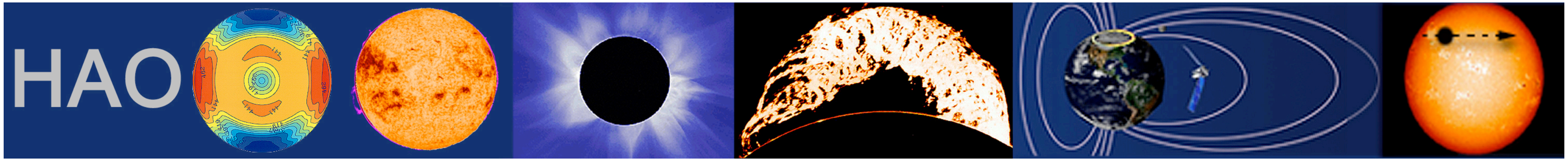

Coronal heating via nanoflares:

Spontaneous Current Sheets Unavoidable in 3D fields!

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Coronal heating

- Energy flux needed

  ~ 10^4 W m^{-2} in active regions

  ~ 10^2 W m^{-2} in the quiet sun (Withbroe & Noyes 1977)

- Photospheric motions moving the footpoints of coronal magnetic fields increases the magnetic free energy by
  - Poynting flux: ~10^4 W m^{-2}
- Problem: How is this energy dissipated in the corona?
  - Nanoflares?

Nanoflares:
Dissipation of current sheets

- CS Formation:
  - Each individual flux tube moves independently of its neighbours (due to the photospheric motions)
  - In the corona where these flux tubes expand against each other
  - **In general, the magnetic fields at the boundary are not aligned**

  ⇒Tangential discontinuities (i.e. current sheets)

- CS Dissipation:
  - Release (built up) magnetic free energy

If nanoflares is the solution then...

- First of all
  - **Current sheets form easily!**
  - **Their formation is spatially extensive**

- Furthermore
  - They form & dissipate quickly enough to release the desired energy flux

Spontaneous current sheets

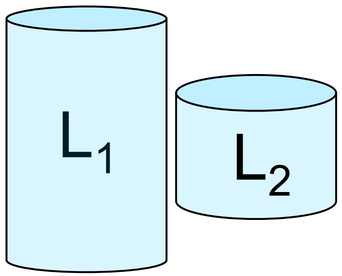
In the highly electrically conducting corona:

- The magnetic field is frozen into the plasma
- Preservation of field topology (footpoint map and twist)

Parker theory:
A field of fixed field topology and B_n can be in a continuous state in one equilibrium but may have to contain inevitable tangential discontinuities on transition to another equilibrium

Field deformation: Footpoint motion, volume change...

$\Rightarrow$Current sheet formation is unavoidable!

