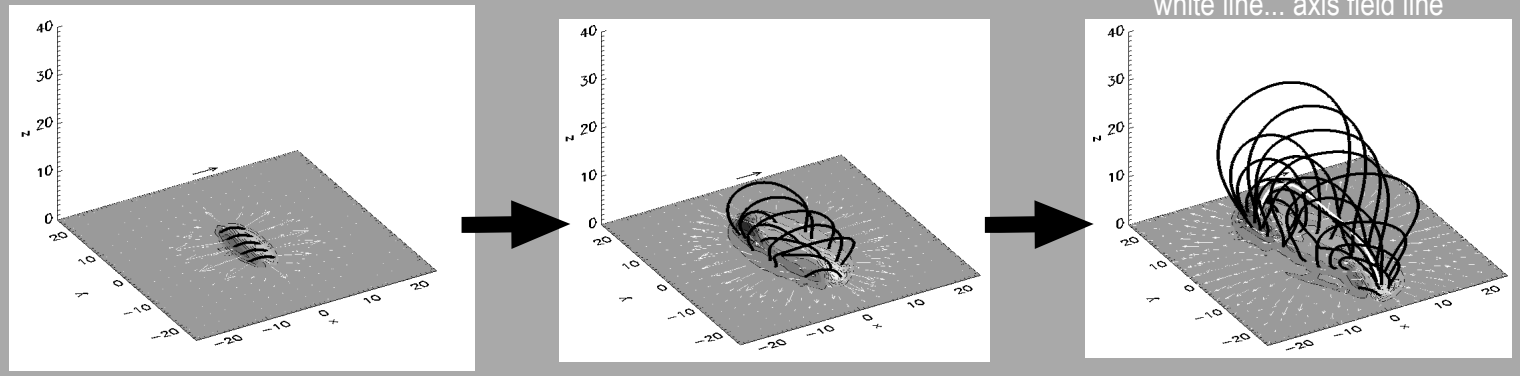
Evolution of magnetic structure and flows produced by emerging twisted flux tube

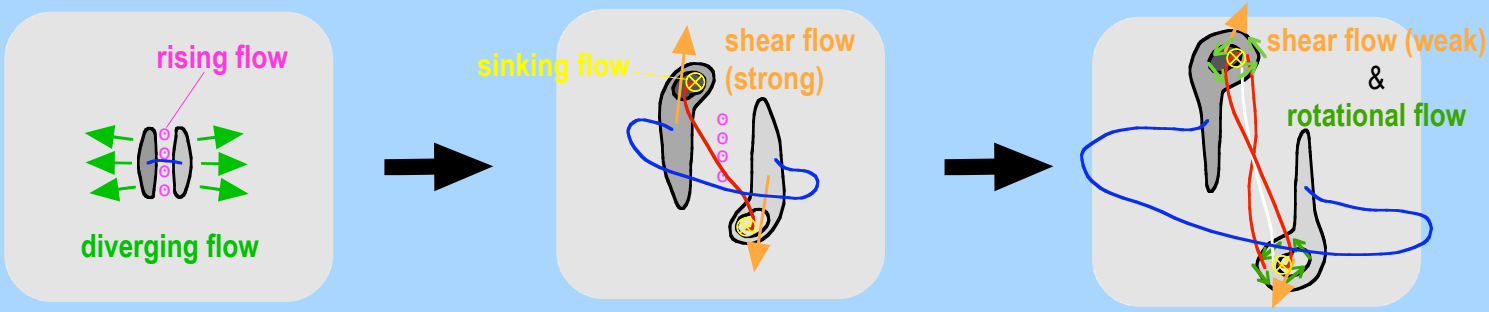
3D view of magnetic structure (black lines) & **flows** (white arrows)

white line... axis field line



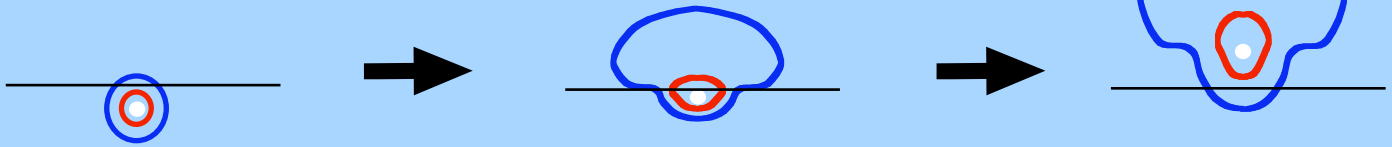
Early state ***Developing state*** ***Developed state***

