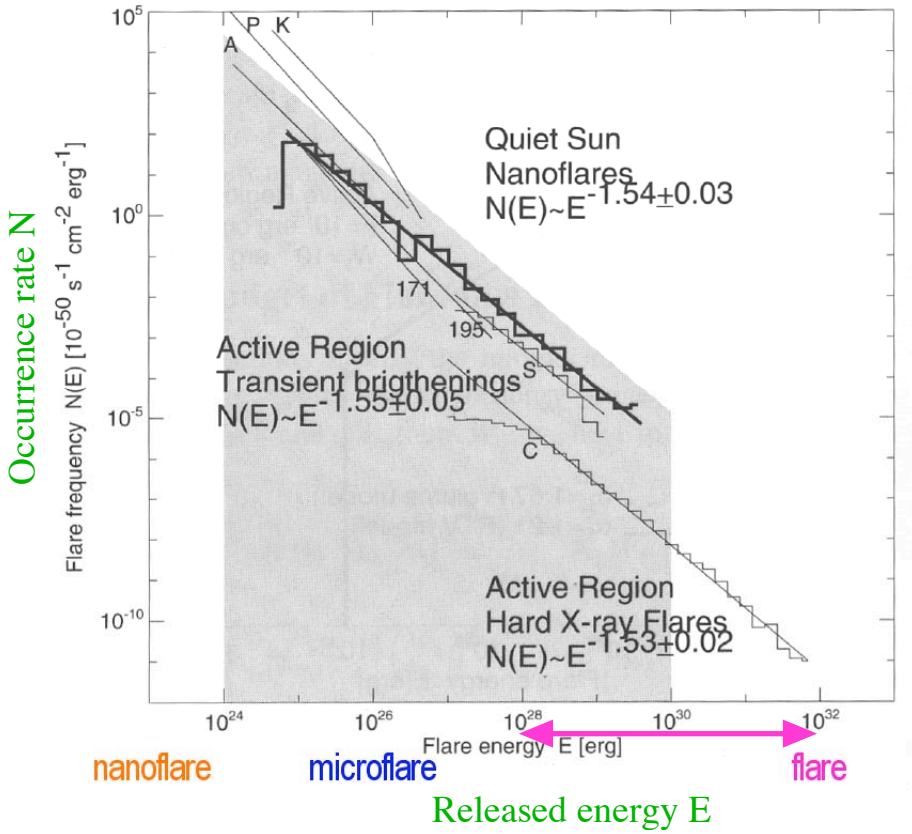
Statistical features

Frequency distribution of flaring events



Power-law distribution

$$N \propto E^{-\alpha}$$

$$\alpha \sim 1.5$$

Aschwanden (2004)

Power-law index α → **Key factor of coronal heating**

path-dependent process + path-independent process

Evolution of a flare

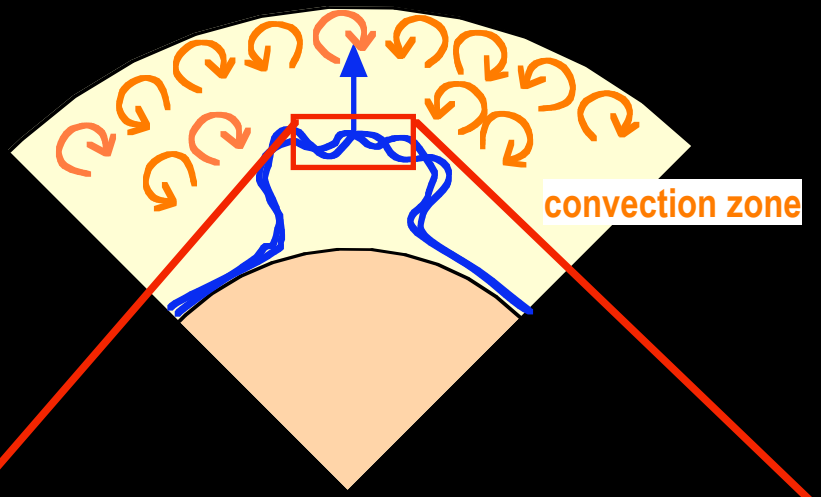
Energy built-up phase
Preflare phase (toward the onset of a flare)
Energy-release (main) phase
Post-flare phase

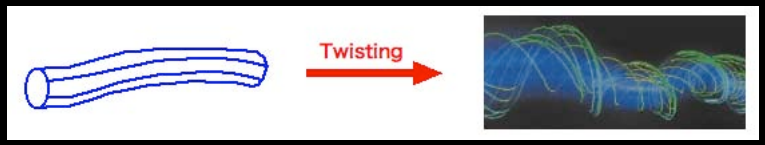
Energy built-up phase

generate & transport free magnetic energy
from solar interior to atmosphere

How to generate & transport free magnetic energy to the corona?