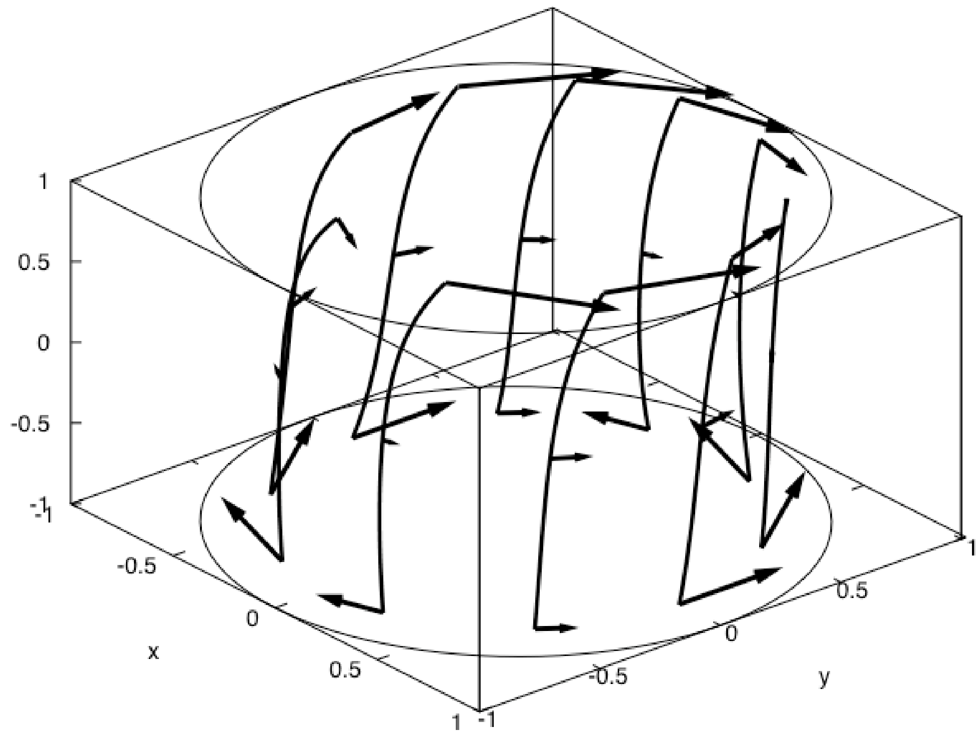


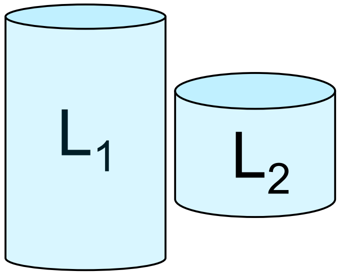
In 3D fields current sheets form easily
Example: Volume change

(Janse & Low2009, ApJ 690)

A potential field inside a cylinder of perfectly conducting fluid.
The field is anchored at the cylinder ends:
Topology invariant to a change in L
(Field remains untwisted & footpoint map preserved)

Fully 3D field, i.e.
azimuthal dependency
No symmetries!





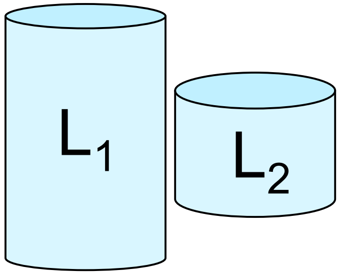
In 3D fields current sheets form easily
Example: Volume change

A potential field inside a cylinder of perfectly conducting fluid.
The field is anchored at the cylinder ends:
Topology invariant to a change in L
(Field remains untwisted & footpoint map preserved)

Then $L_1 \rightarrow L_2$:
The deform field seeks a new equilibrium

Can $\mathbf{B}_{\mathbf{deformed}}$ evolve, under the frozen-in condition, into $\mathbf{B}_{\mathbf{potential}}$?

($\mathbf{B}_{\mathbf{potential}}$: the only continuous untwisted equilibrium state
in the deformed volume)



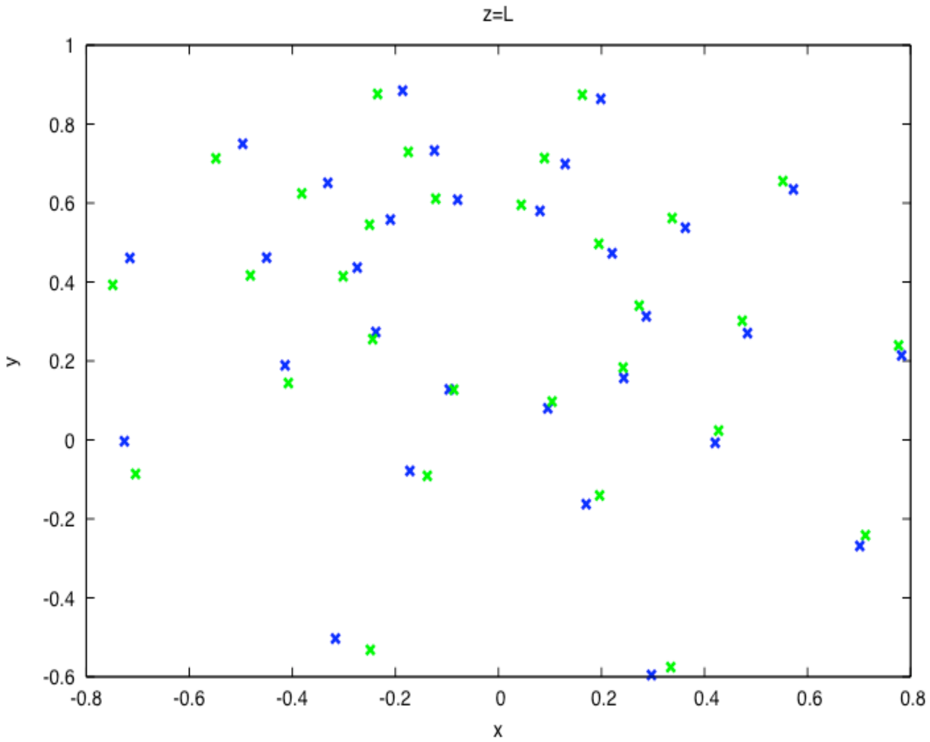
Volume change in 3D fields: Current sheets must form and dissipate!

