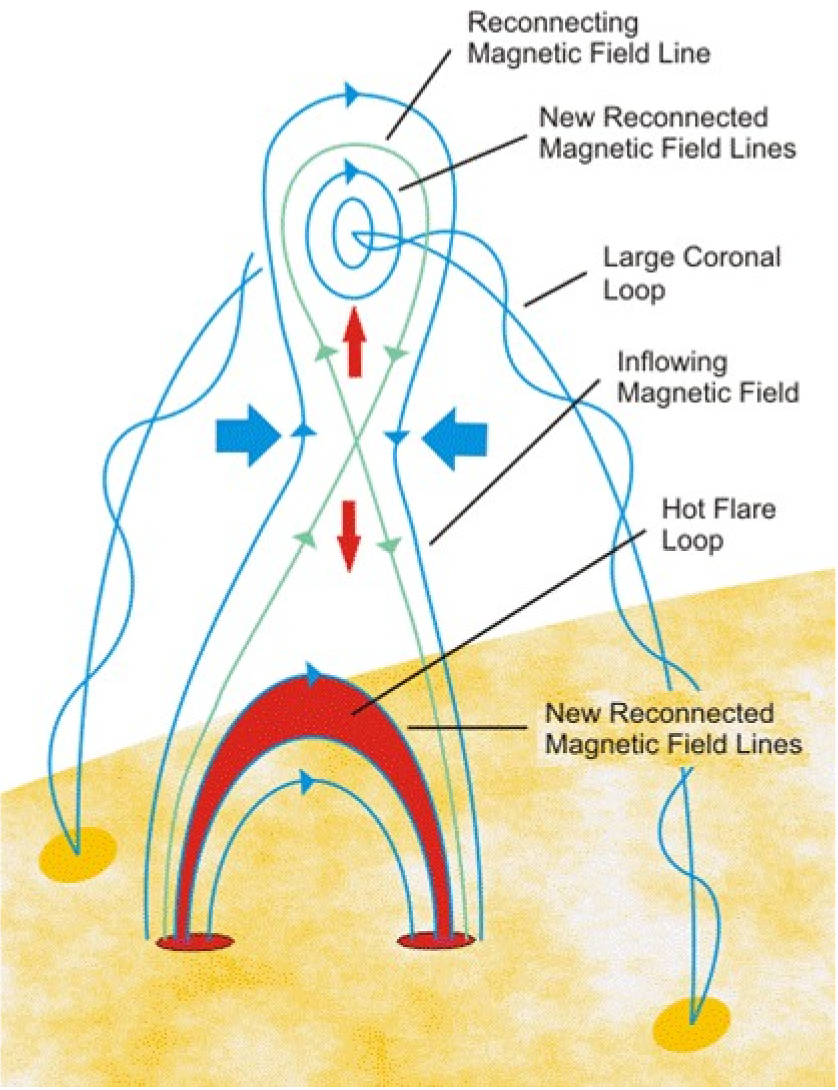
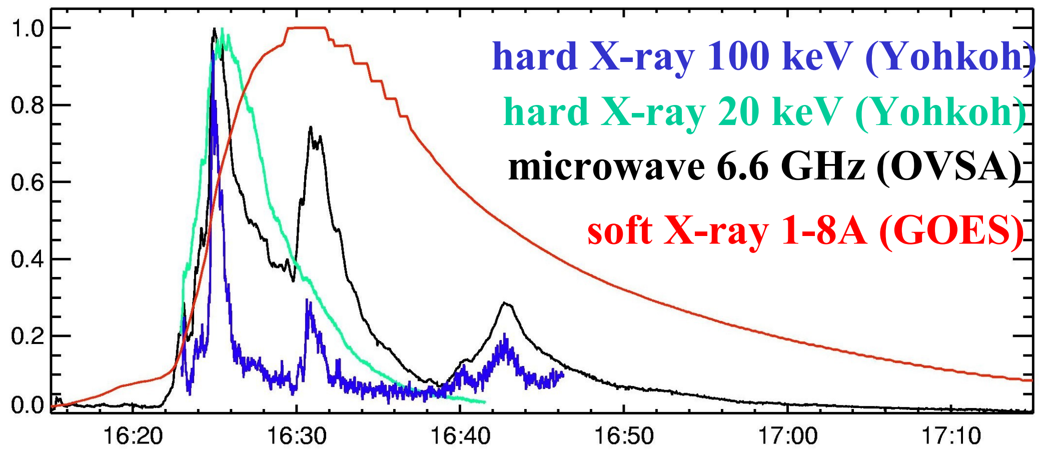
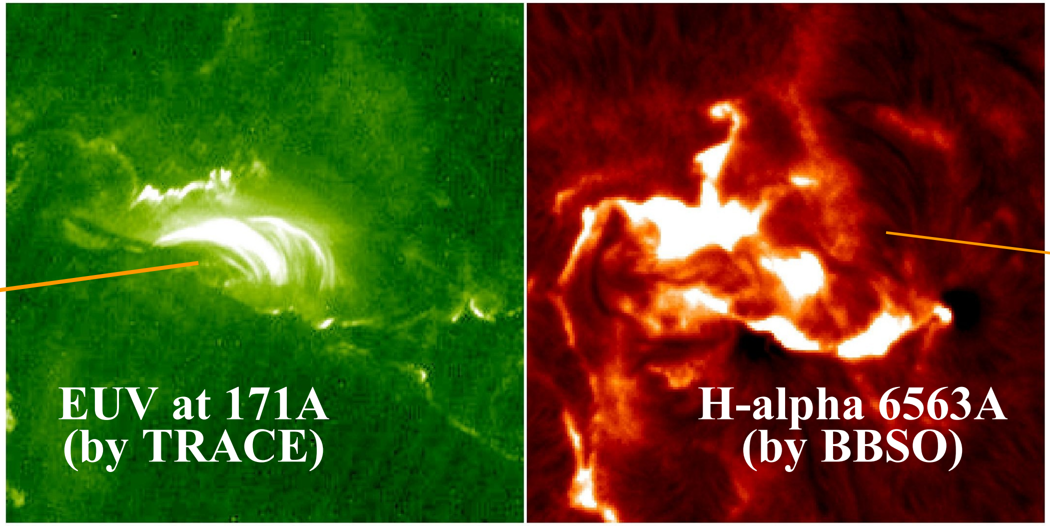
The Standard Model

of a flare





flare loops
in the corona



flare ribbons
in the
chromosphere

a large flare observed in different wavelengths
(Qiu et al.)

What does trigger a flare?

In the standard flare model it is expected that there is some mechanism that opens up the magnetic field.

This is commonly assumed to be a filament eruption.

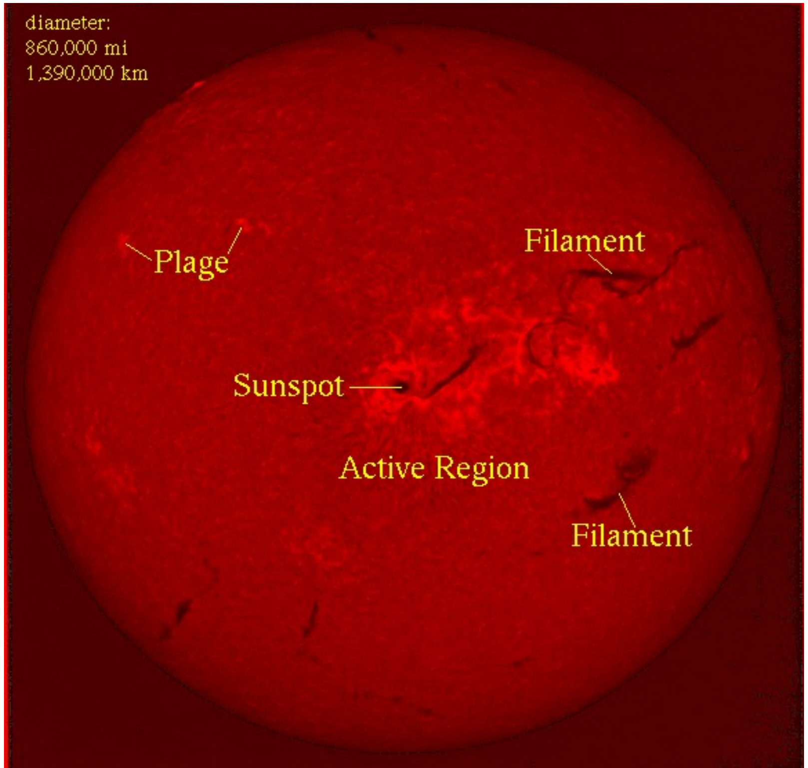
Filaments and Prominences

Filaments and prominences are cool and dense gas suspended high in the solar atmosphere, and embedded in the very hot solar corona.

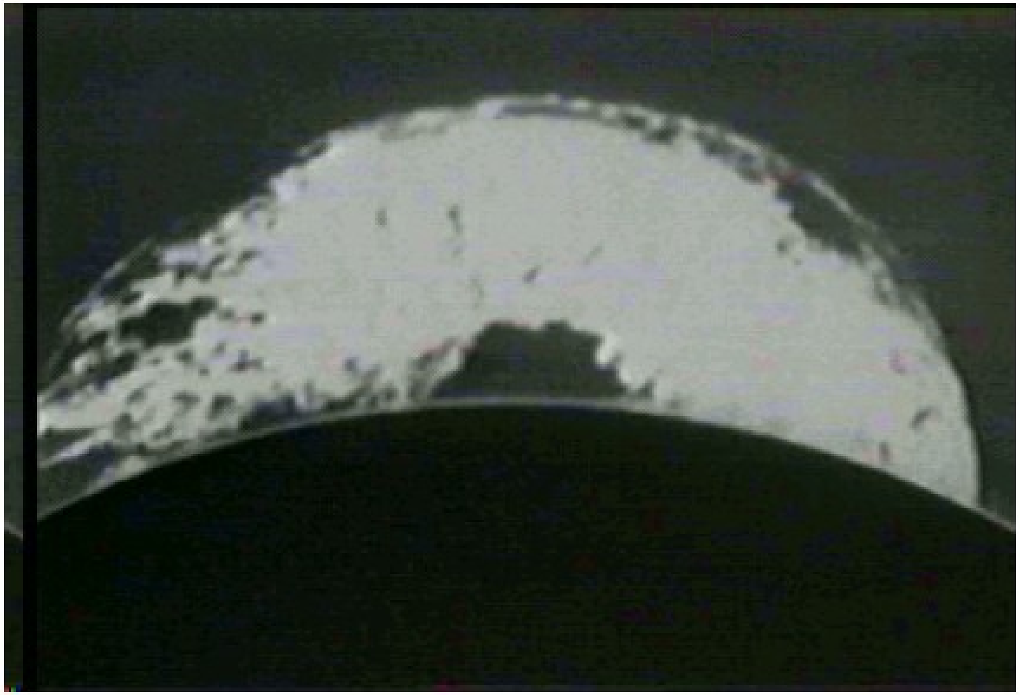
- When they are observed on the solar surface, they appear as dark absorption features…filaments!
- When the are observed outside of the solar limb, they appears as bright features because they reflect sunlight toward us…prominences!