Top view (magnetic polarity regions & flow patterns at a solar surface)



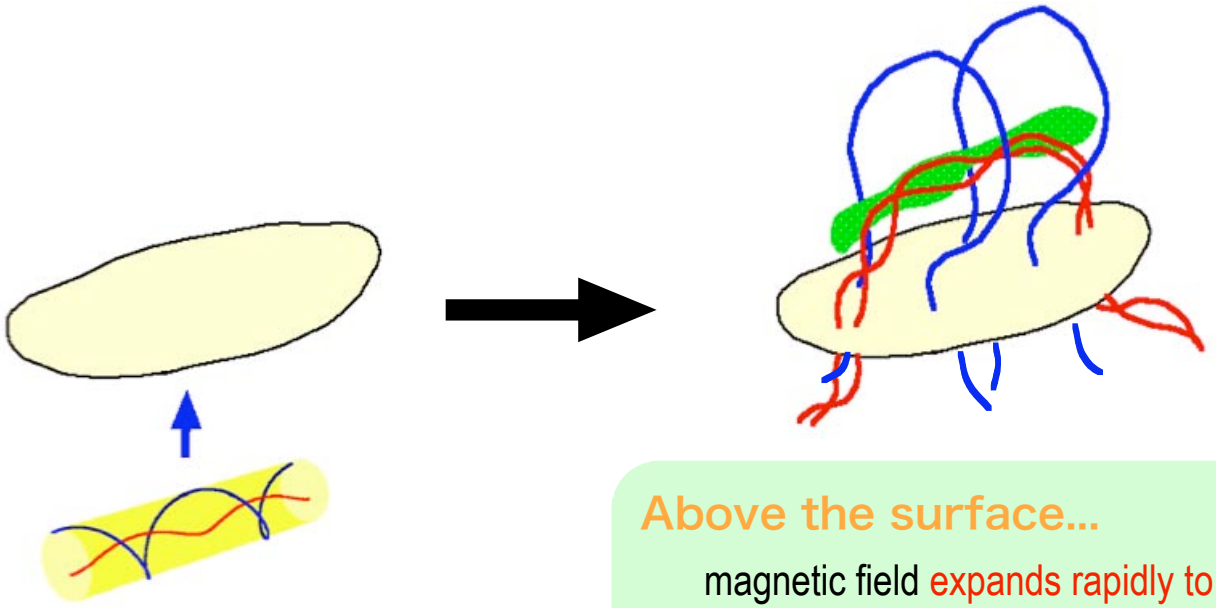
blue... outer field
red... inner field
white... axis field line

Side view (cross section)



Coronal magnetic structure

Coronal magnetic structure formed via flux emergence...



Below the surface...

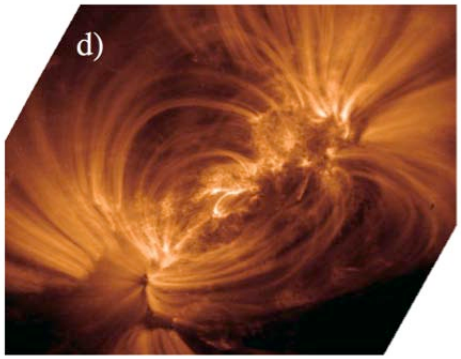
magnetic field takes the shape of a thin flux tube because the gas pressure of a surrounding plasma is high.

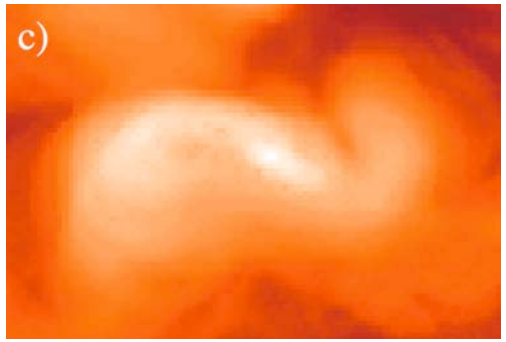
Above the surface...

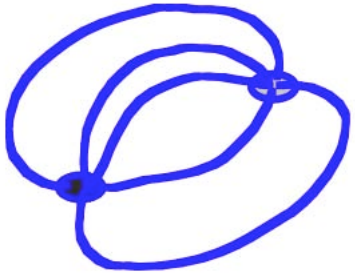
magnetic field expands rapidly to form coronal magnetic structure because the gas pressure of a surrounding plasma is low.

