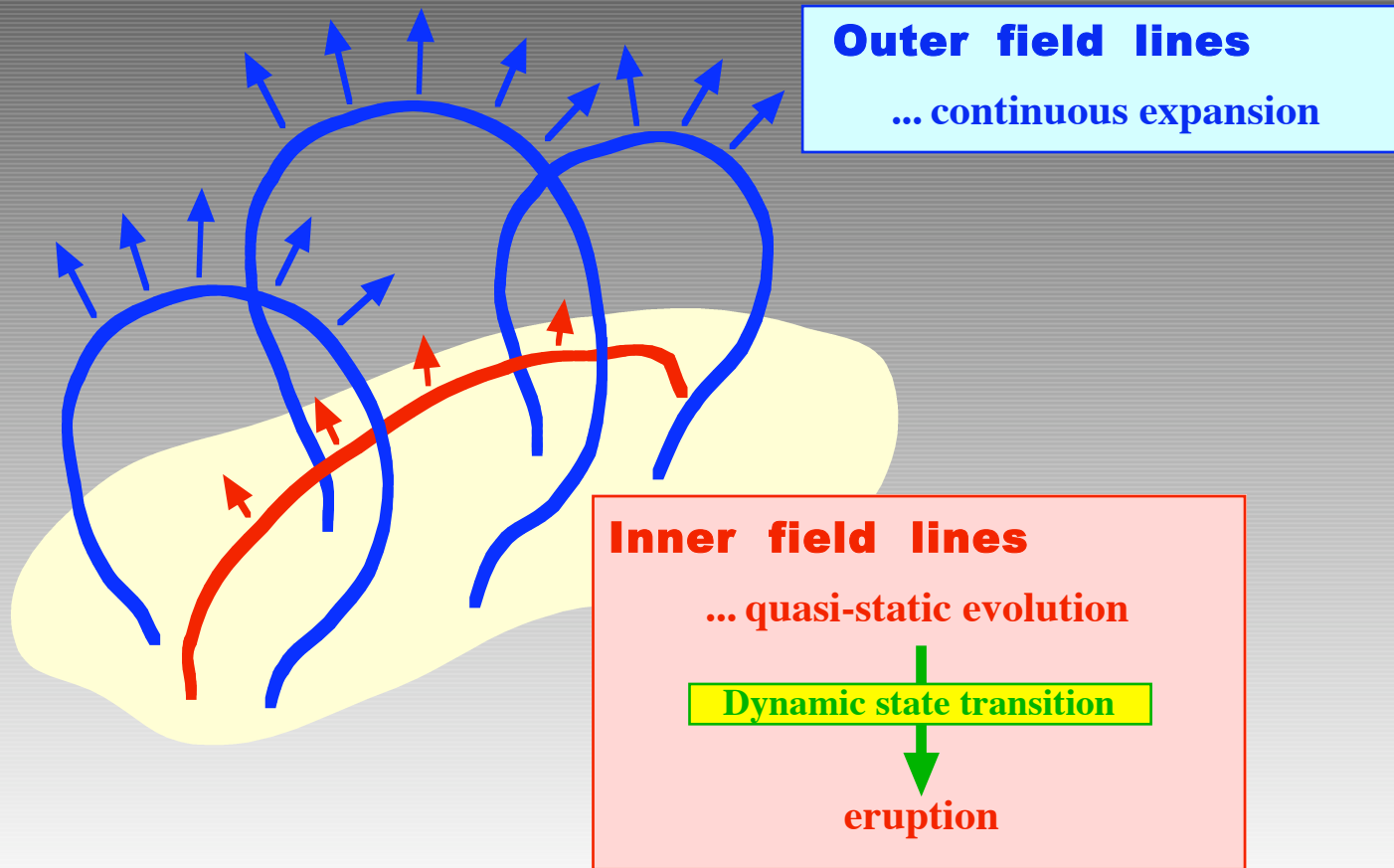
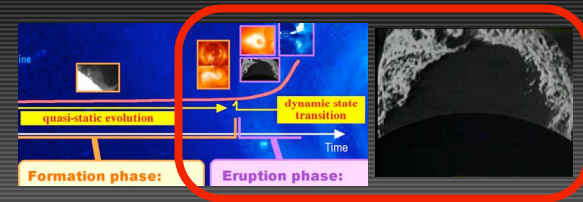