Relatively cool gas (60,000 – 80,000 ^{o}K) compared with the low density gas of the corona

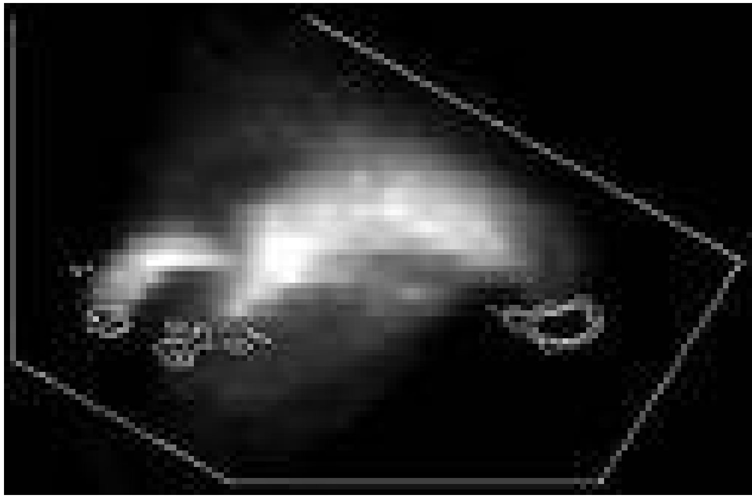
A huge solar prominence observed in 1946



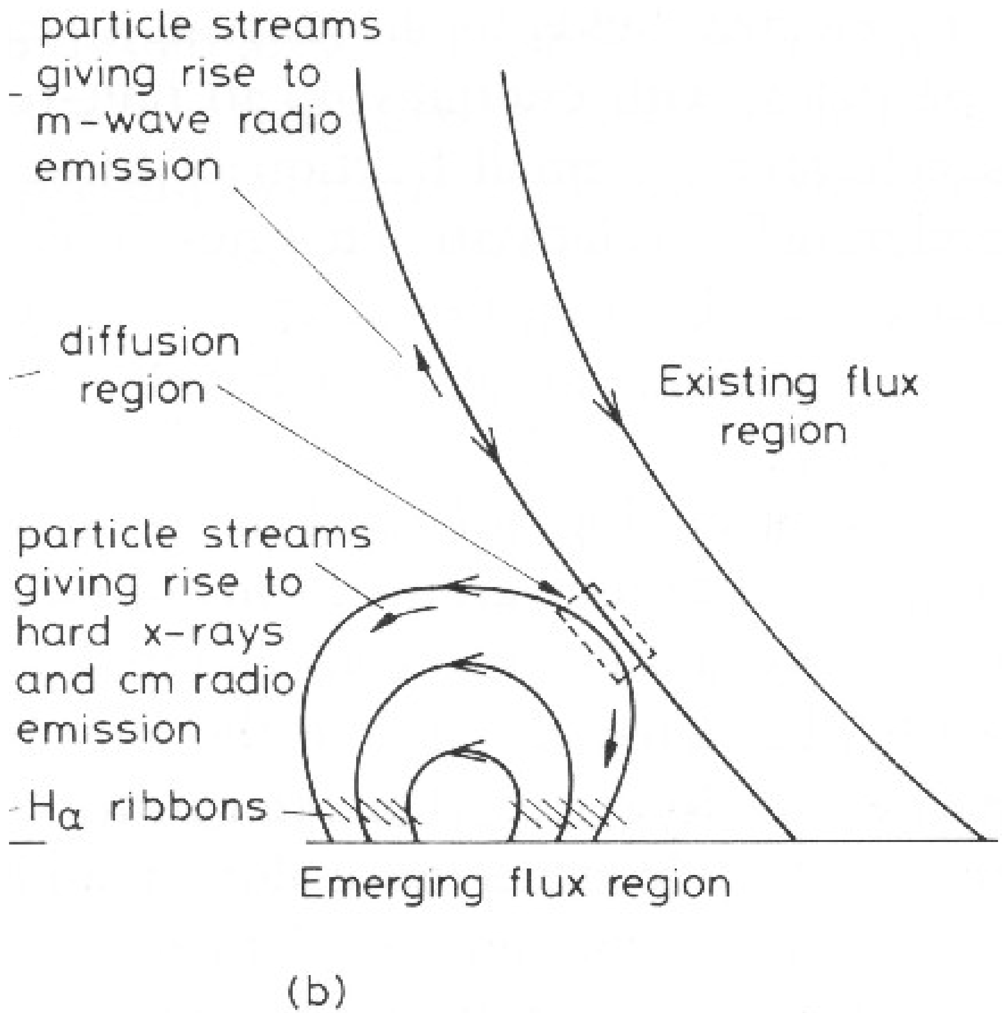
Solar flares are often associated with prominence eruptions



What does trigger a flare?

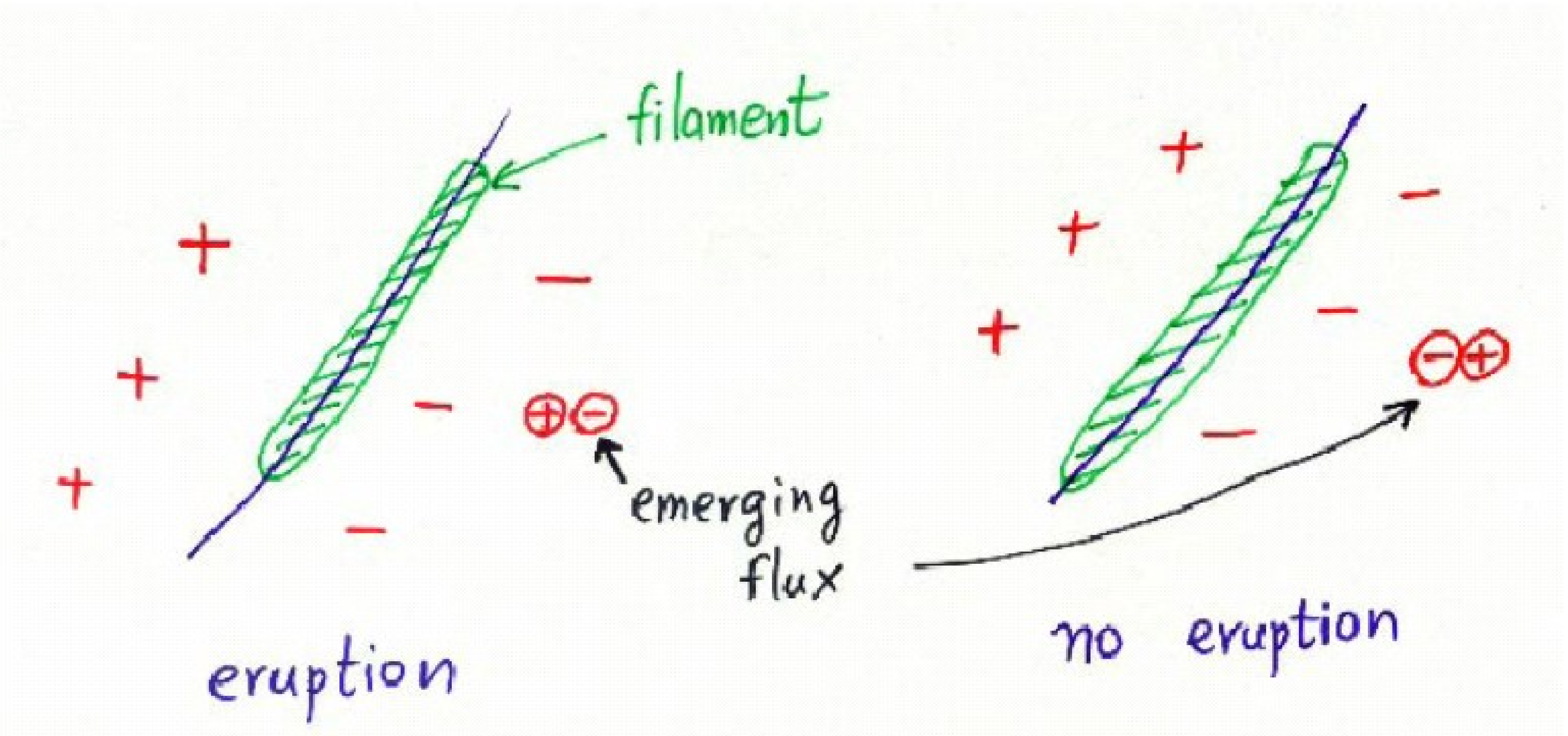


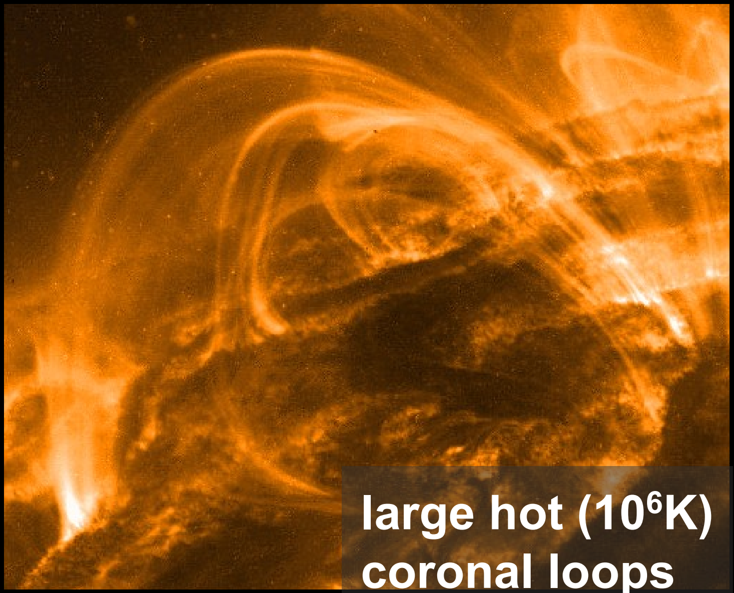
Emerging flux model. Interaction between separate magnetic structures

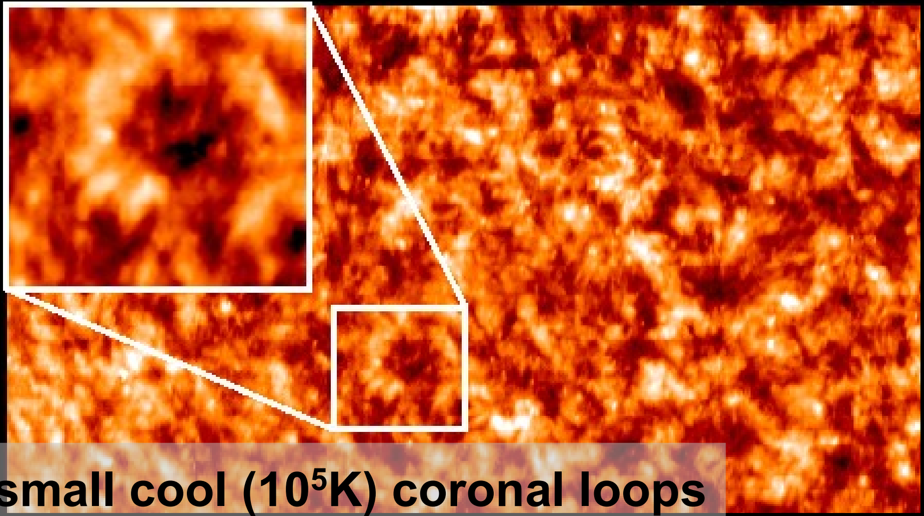


Flare model of Heyvaerts et al. (1977)