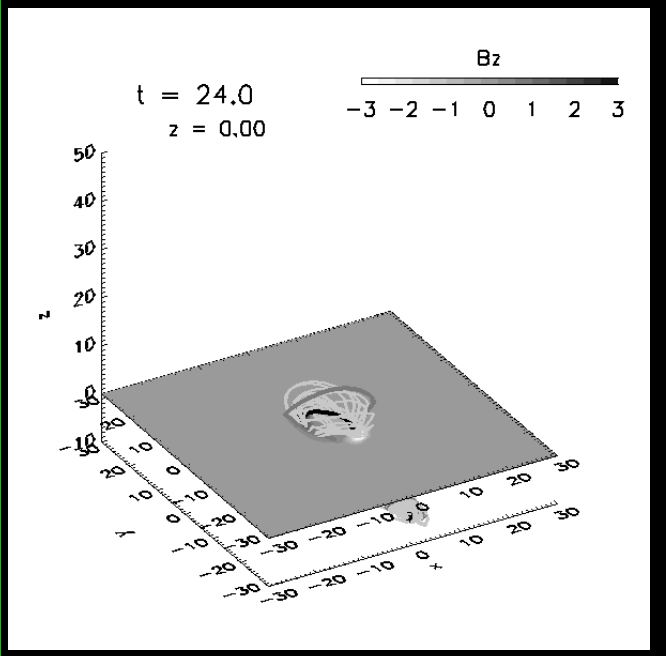
... Formation and emergence of a twisted flux tube





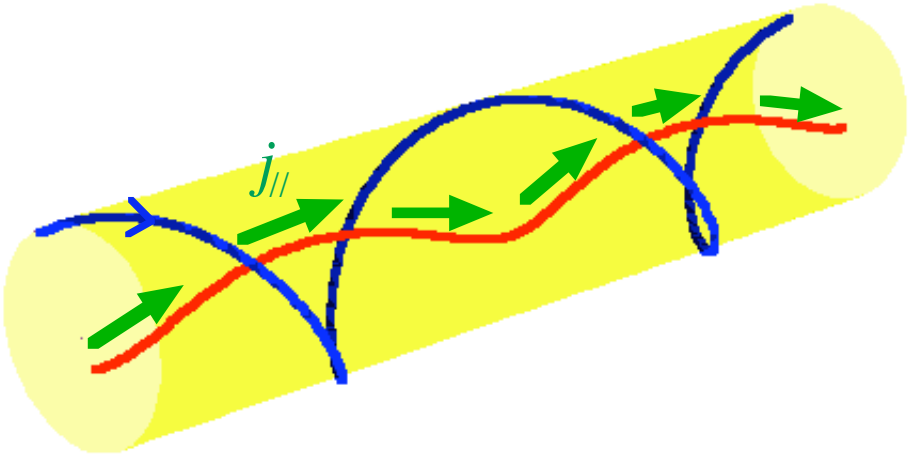
Plasma motions add **twist** to a magnetic flux tube, generating **field-aligned current (FAC)** in it.

kinetic energy => free magnetic energy



A twisted flux tube with FAC emerges into the corona.

Twisted flux tube *is a* ***carrier of free magnetic energy...***



Twisted flux tube... contains **field-aligned current-based free magnetic energy**

Field-aligned current => **does not** produce Lorentz force that converts free magnetic energy to kinetic energy