Footpoint connectivity, $L=L_2$

$B_{deformed}$ & **$B_{potential}$**

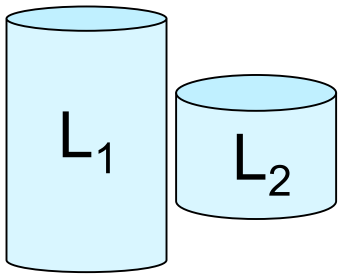
Same starting footpoint at $z=-L$
Different ending footpoint at $z=L$

$\Rightarrow T(B_{deformed}) \neq T(B_{potential})$



Implications:

1. Under the frozen-in cond: **$B_{deformed}$** cannot reach **$B_{potential}$**
2. We suggest that **current sheets must form throughout the field**, whose dissipation can then change $T(B_{deformed})$ to match $T(B_{potential})$

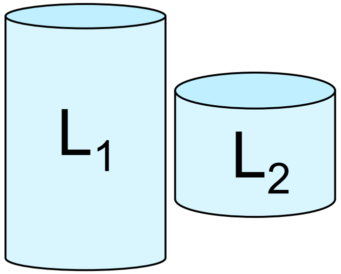


Volume change in 2D fields

An <u>axisymmetric</u> potential field inside a cylinder
Topology invariant to a change of L

Then $L_1 \rightarrow L_2$:
Can $\mathbf{B}_{\mathbf{deformed}}$ evolve, under the frozen-in condition, into $\mathbf{B}_{\mathbf{potential}}$?

If no neutral points: $T(\mathbf{B}_{\mathbf{deformed}})=T(\mathbf{B}_{\mathbf{potential}})$, T fixed by B_n by
No current sheets



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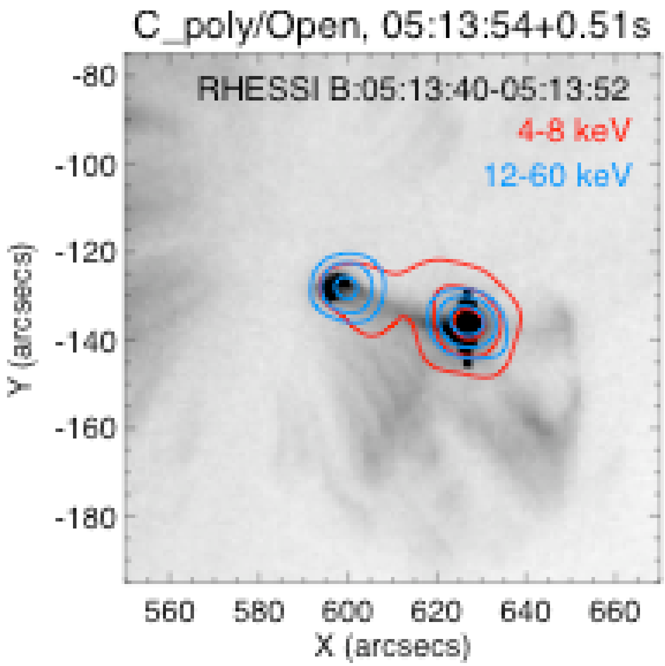
Can $\mathbf{B}_{\mathbf{deformed}}$ evolve, under the frozen-in condition, into $\mathbf{B}_{\mathbf{potential}}$?

If no neutral points: $T(\mathbf{B}_{\mathbf{deformed}})=T(\mathbf{B}_{\mathbf{potential}})$, T fixed by B_n by
No current sheets

If neutral points: $T(\mathbf{B}_{\mathbf{deformed}})\neq T(\mathbf{B}_{\mathbf{potential}})$,
Current sheets only at specific locations:
in the vicinity of <u>separatrix surfaces</u>

Hard X-ray flare footpoints & current sheet formation



Hannah et al. 2008, A&A 481

Footpoint brightening of macroscopic size
\+ electrons channeled along the field lines
⇒ suggests spatially extensive current sheet formation
(for 3D twisted fields)

Concluding remarks ...

Current sheet formation in 3D fields:

- Current sheets form readily
- Current sheets form throughout the field

Is the dissipated energy large enough?