Typical magnetic field configurations of coronal magnetic structure:

Sheared (twisted) or Shearless







Potential field-like structure

shearless

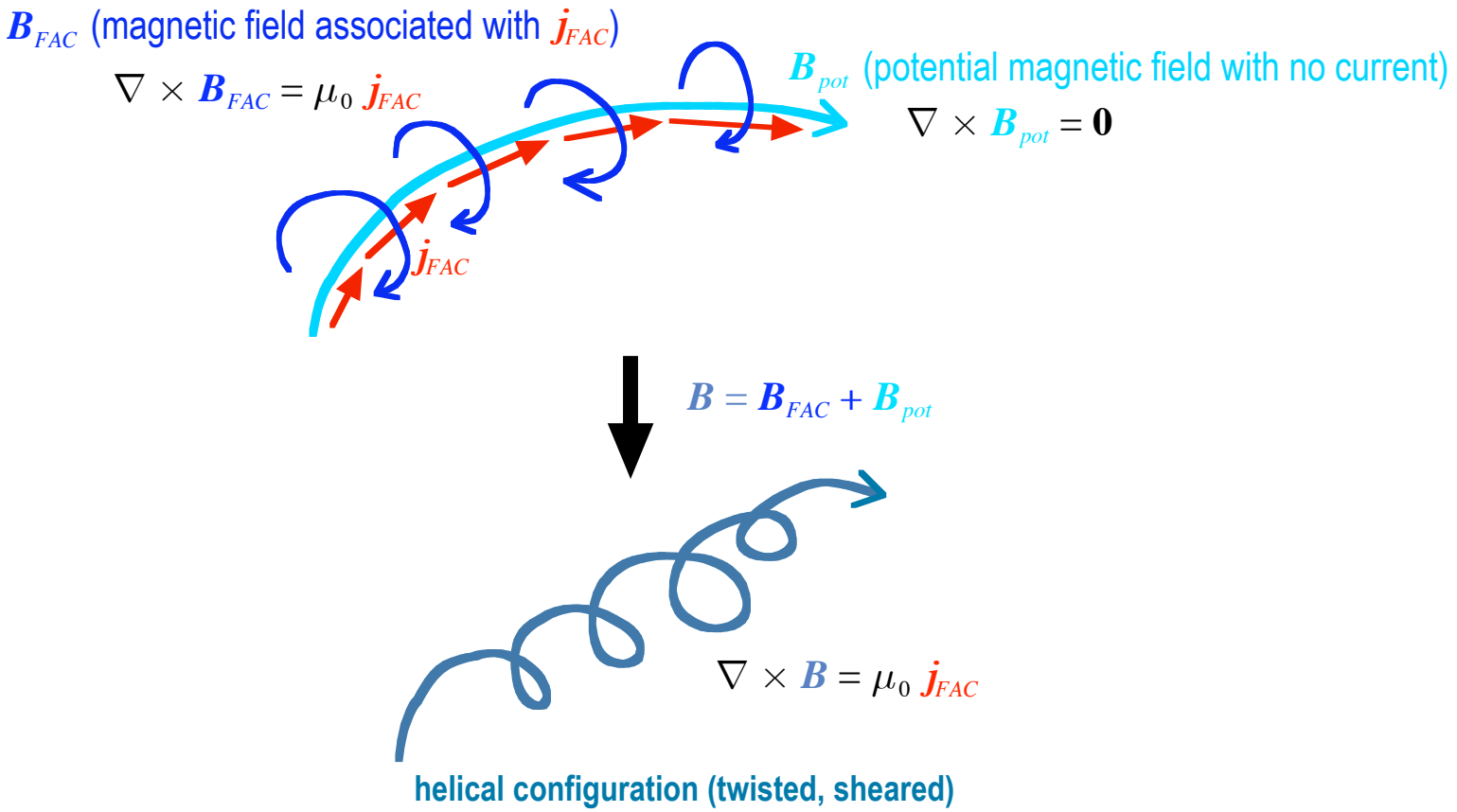
Sigmoidal structure

sheared (twisted)

What gives shear (twist) to coronal magnetic structure?

Field-aligned current (FAC)

FAC produces a helical magnetic field configuration...