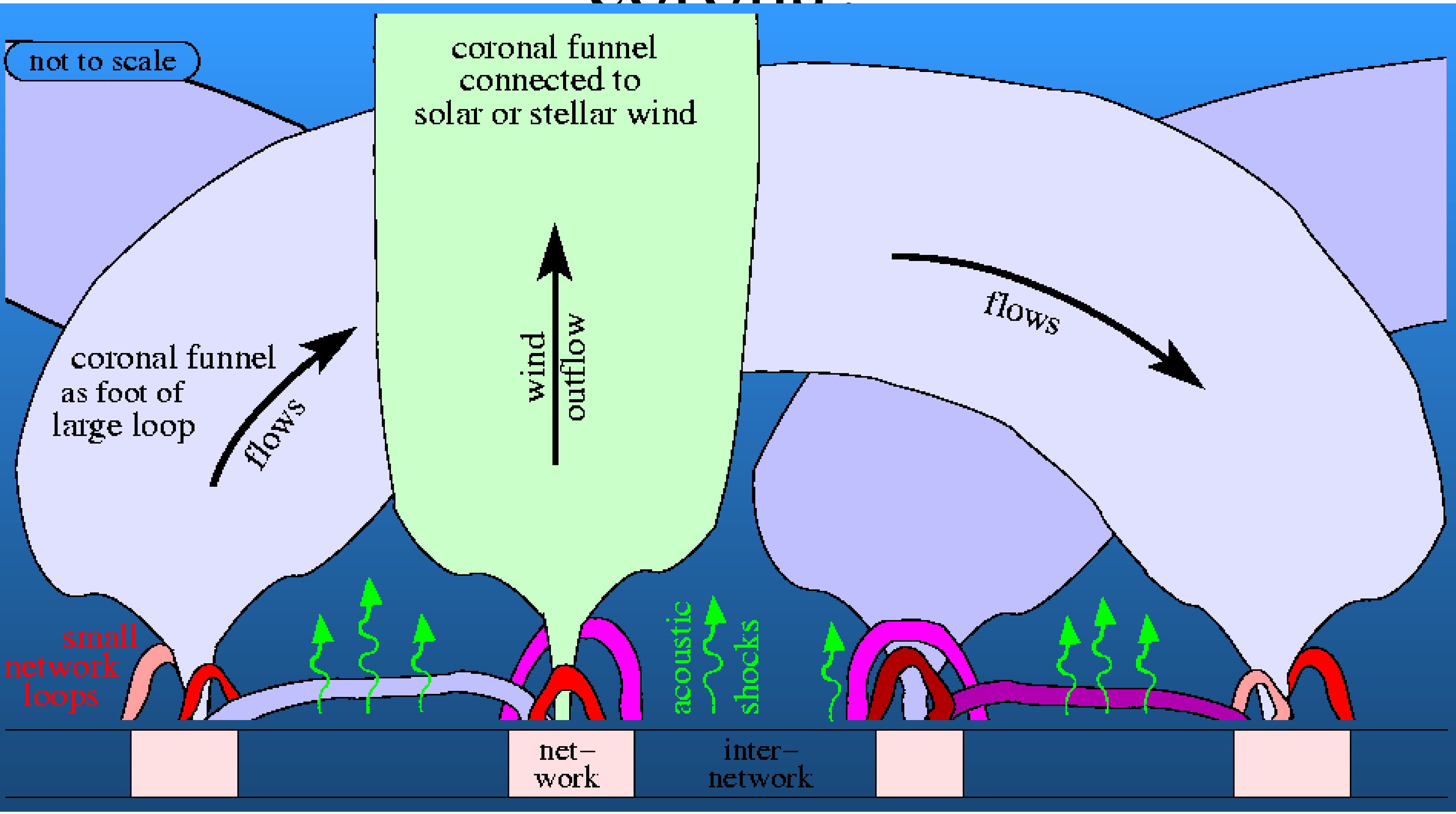
emerging flux triggering filament eruption
(Feynman and Martin 1994)



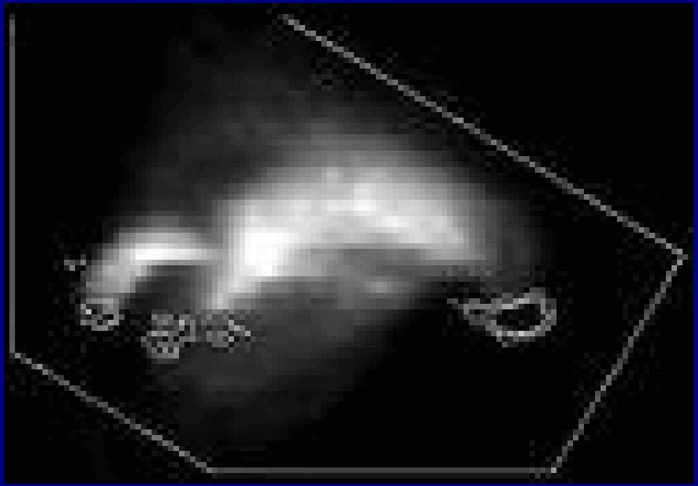

large hot (10^6K)
coronal loops


small cool (10^5K) coronal loops

What is the structure of the low corona?

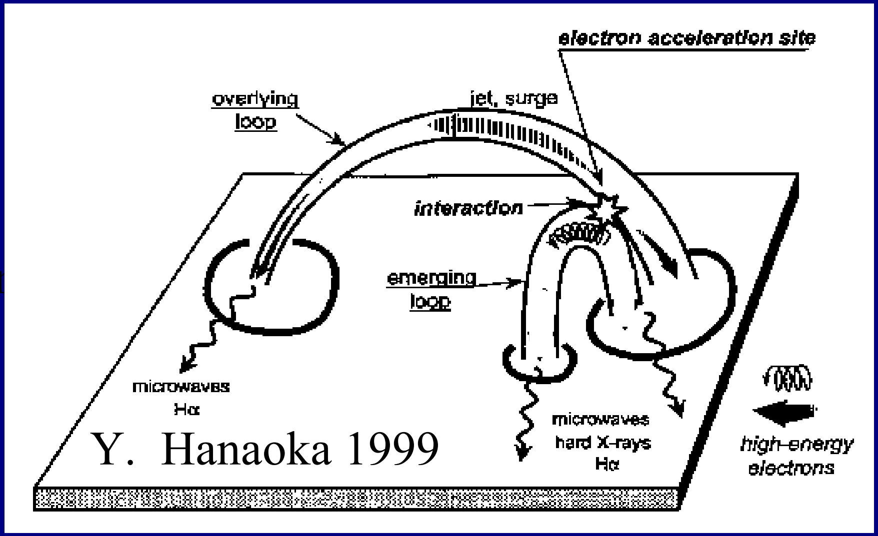


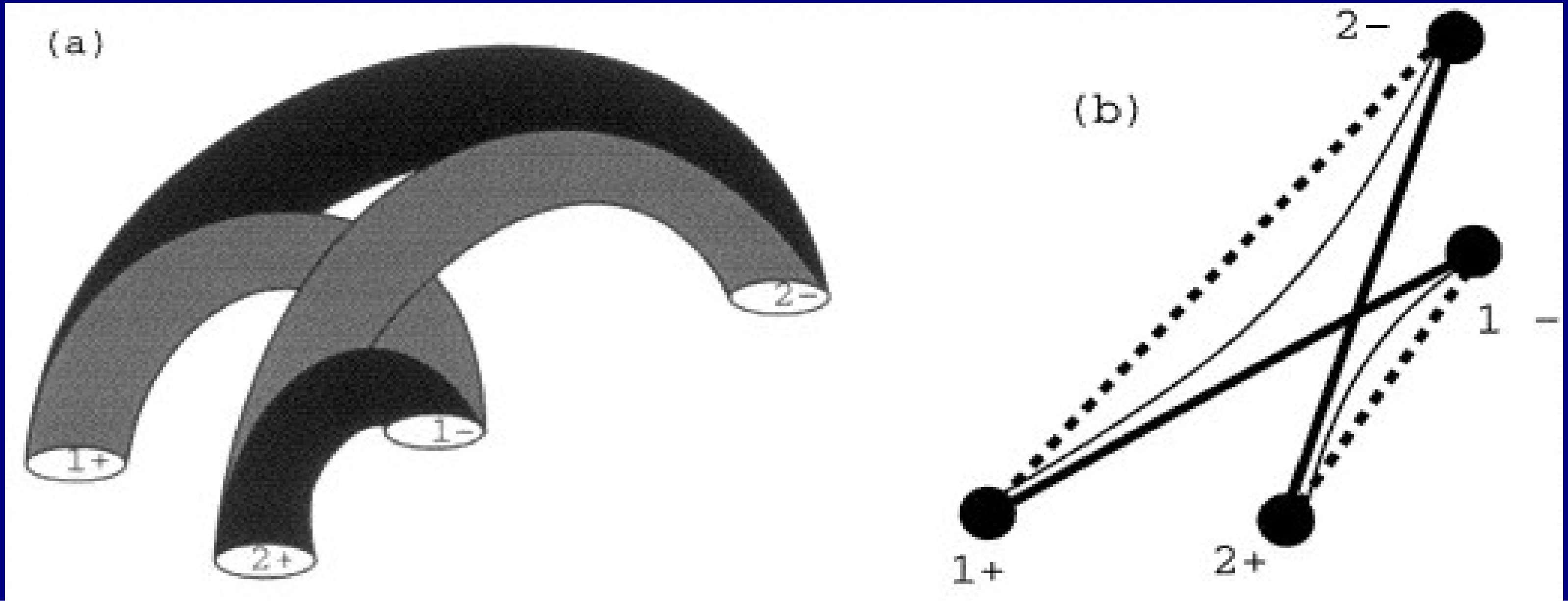
Loop-Loop interactions



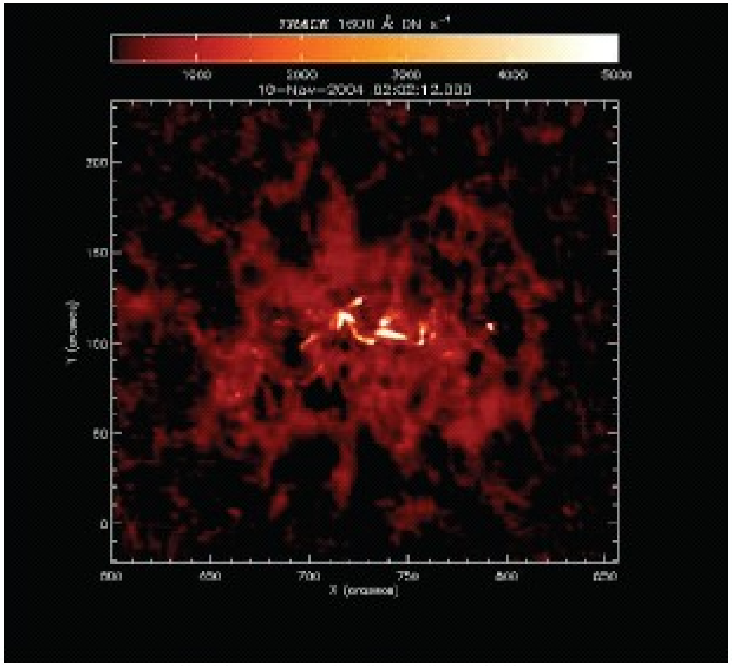
www.astro.uni.wroc.pl/nauka/helpap/rf/1093.htm

Magnetic-reconnection

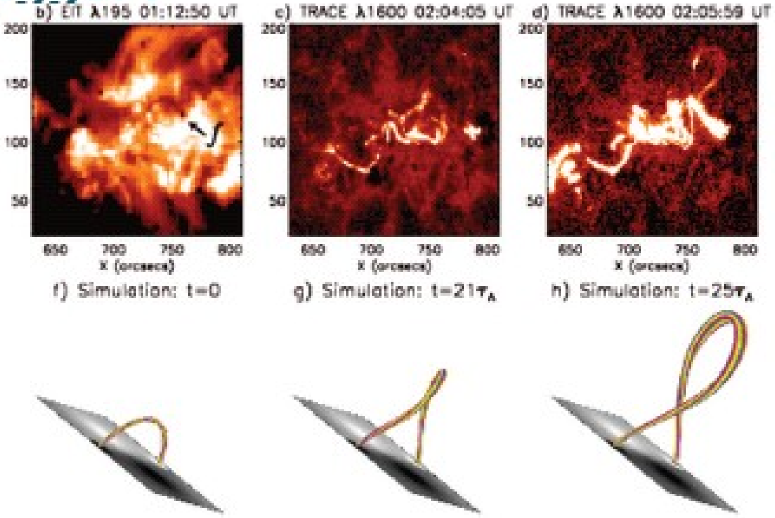




Can a kink instability be a trigger?