Stored in an emerging twisted flux tube

Preflare phase

prepare for the rapid release of
free magnetic energy

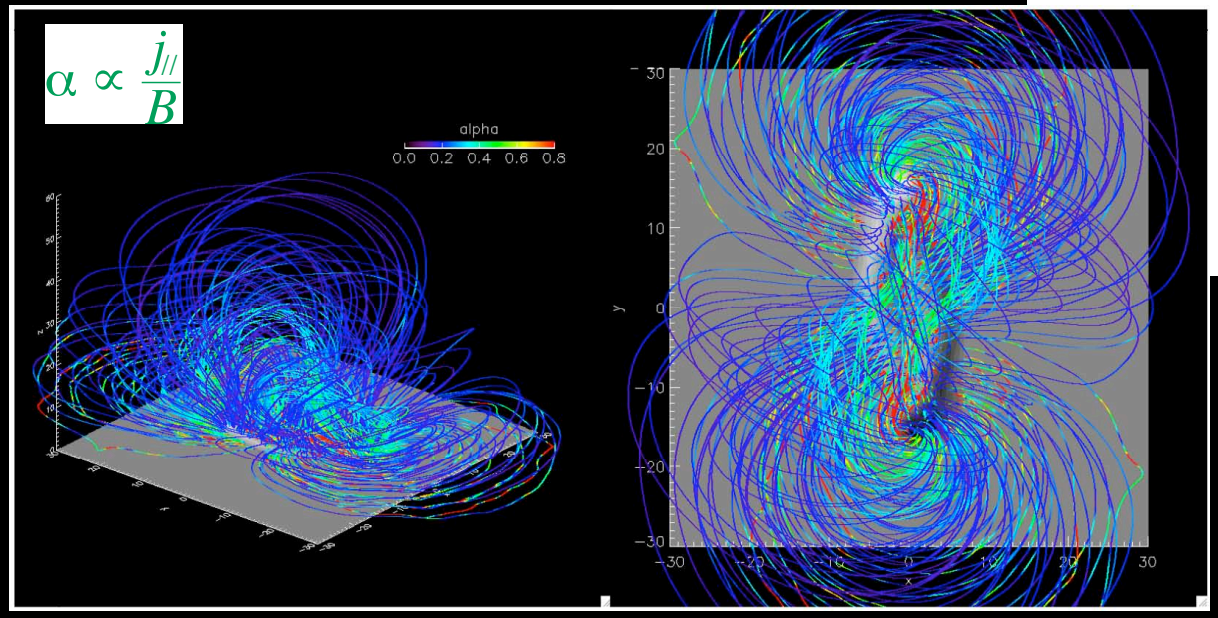
Preflare structure

sigmoid

Sigmoid: ***S-shaped coronal structure formed during the preflare phase***

=> *could be composed of* **underlying field lines** with **strong field-aligned current** along **them**

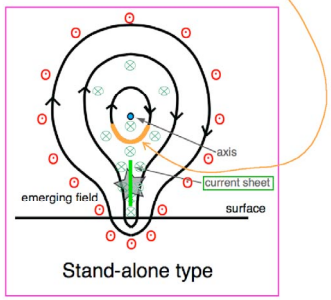
=> *suggests that* **flux-tube axis reaches the corona** below which **current sheet formation** proceeds



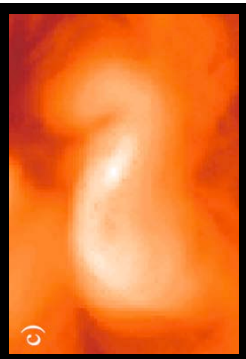
Distribution of FAC Lee and Magara (2014)