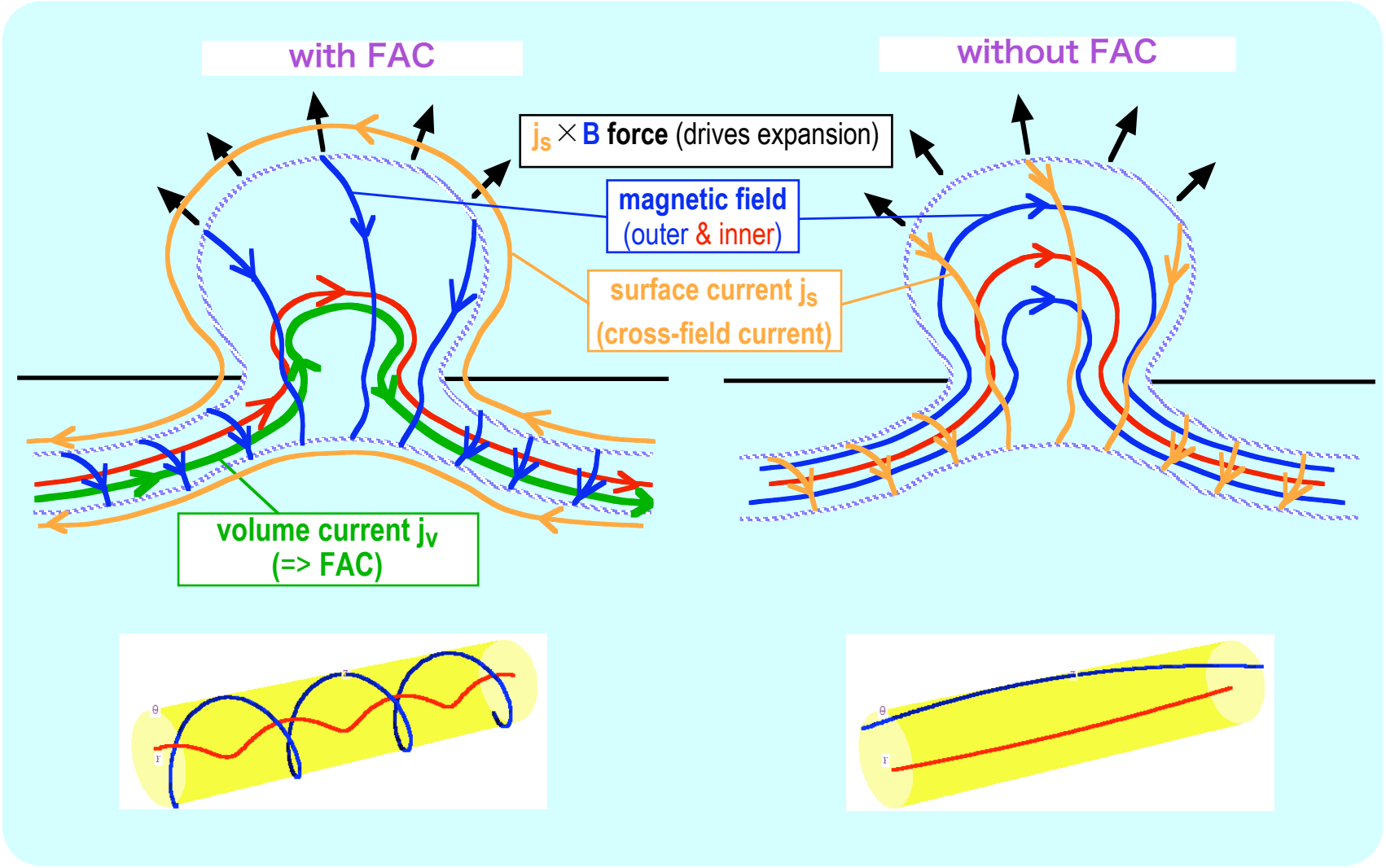


Force-free field ($\nabla \times B = \alpha B$):

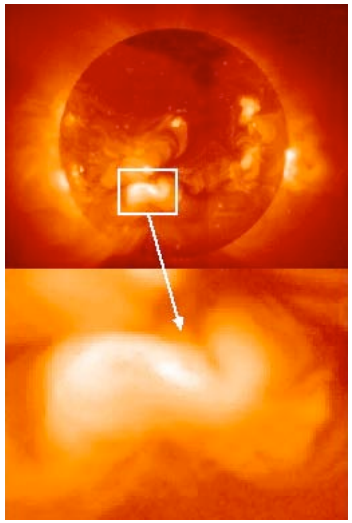
When FAC and magnetic field are parallel (right-handed twist) => $\alpha > 0$

When FAC and magnetic field are antiparallel (left-handed twist) => $\alpha < 0$

Magnetic structure with and without FAC...



