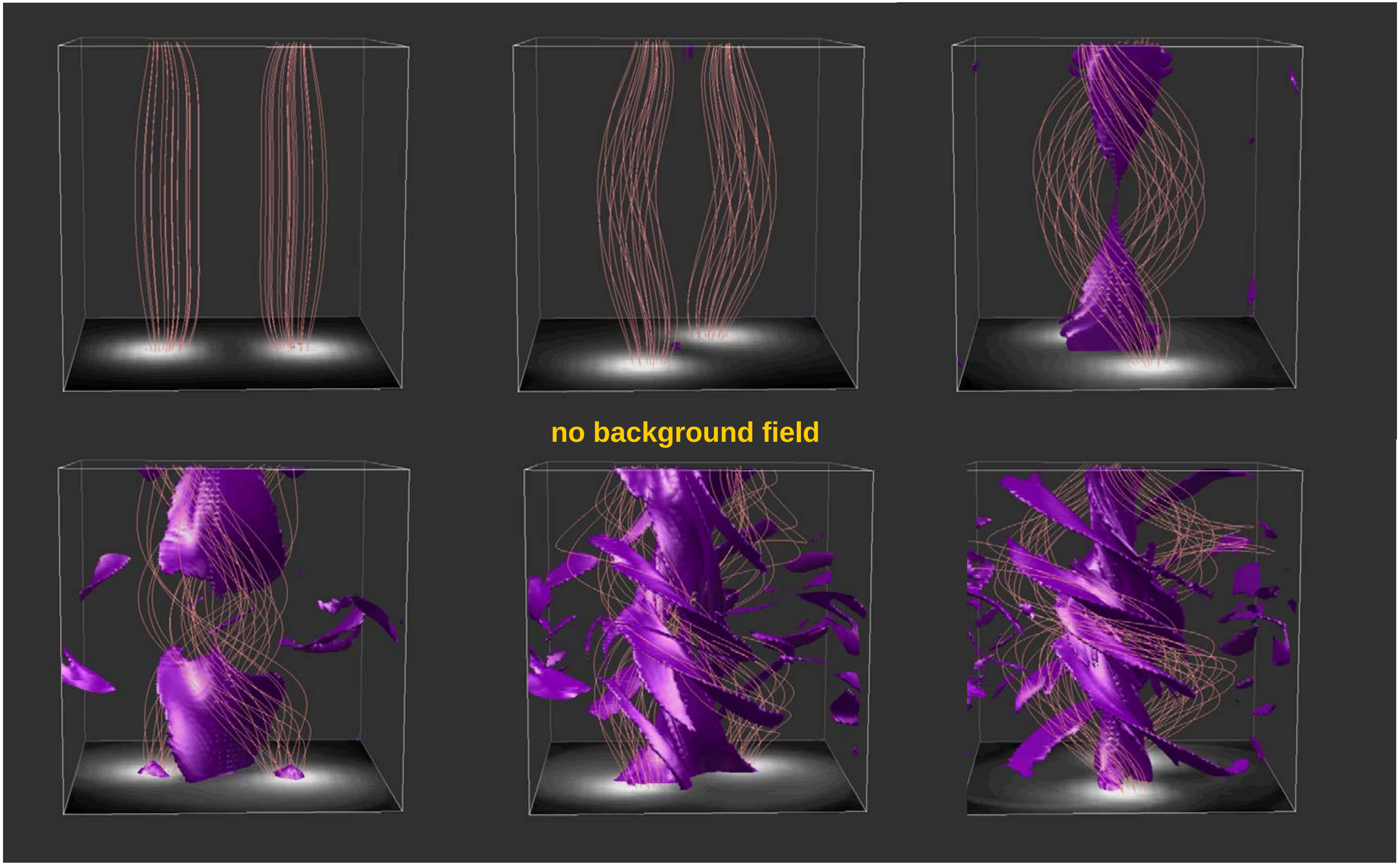
$$\underline{E} = -(\underline{v} \times \underline{B}) + \eta \underline{j}$$

$$\underline{j} = \nabla \times \underline{B}$$

$$P = e(\gamma - 1)$$

$$T = P / \rho$$

Dynamical Evolution (1a)



Dynamical Evolution (1b)