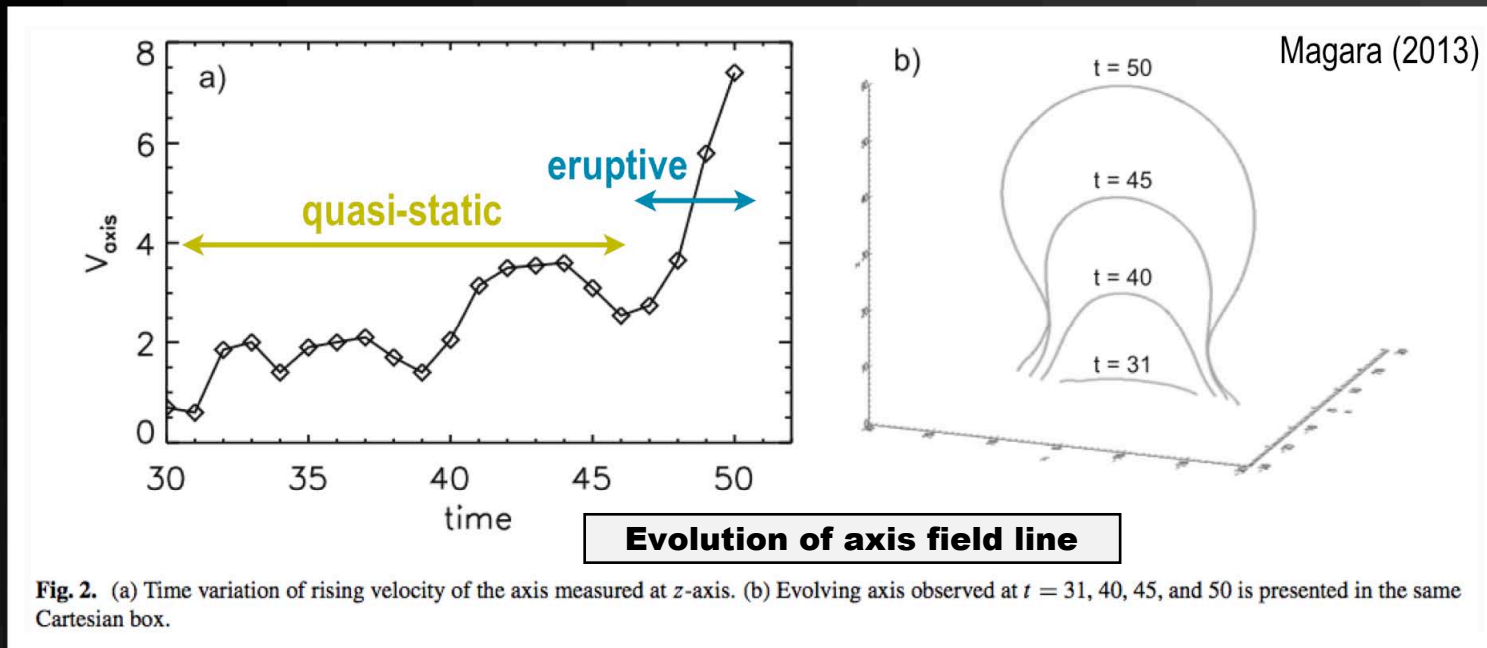