Sigmoidal magnetic structure



Chirality rule of sigmoids observed on the Sun

TABLE II

CHIRALITY OF SOLAR ACTIVE REGIONS [37] AND SHAPE OF THE CORONAL SIGMOIDS [38] BY HEMISPHERE.

	N-hemisphere	S-hemisphere
Positive α	38%	66%
Forward S	41%	68%
Negative α	62%	34%
Backward S	59%	32%

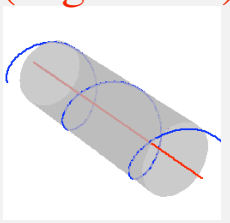
Canfield, Hudson, McKenzie (1999)

○... dominant part

Rust & Kumar (1994)

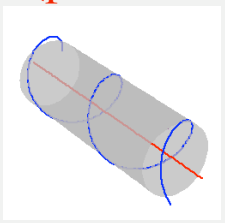
Northern hemisphere...

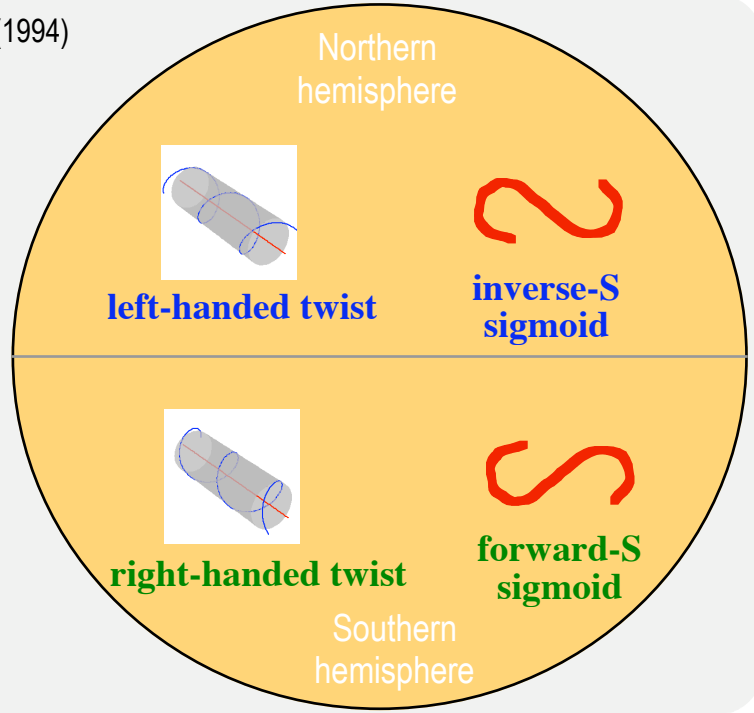
left-handed twist (negative α), inverse S



Southern hemisphere...

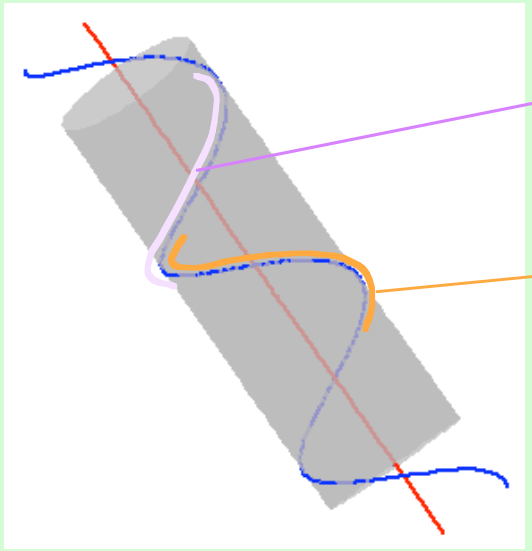
right-handed twist (positive α), forward S





Coexistence of forward and inverse S-shaped field lines (loops)

Left-handed twist case (northern hemisphere)



Underlying loop (below the axis of flux tube)