Williams et al. (2005)



This is the process where twist is abruptly converted into writhe.

What does trigger a flare?

Kink Instability: Tanaka (1991) proposed a model in which the rising magnetic flux bundle is already twisted and kinked prior to reaching the surface.

Dynamical Corona

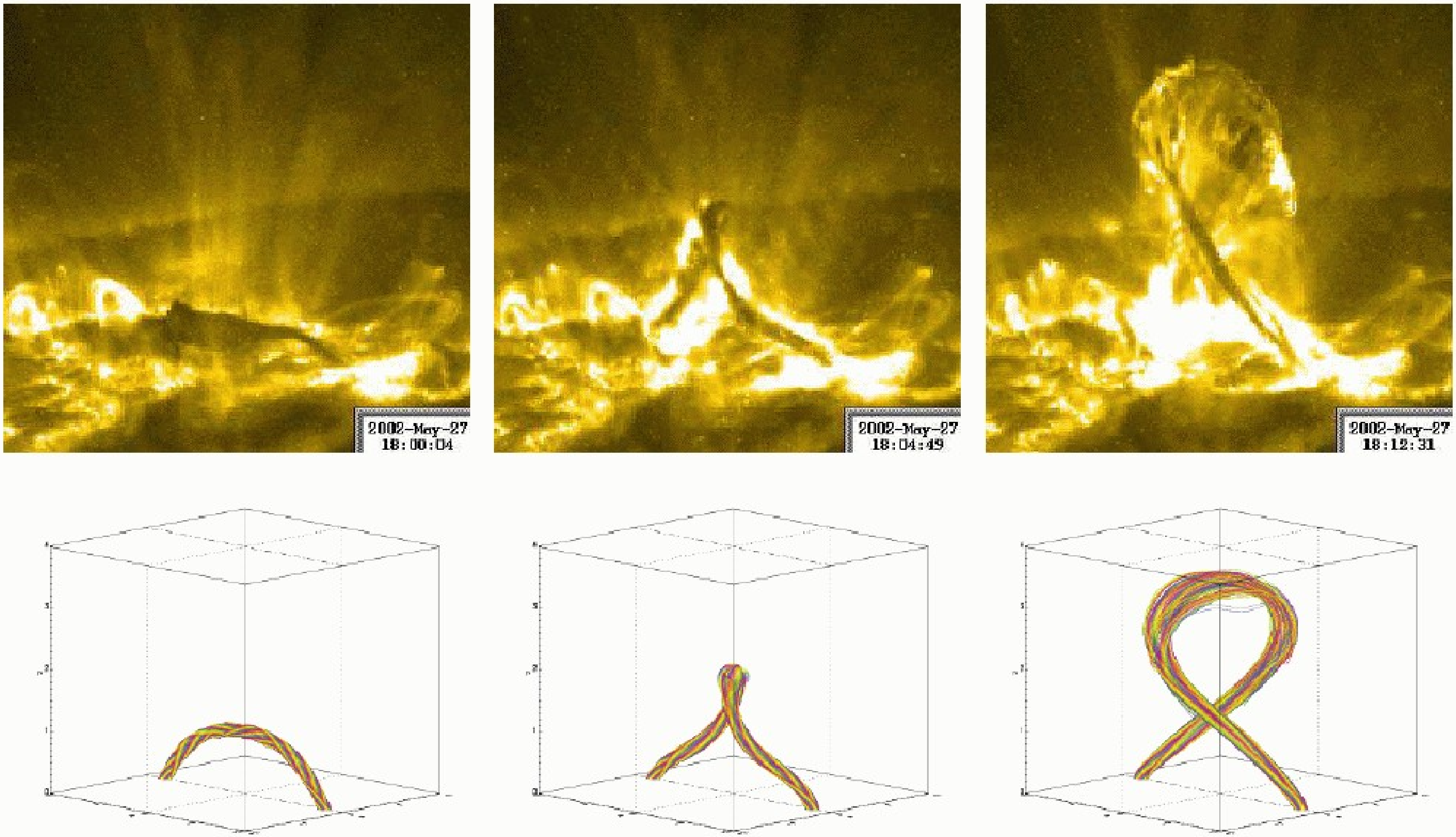


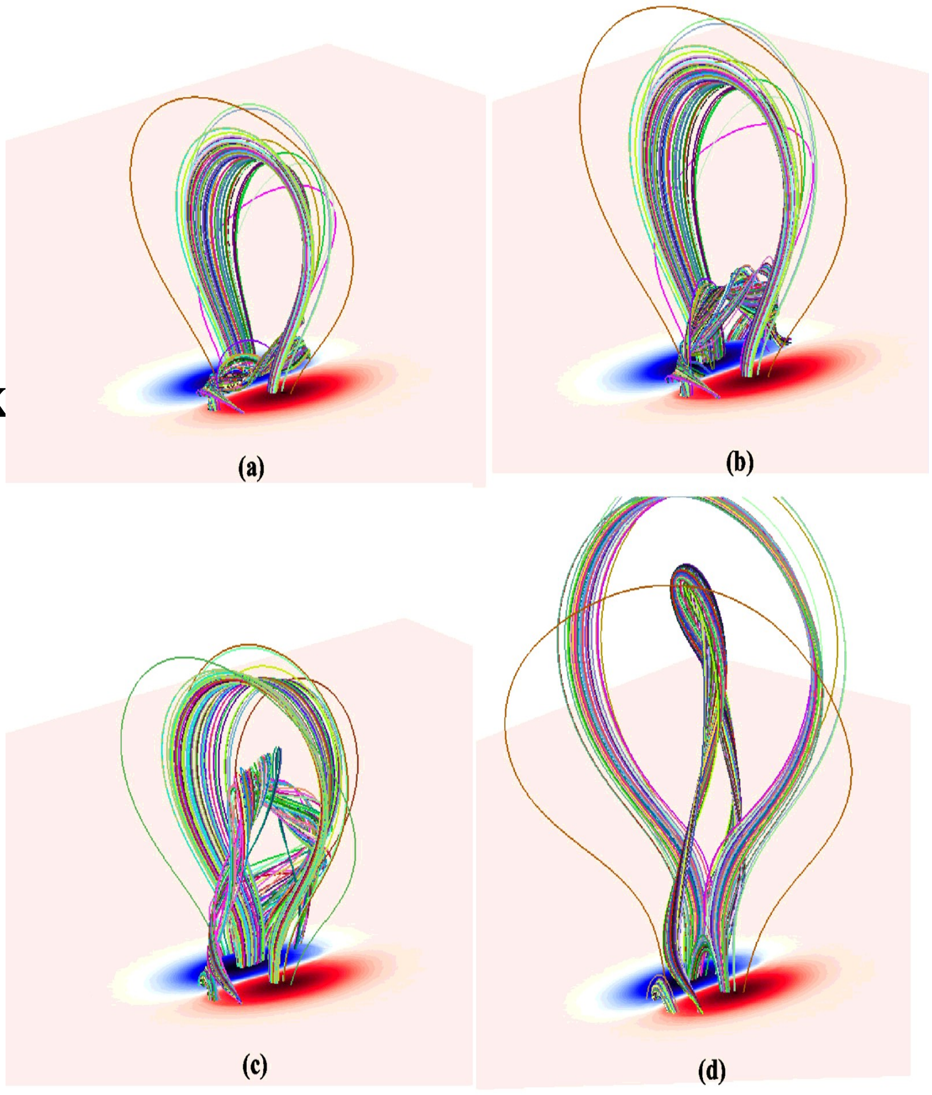
Figure 9. **Top:** TRACE 195 Å images of the confined filament eruption on 2002 May 27. The right image shows the filament after it has reached its maximum height. **Bottom:** magnetic field lines outlining the kink-unstable flux rope reproduced with 3D MHD simulations (Török & Kliem 2004).

ppt presentation : Markus Aschwanden (AIA/HMI workshop, Monterey 2006)

- eruption of twisted flux rope above the magnetic inversion line

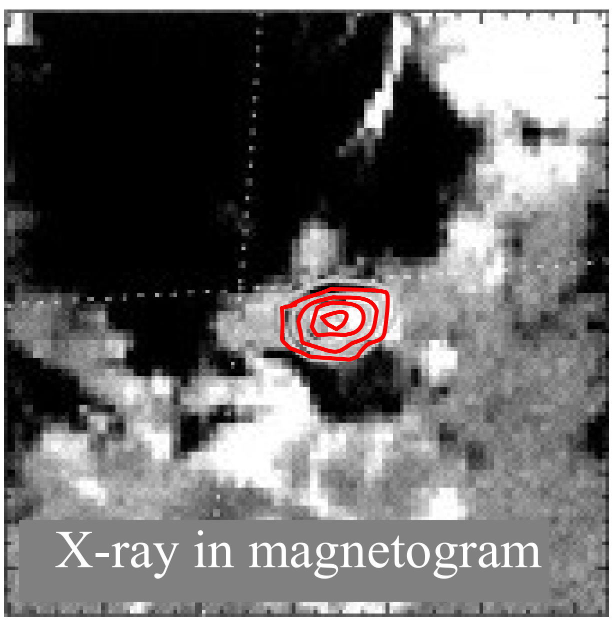
•Magnetic reconnection occurs underneath the flux rope,

flux rope escape

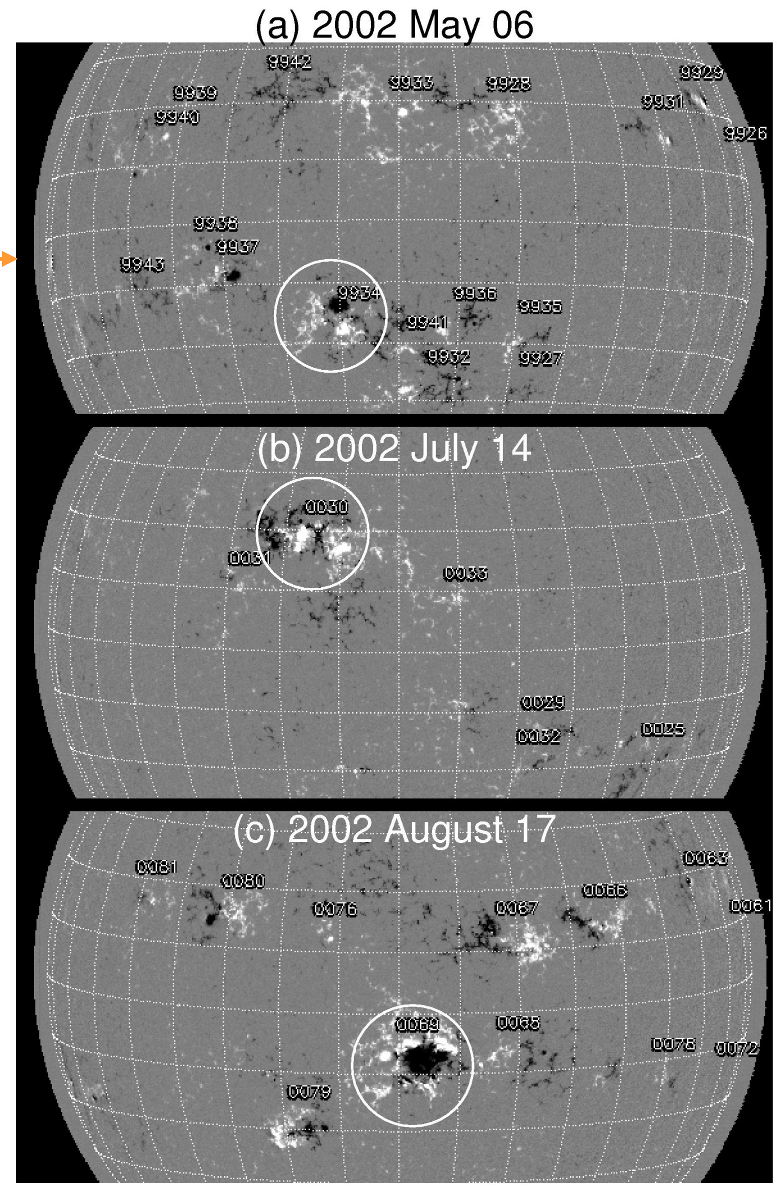


Most flares occur in active regions where magnetic fields concentrate and are complex.