Toward eruption phase...

Dynamic state transition of inner field lines

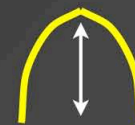


Dynamic state transition from **quasi-static state** to **eruptive state**

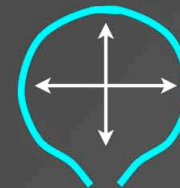


A key to understanding **dynamic state transition**... Change of **field-line shape**

Quasi-static state... Vertically expanded shape



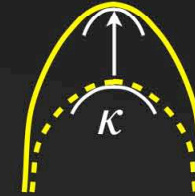
Eruptive state... Vertically and Laterally expanded shape



Why does field-line shape play a key role in the transition?

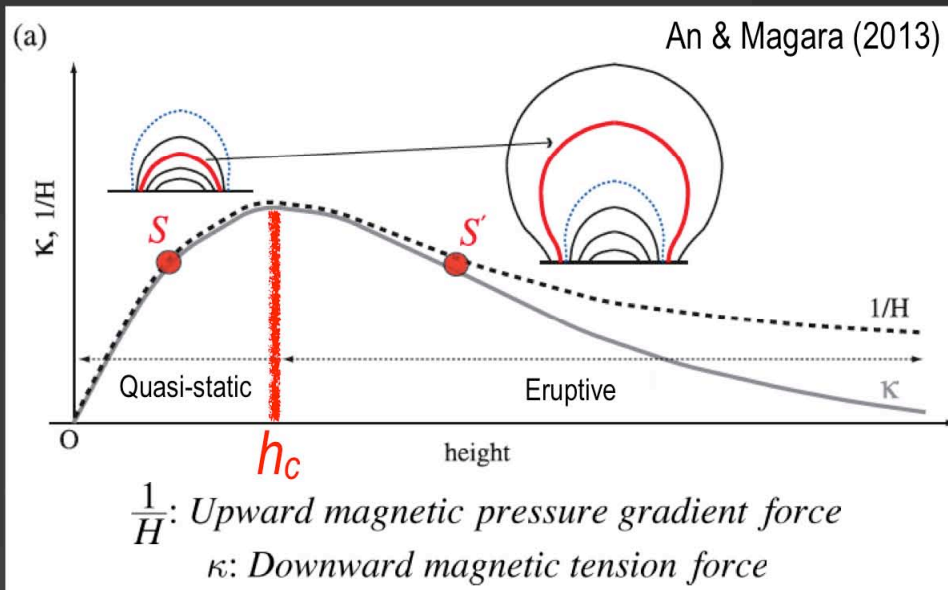
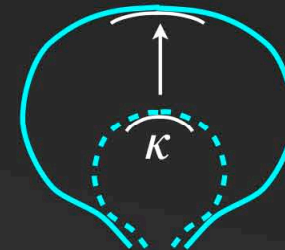
Quasi-static state... expands vertically

κ (curvature) increases \Rightarrow downward tension becomes effective



Eruptive state... expands vertically and laterally

κ (curvature) decreases \Rightarrow downward tension becomes less effective



There is a **critical loop height (h_c)** over which an emerging field line **changes its expansion manner**.



Dynamic state transition from **quasi-static state** to **eruptive state**

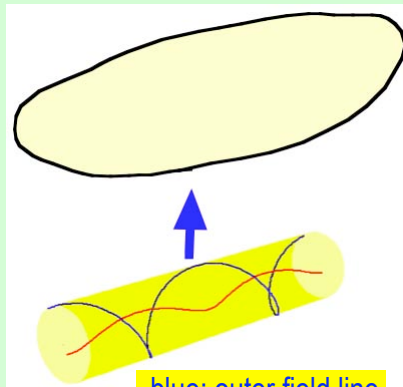
Lee & Magara (2018)

Evolutionary phases of an emerging magnetic field



Emergence phase:

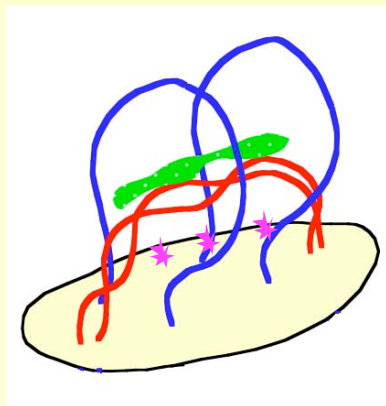
Emergence of subsurface magnetic field in **twisted flux-tube shape**



blue: outer field line
red: inner field line

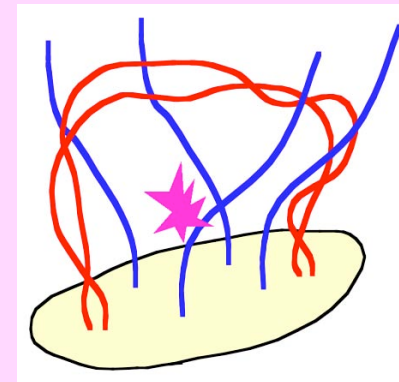
Formation phase:

Formation of magnetic structure called **flux rope** in solar corona (prominence / filament, sigmoid, small flare are observed)



Eruption phase:

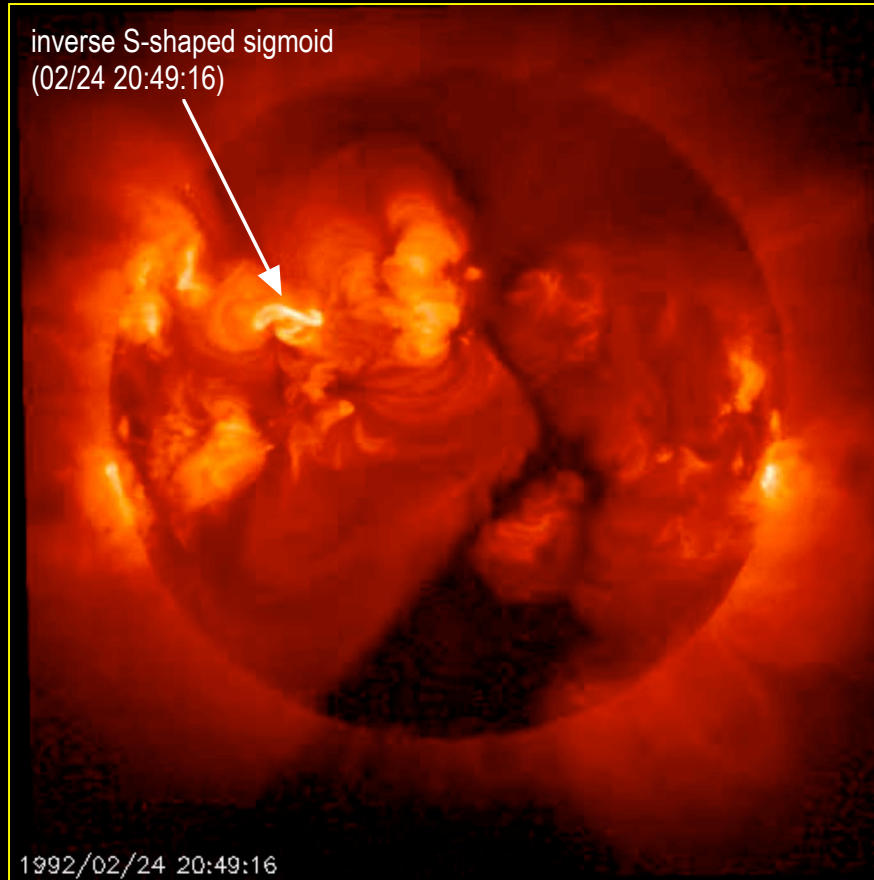
Eruption of flux rope toward interplanetary space (sometimes accompanied by flare with plasmoid ejection)



Solar flare

Solar corona is full of dynamic events (explosion & eruption) ...

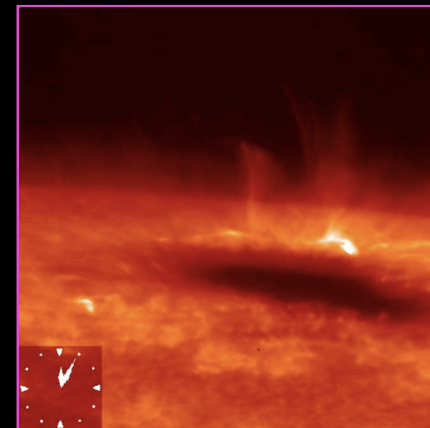
=> a different world from a solar surface (photosphere) observed in visible light



The Sun in soft X-ray (*Yohkoh*)
(Corona)