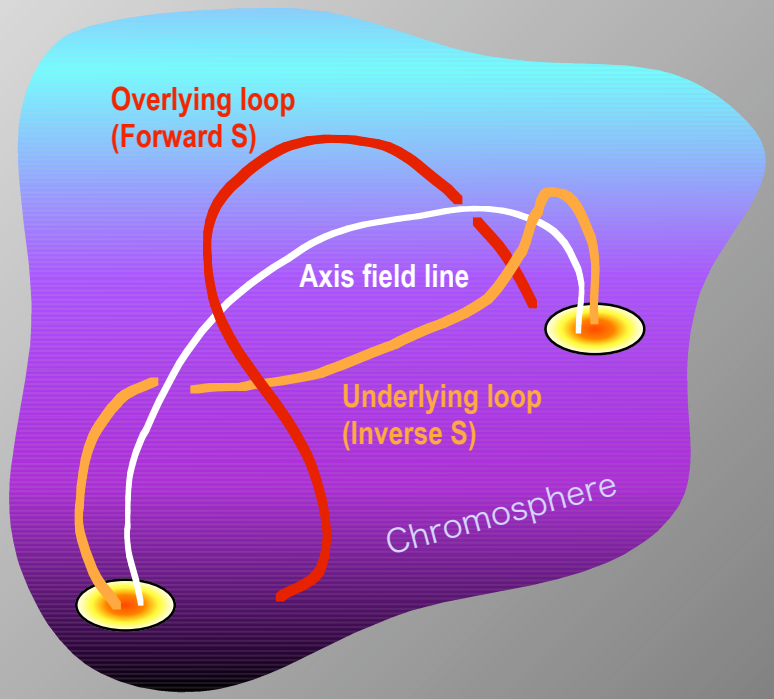
→ inverse S-shape

Overlying loop (above the axis of flux tube)

→ forward S-shape

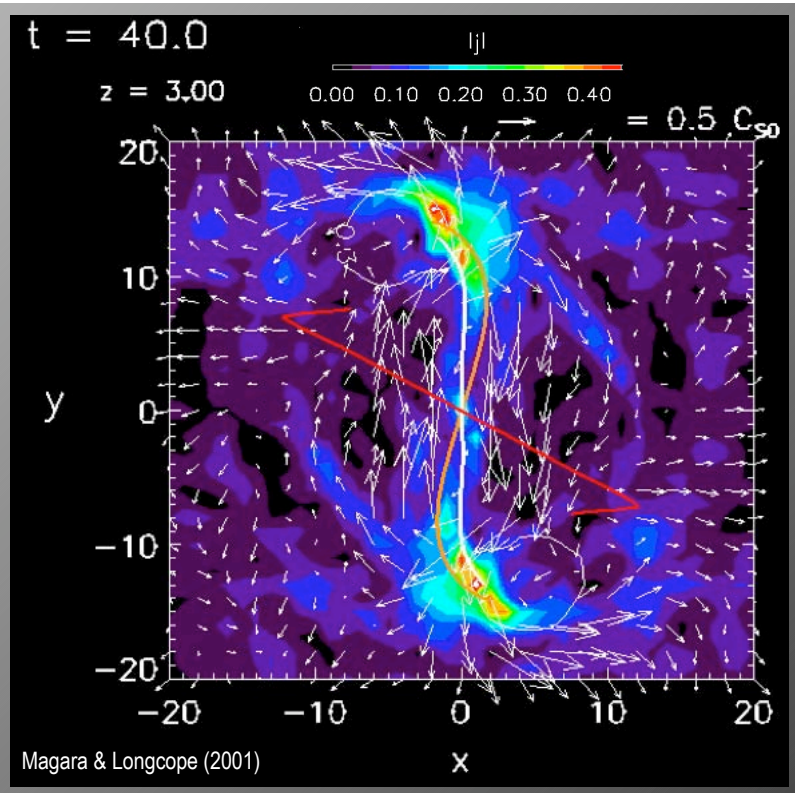
Question: *Why is an inverse S-shaped sigmoid preferentially observed?*

A possible scenario...



... Region where high current density is distributed

A physical expanation... $\nabla \bullet \boldsymbol{j} = 0$ with force-free approximation suggests that the underlying loop has a smaller cross section than overlying loop.



High current density is distributed at **footpoints of the underlying loop.**

This suggests that current could be dissipated to heat the plasma distributed along the underlying loops, thereby illuminating an inverse S-shaped sigmoid.