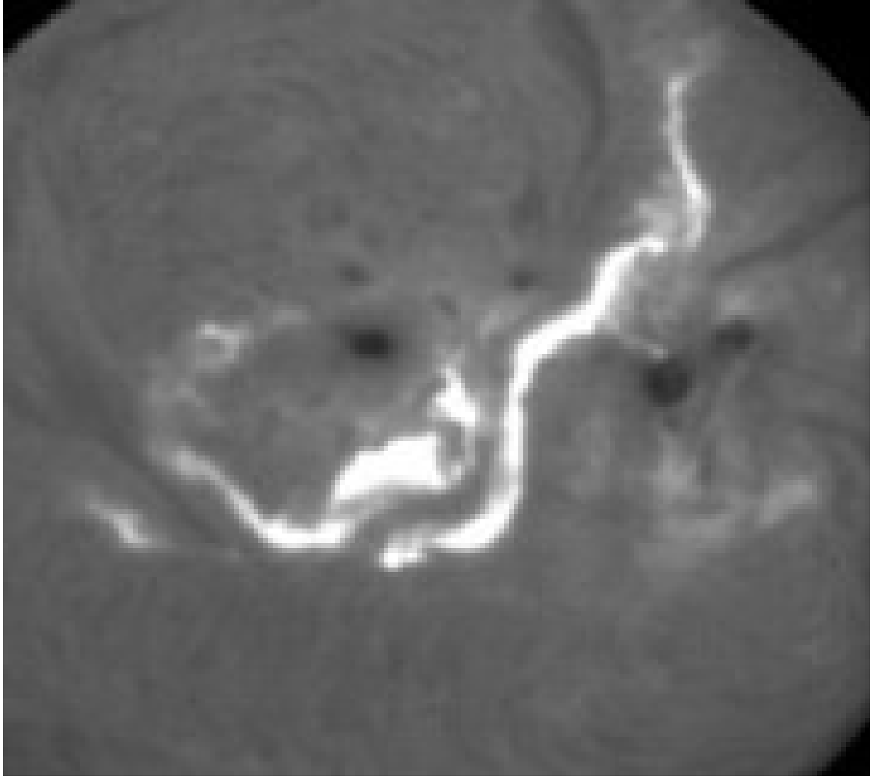
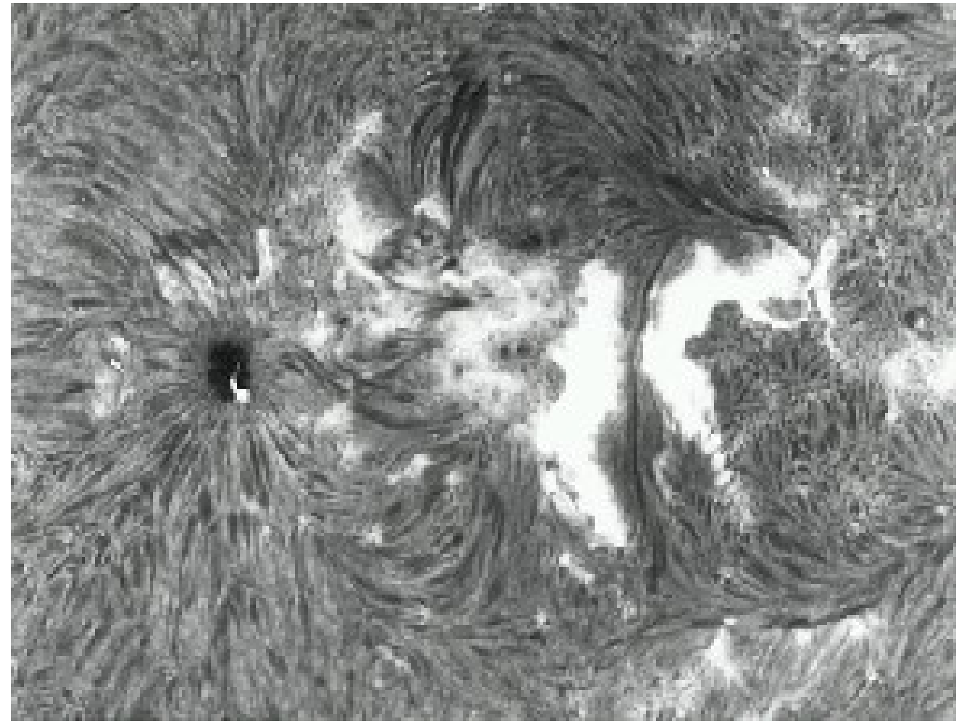
They are located at where the <u>polarity of magnetic fields reverses.(neutral line)</u>



(Liu et al. 2005)



(Qiu et al. 2005)

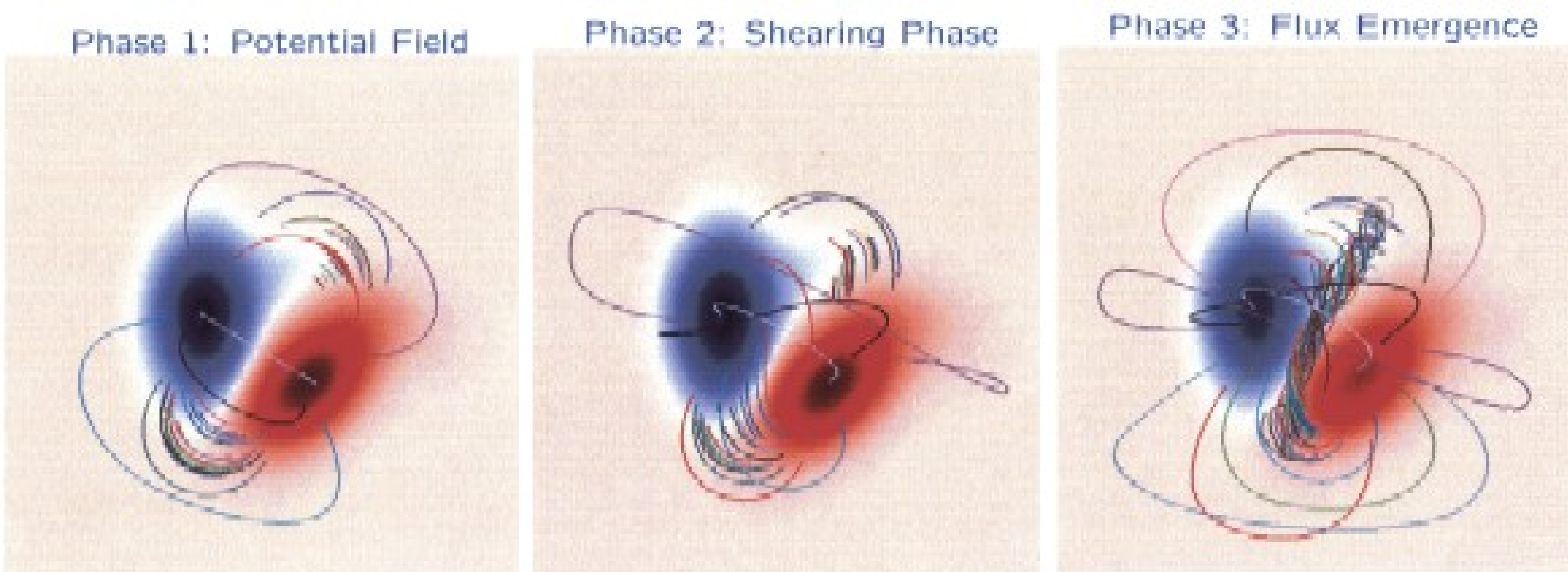
(Ribbon Flare)

Halpha emission is observed on both sides of the neutral line

Production of magnetic shear:

vector .magnetograph measurements.......field sheared along the neutral line, i.e. It is oriented more nearly parallel to the neutral line than peperndicular to it.

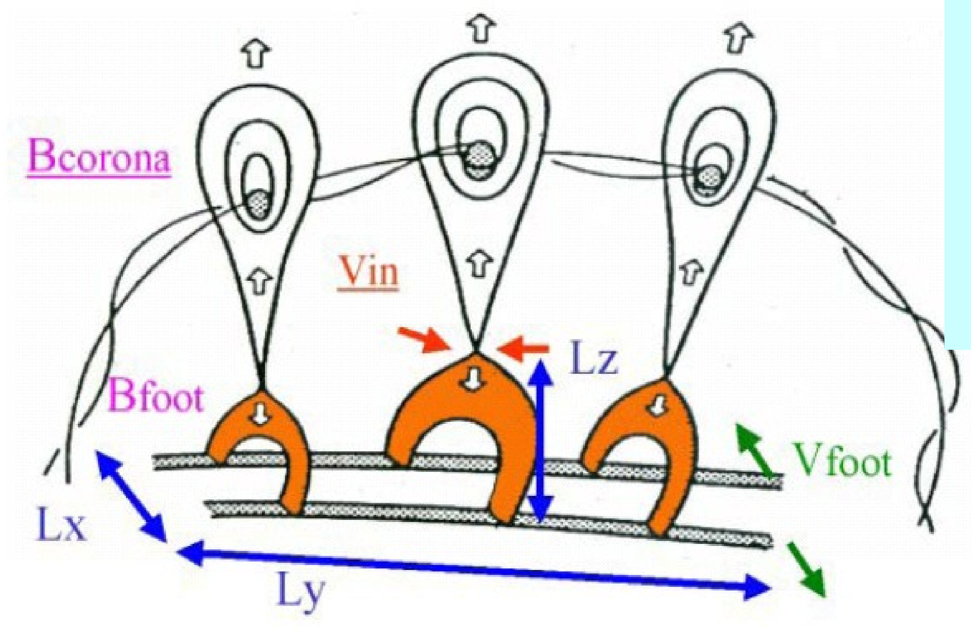
- **Twisted magnetic flux rope** forms above the **neutral line** due to shearing motion of photospheric magnetic field
- Flux rope carries strong electric current (Ampere's Law), thus carries a large amount of free energy