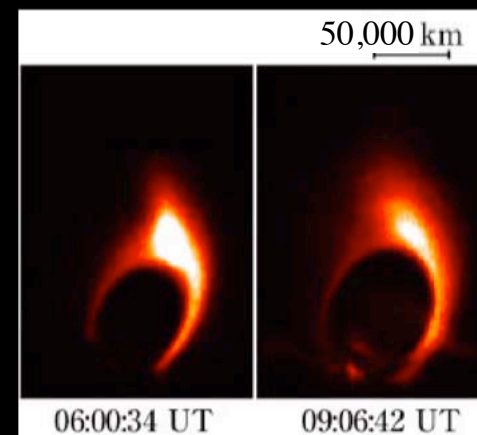
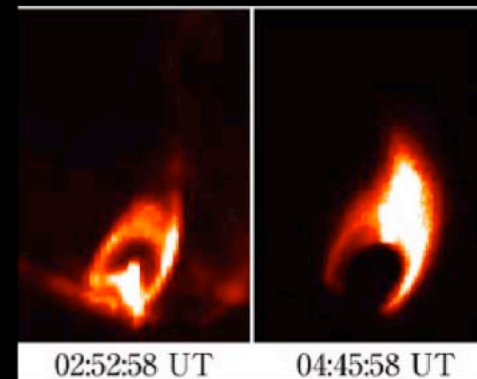
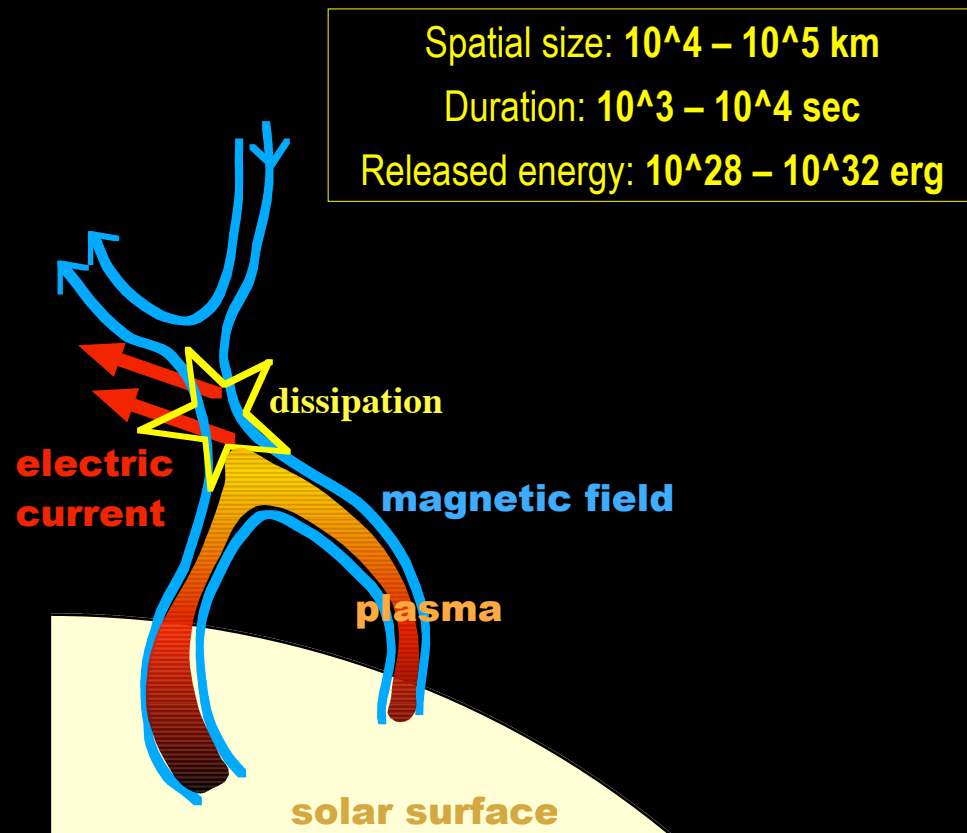


Sunspot in Ca II H (*Hinode*)
(Chromosphere)



What is a solar flare?