Appearance of a sigmoid **(precursor of a flare)**

=> suggests the emergence of the underlying field lines



Stand-alone type

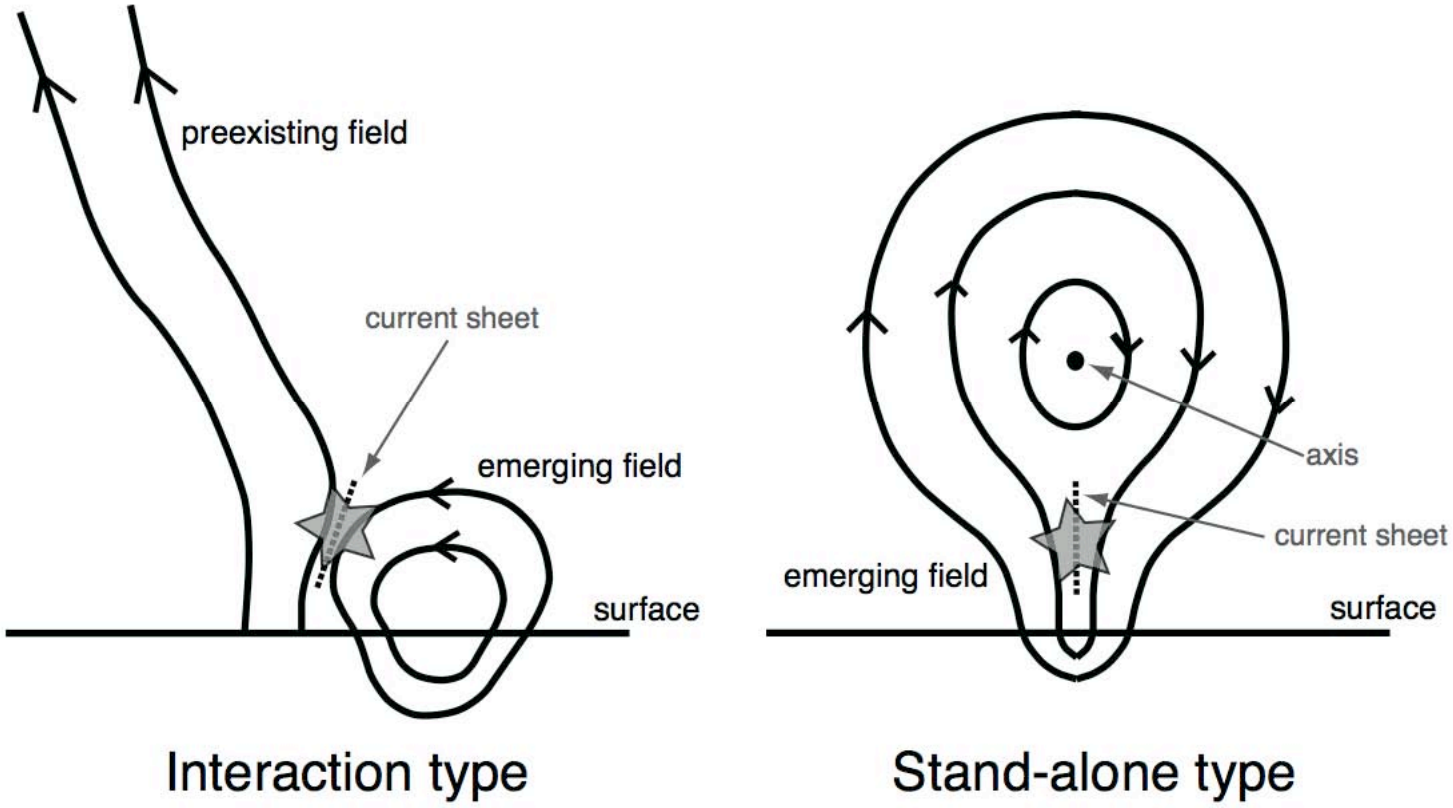


An inverse S-shaped sigmoid observed in soft X-ray (Yohkoh)

Current sheet formation

Current sheet formation

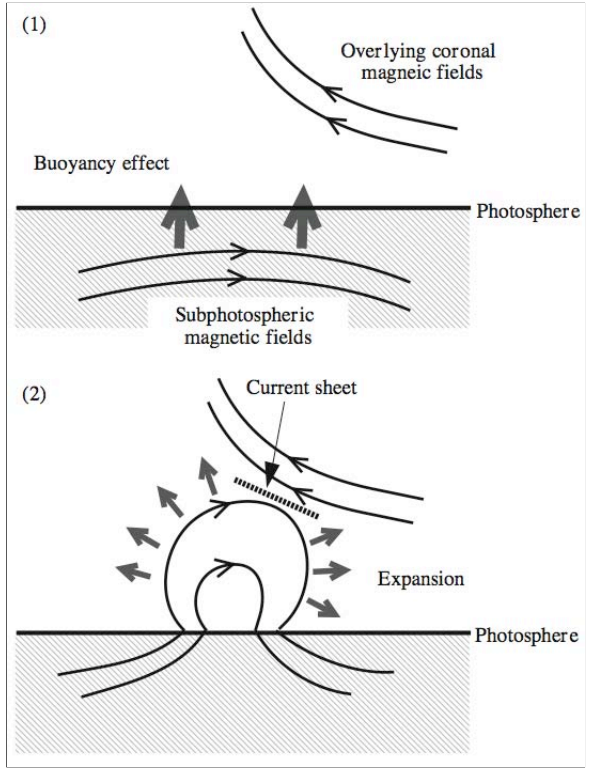
... Two types of current sheet formation