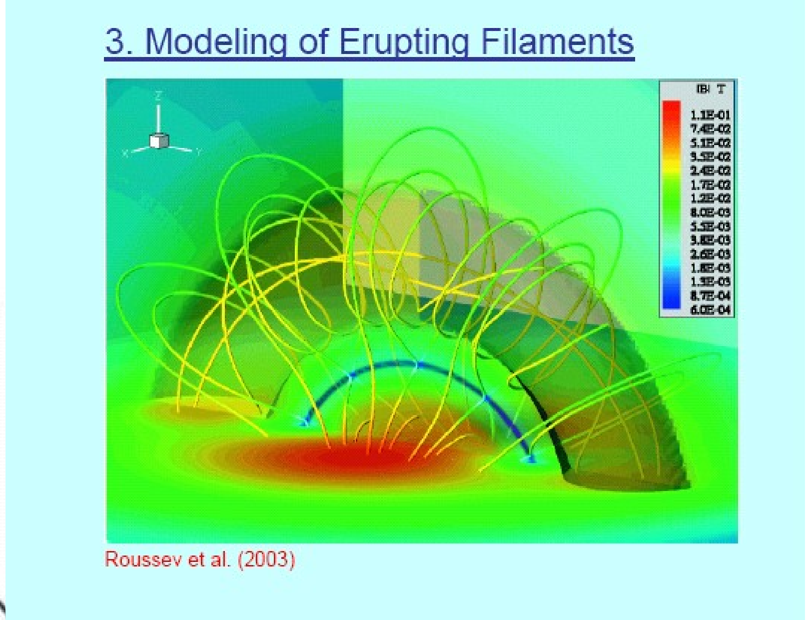


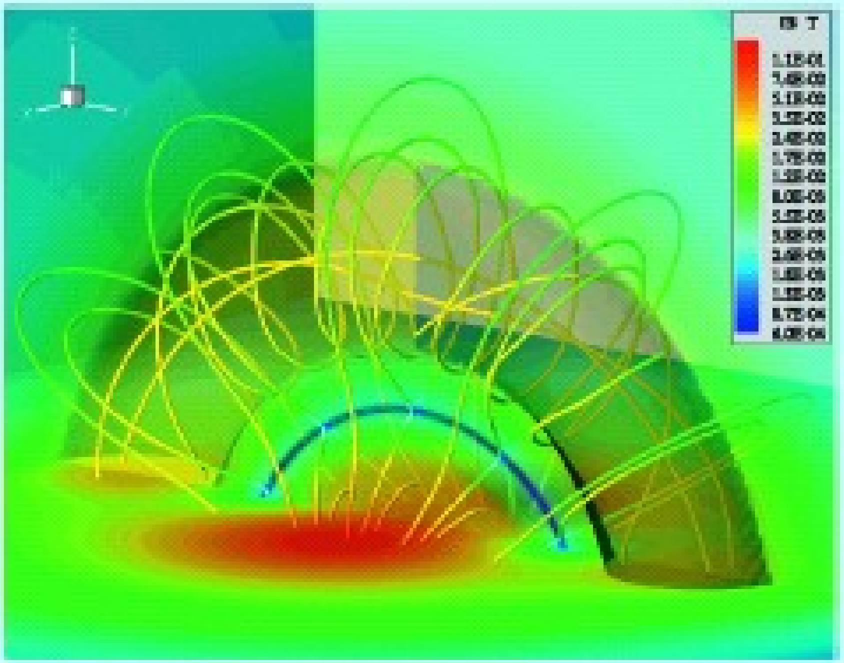
Primary publication: Amari T., Luciani, J. F., Mikic, Z., and Linker, J. A., "Three-Dimensional Solutions of Magnetohydrodynamic Equations for Prominence Magnetic Support: Twisted Magnetic Flux Rope, *The Astrophysical Journal*, **518**, L57-L60, 1999.

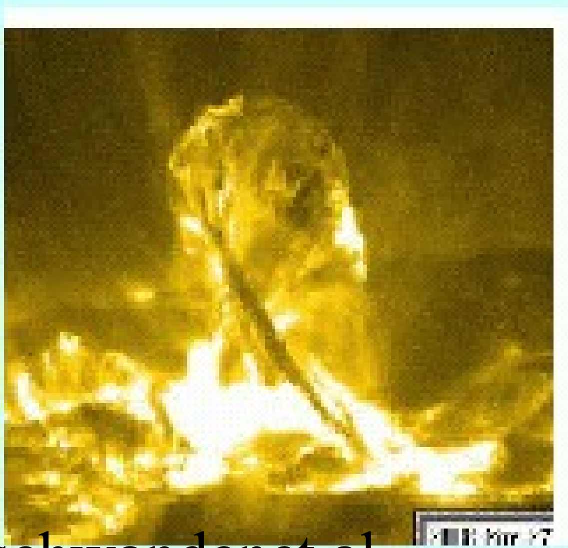
•A filament always sits along the magnetic inversion line (magnetic neutral line) that separates regions of different magnetic polarity

•Helical or twisted magnetic structure is seen within filament









Triggers for of filaments or
Magnetic flux ropes:

-<u>draining of prominence materia</u>
<u>→bouancy force</u>
(Gibson & Low 1998)
(Manchester et al. 2004)

-<u>current increase and</u>
<u>loss of equilibrium</u>
(Titov & Demoulin 1999)
(Roussev, Sokolov, & Forbes)
(Roussev et al. 2003)

-<u>kink instability</u>
→ unstable if twist > 3.5π
(Toeroek & Kliem 2003,
Toeroek, Kliem, & Titov 2003)

Markus Aschwandenet al.

The Standard Model of a flare

Model proposed by Kopp and Pneuman (1976).

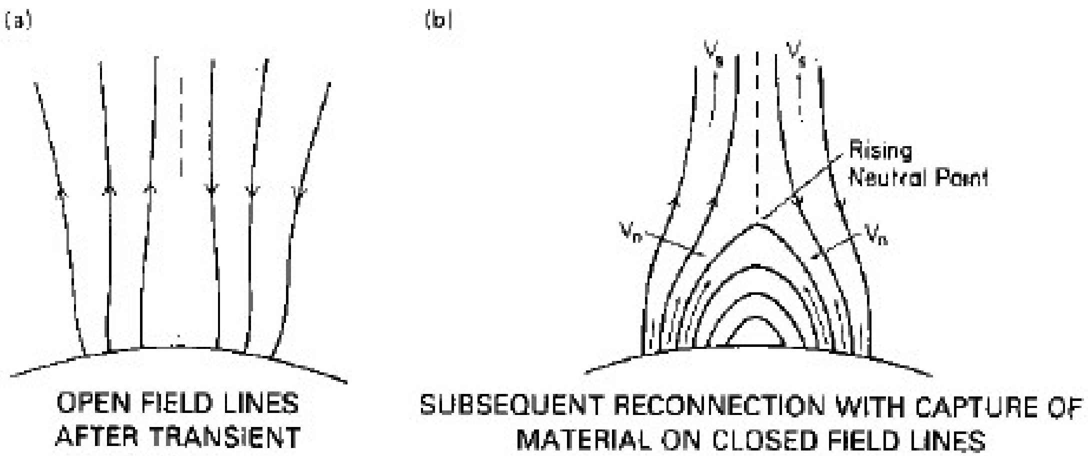
1) It requires a „transient“ that opens up the magnetic field lines.

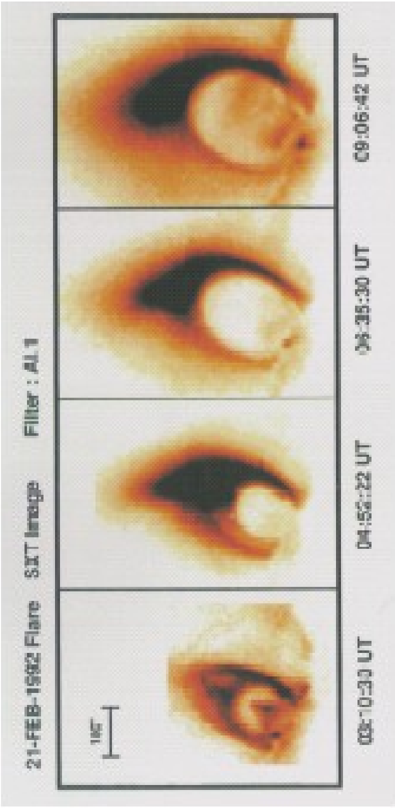
2) As they close down and reconnect, energy is released that goes into accelerating electrons which travel down the magnetic field lines.

3) These highly energetic particles will heat the dense chromosphere at the footpoints

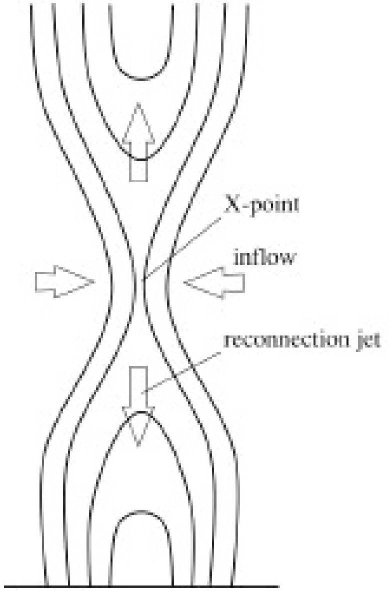
4)and this plasma is heated and conducted into the loops

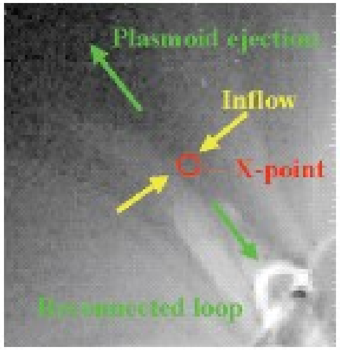
Our ‘Understanding’ of Solar Flares





Reconnection inflow…

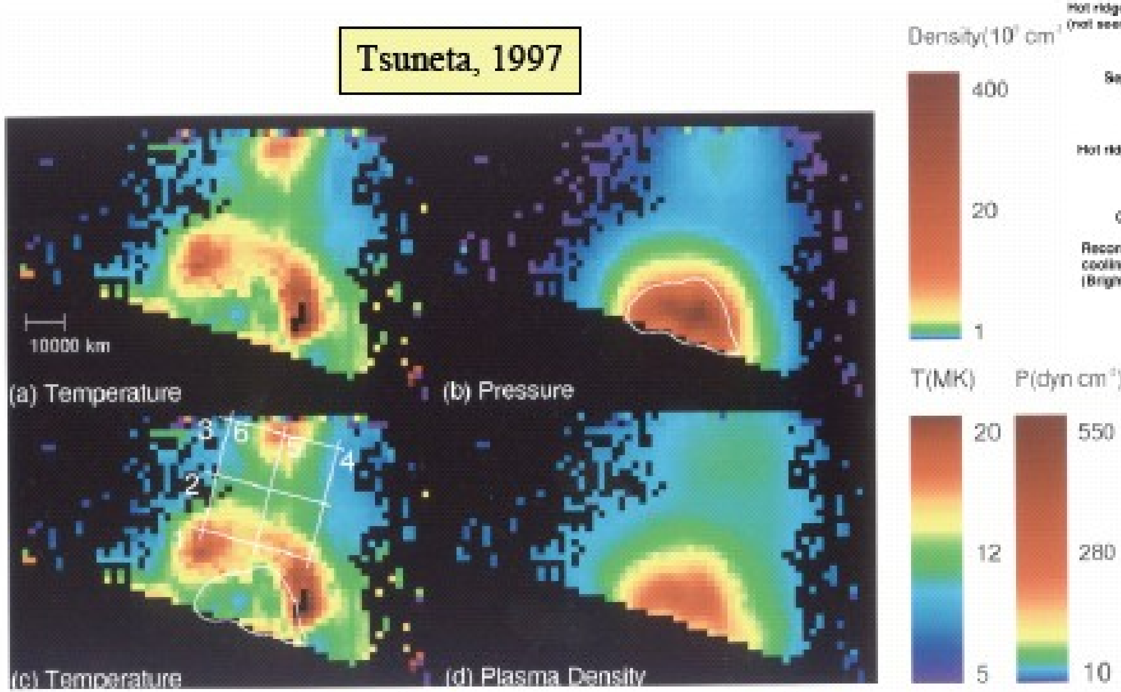


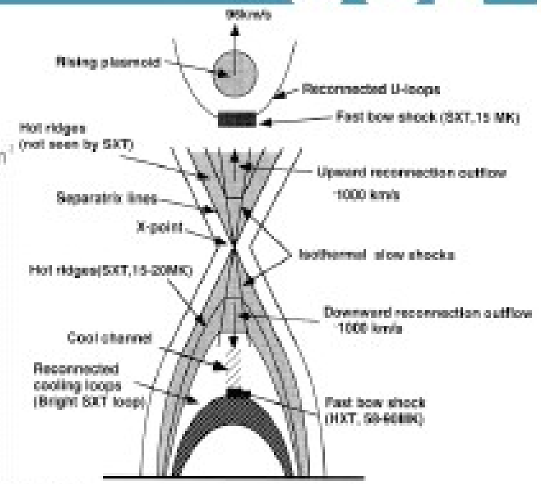


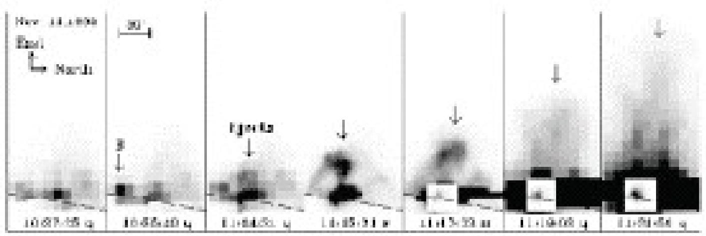
Yokoyama et al.