Coronal explosive phenomenon with rapid release of free magnetic energy
(dissipation of electric current)

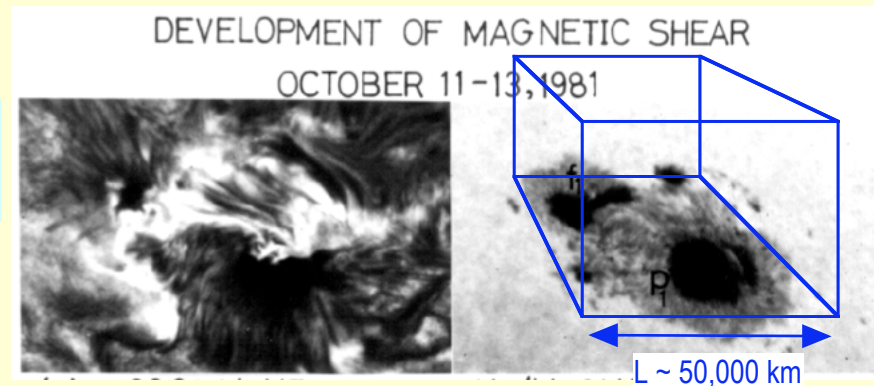


Estimate energy budget of a flare...

Magnetic energy stored in a typical active region:

Size: $L \sim 50,000$ km

Average magnetic field strength: $B \sim 500$ G



Kurokawa (1989)

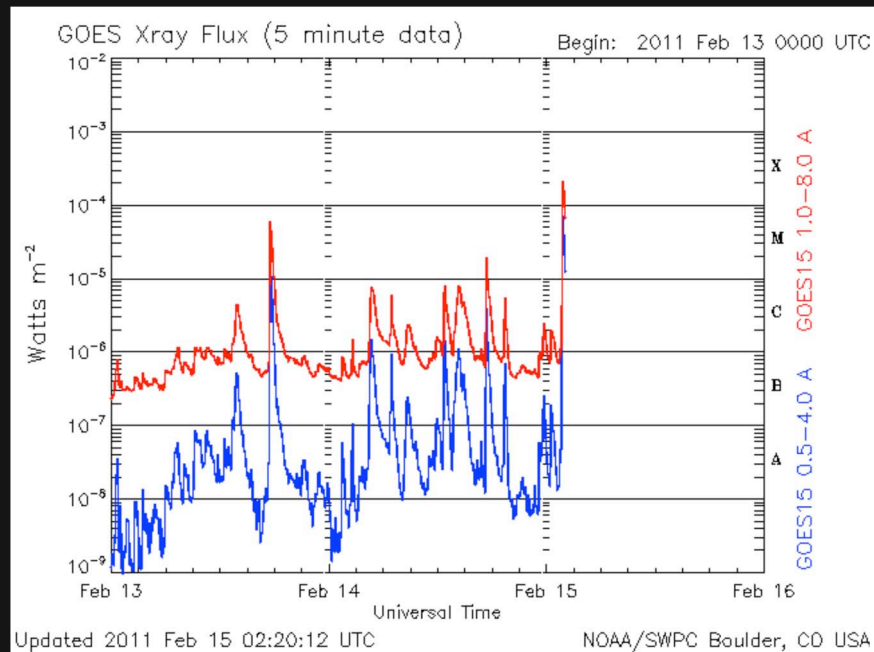
Total magnetic energy stored in the active region is estimated as

$$\left(5 \times 10^9 \text{ cm}\right)^3 \times \frac{(500 \text{ G})^2}{8\pi} \sim 10^{33} \text{ erg}$$

CGS unit

Released energy of a flare: $10^{28} - 10^{32}$ erg

Classification of flares based on X-ray emission flux



Peak value of X-ray flux (1 – 8 Å, W/m²)

A	$10^{-8} - 10^{-7}$
B	$10^{-7} - 10^{-6}$
C	$10^{-6} - 10^{-5}$
M	$10^{-5} - 10^{-4}$
X	$> 10^{-4}$