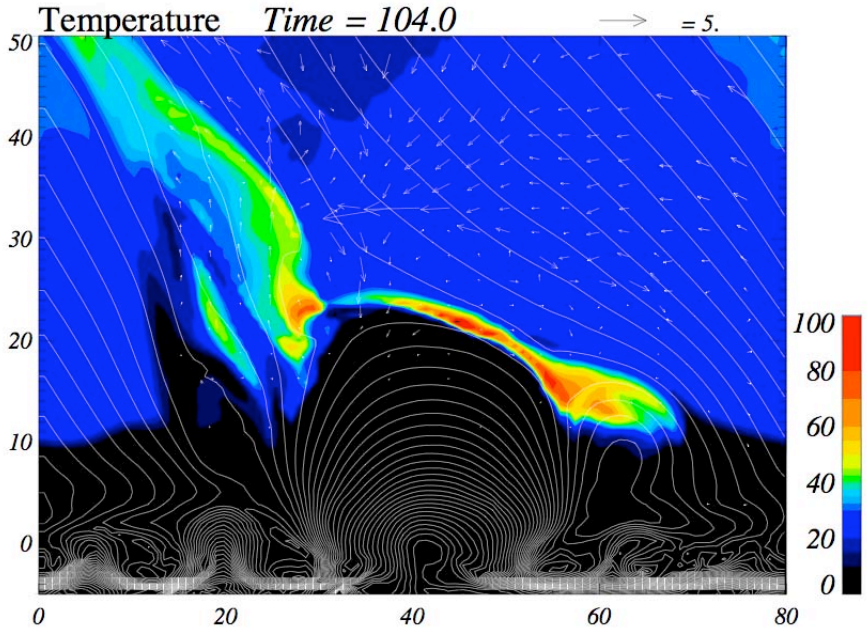


Magara & Tsuneta (2008)

Interaction type:

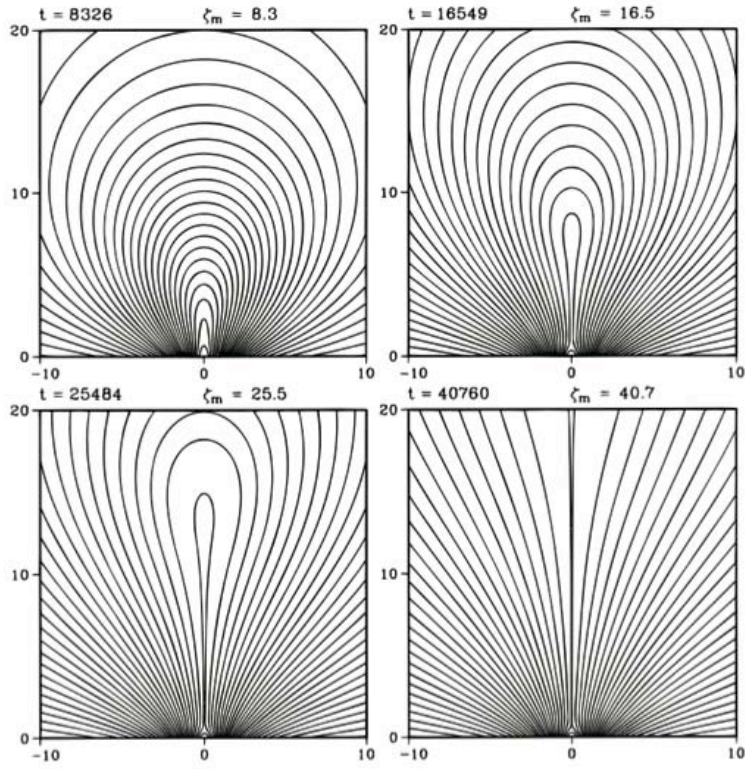
When the magnetic fields that belong to **different magnetic flux domains** interact with each other, a **current sheet** is formed around an **interface between them.**



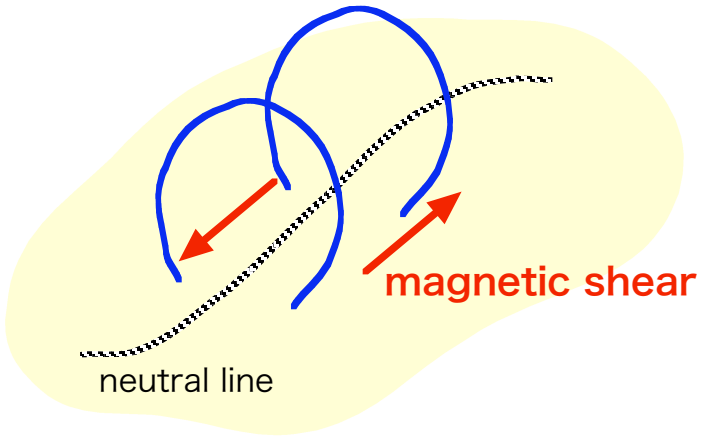


Yokoyama & Shibata (1996)