Observation of the upward moving plasmoid

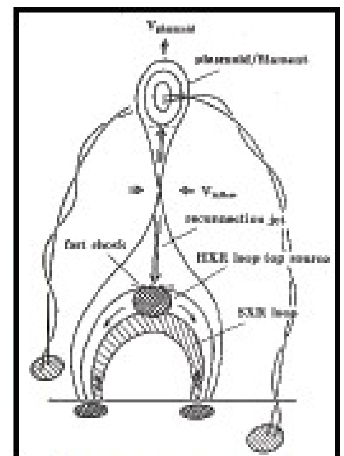
Tsuneta, 1997





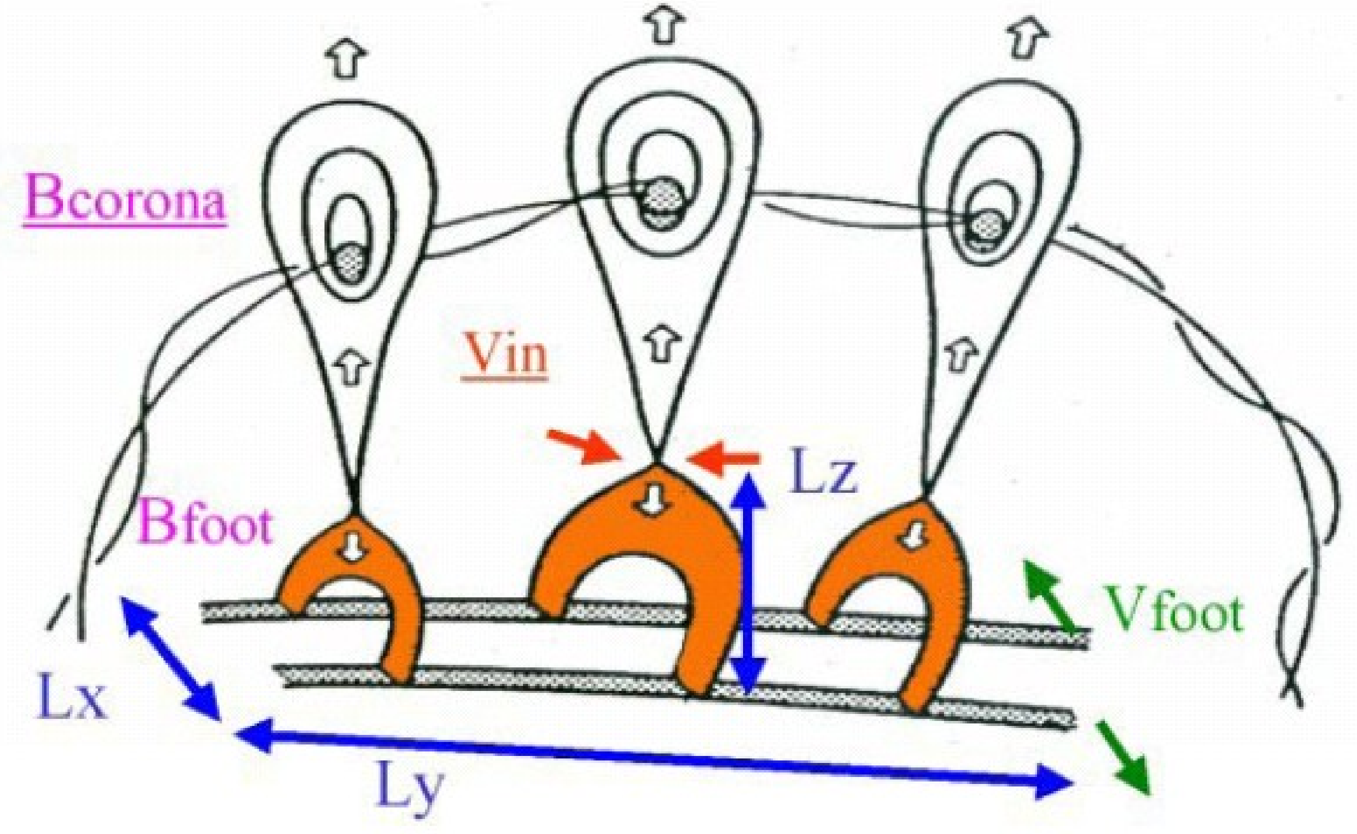


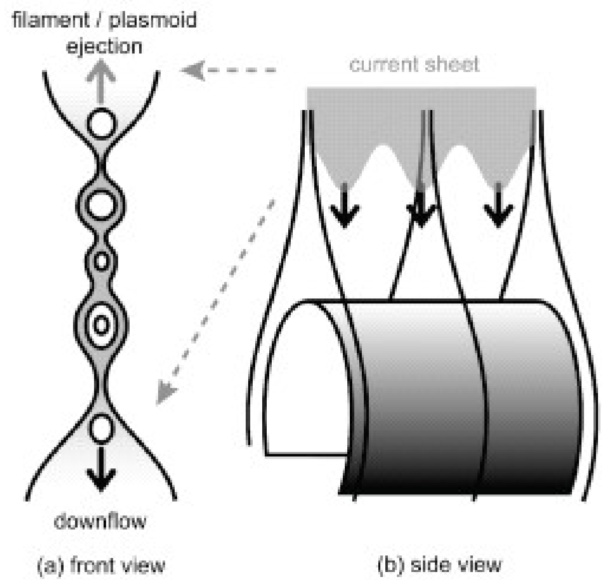
Plasmoid ejection (Shibata et al, 1995; Ohyama et al,1997



Shibata, 1998

Reconnection model (CSHKP model=Carmichael 1964, Sturrock 1966, Hirayama 1974, Kopp-Pneuman 1976)

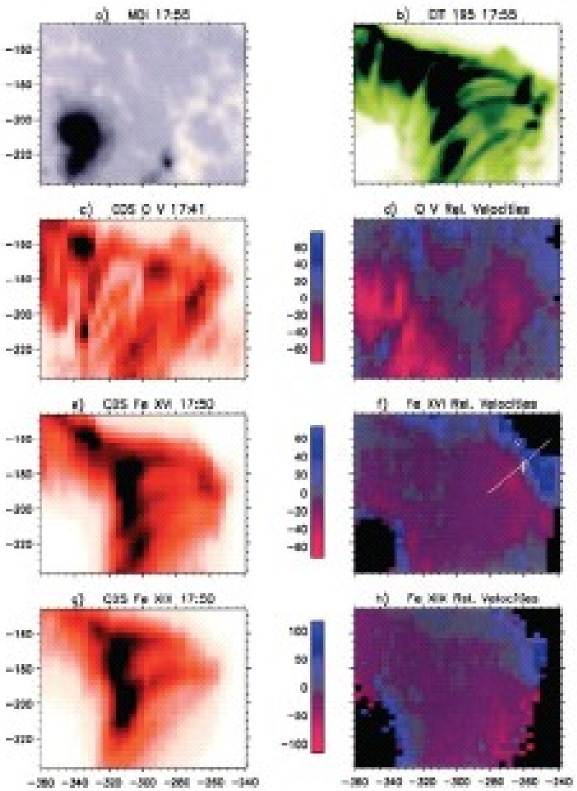


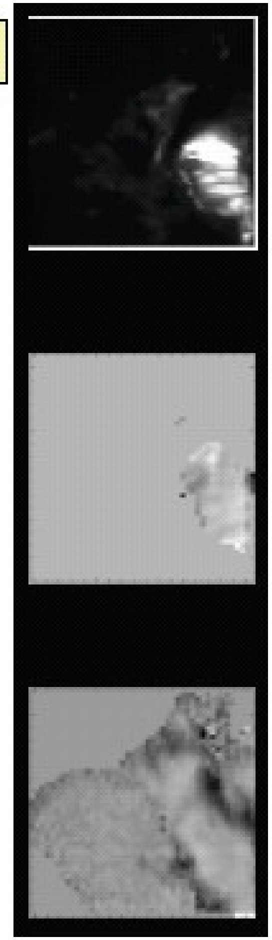


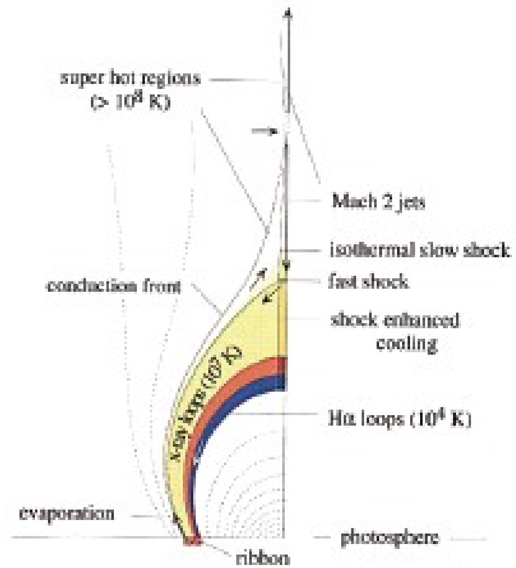
Start of these downflows are associated with non-thermal emission and microwave bursts!