Stand-alone type:



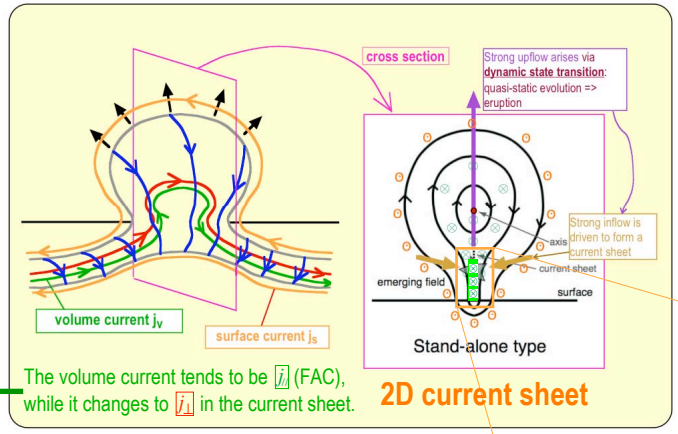
Choe and Lee (1996)



When **magnetic shear** increases in a **single magnetic flux domain,** a **current sheet** is formed **inside the domain.**

3D current sheet formed in an emerging twisted flux tube

(http://163.180.179.74/~magara/page31/Research_evolution-path.html)



The volume current tends to be $j_{//}$ (FAC), while it changes to $j_{\perp}$ in the current sheet.

2D current sheet

Structural properties of 3D current sheet

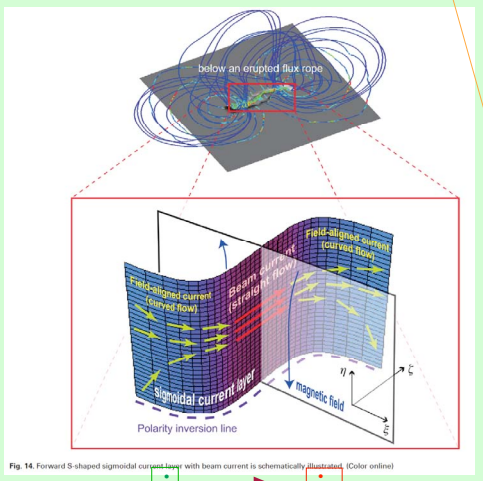
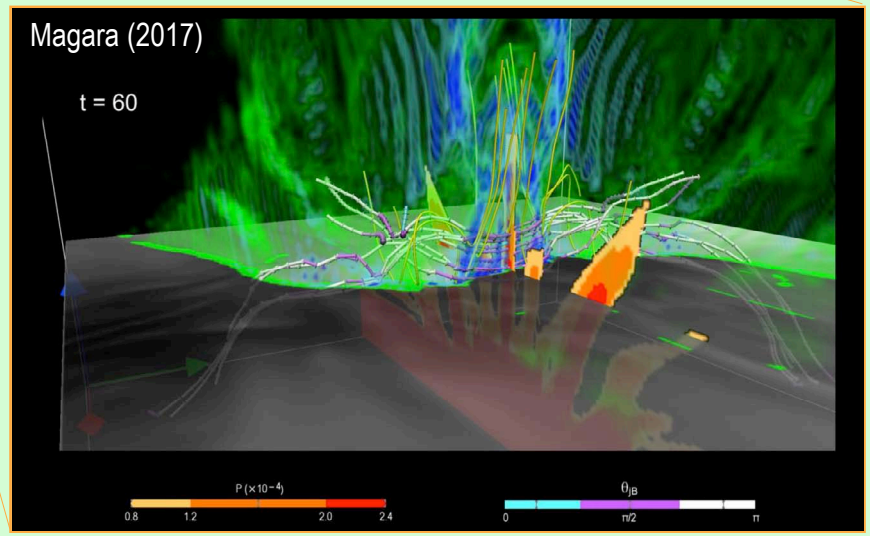


Fig. 14. Forward S-shaped sigmoidal current layer with beam current is schematically illustrated. (Color online)

$j_{//} \rightarrow j_{\perp}$

The free magnetic energy provided by $j_{\perp}$ is not converted to flow energy because Lorentz force $\boldsymbol{j}_{\perp} \times \boldsymbol{B}$ is balanced by $-\nabla P_{gas}$. Instead it is converted to thermal energy via dissipation.



see also http://163.180.179.74/~magara/seminars/flare-producing_current_system.pdf