Chromospheric upflows and downflows:

SOHO/CDS







Forbes, 2002

Blueshifts along outer part of arcade (chrom. evaporation) redshifts along the inner part (cooling downflows)

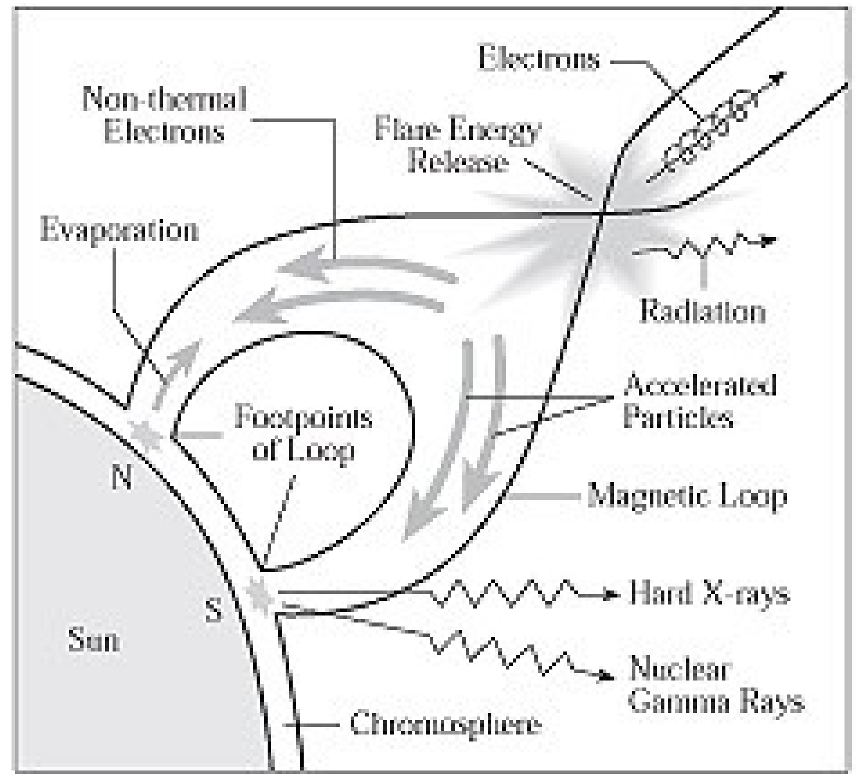
Czaykowska et al (1999)

Harra et al (2005)

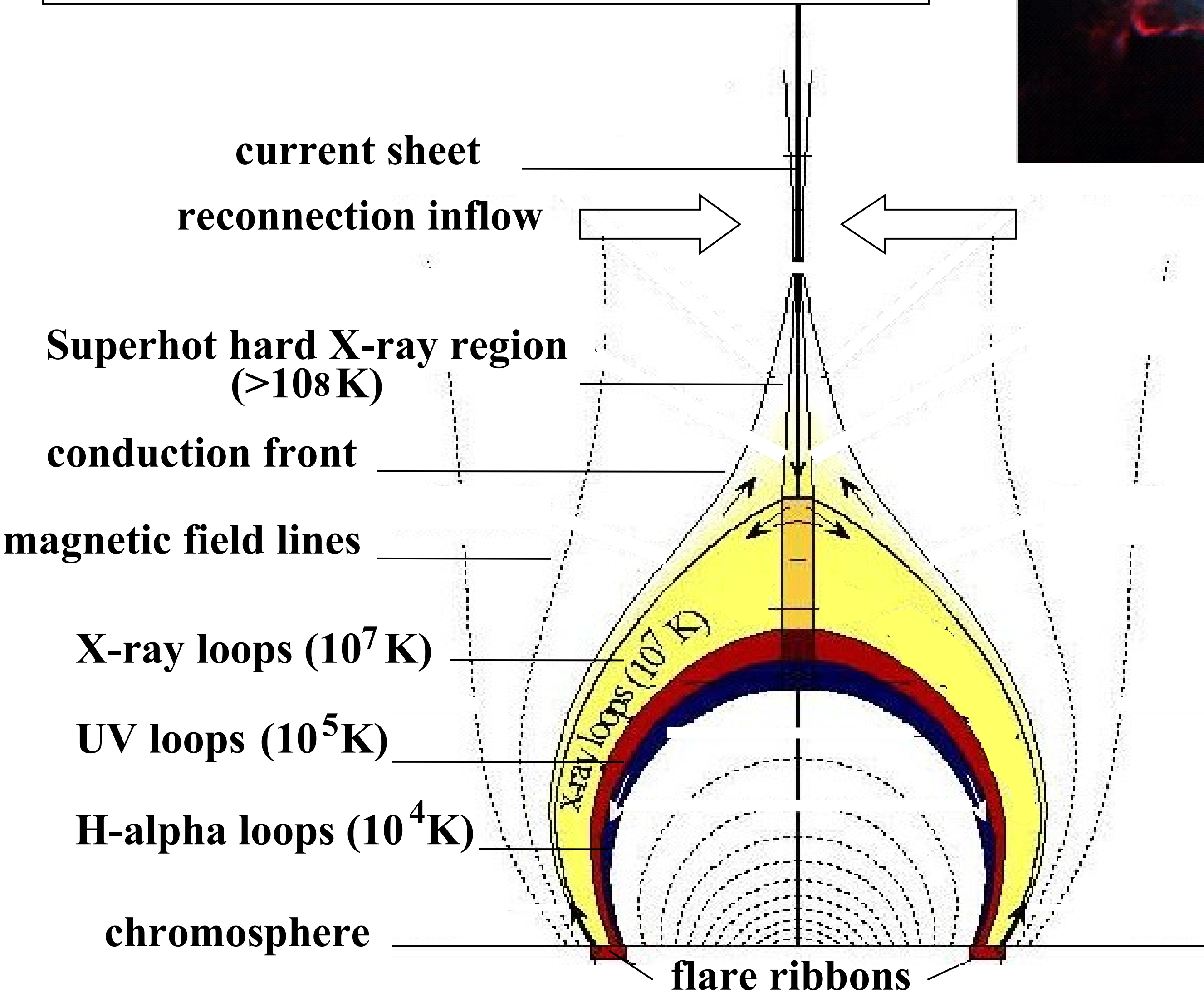
Flare Model

1. Magnetic reconnection occurs at the top of magnetic loop
2. Energetic particles are accelerated at the reconnection site

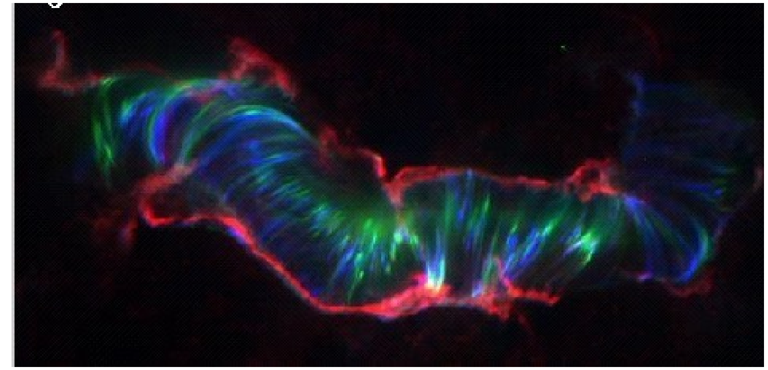
- Particles precipitates along the magnetic loop (radio emission) and hit the chromosphere footpoints (<u>Hard X-ray</u> emission, Hα emission and ribbon)
- Heated chromspheric plasma evaporates into the corona (<u>soft X-ray emission, loop arcade</u>)

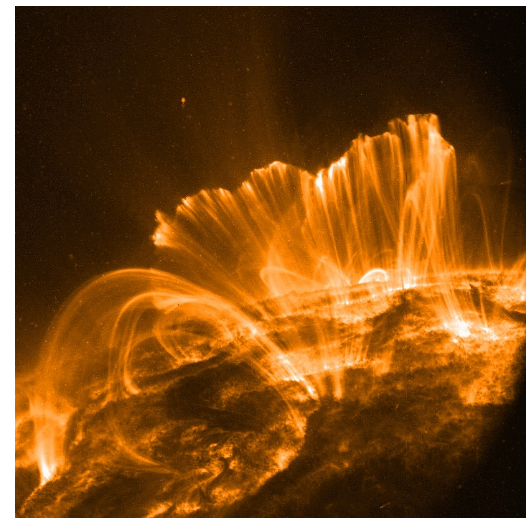


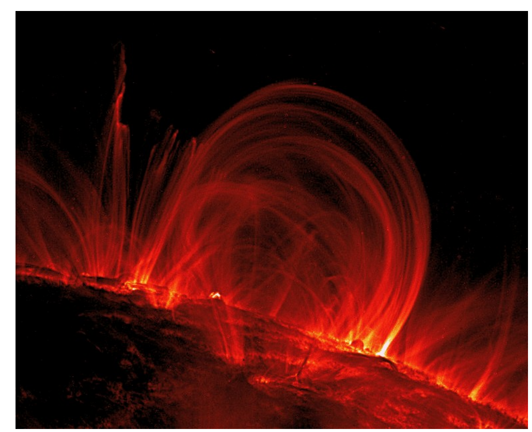
“observe” magnetic reconnection in a standard flare configuration

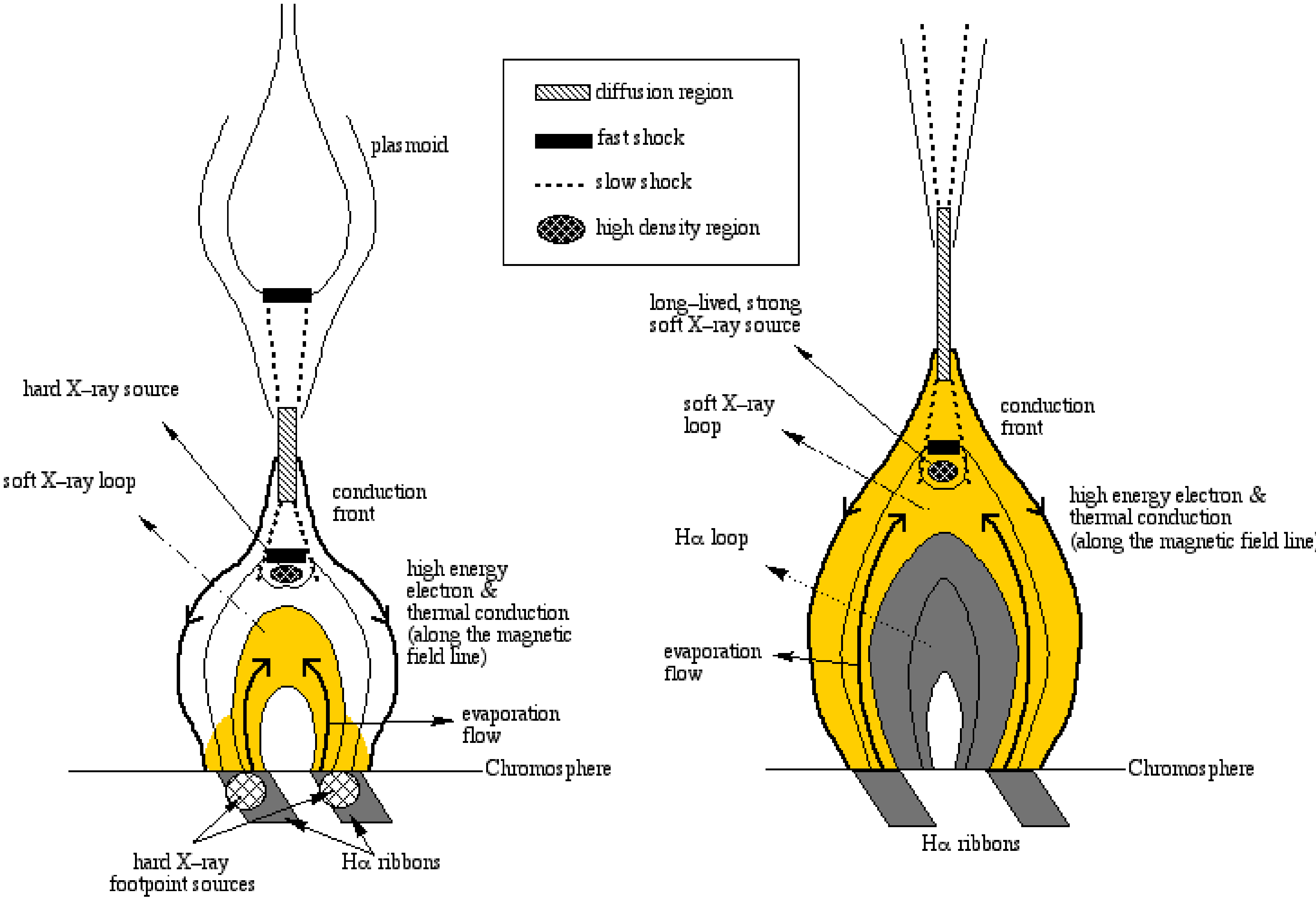


(adapted from Forbes & Acton, 1996)









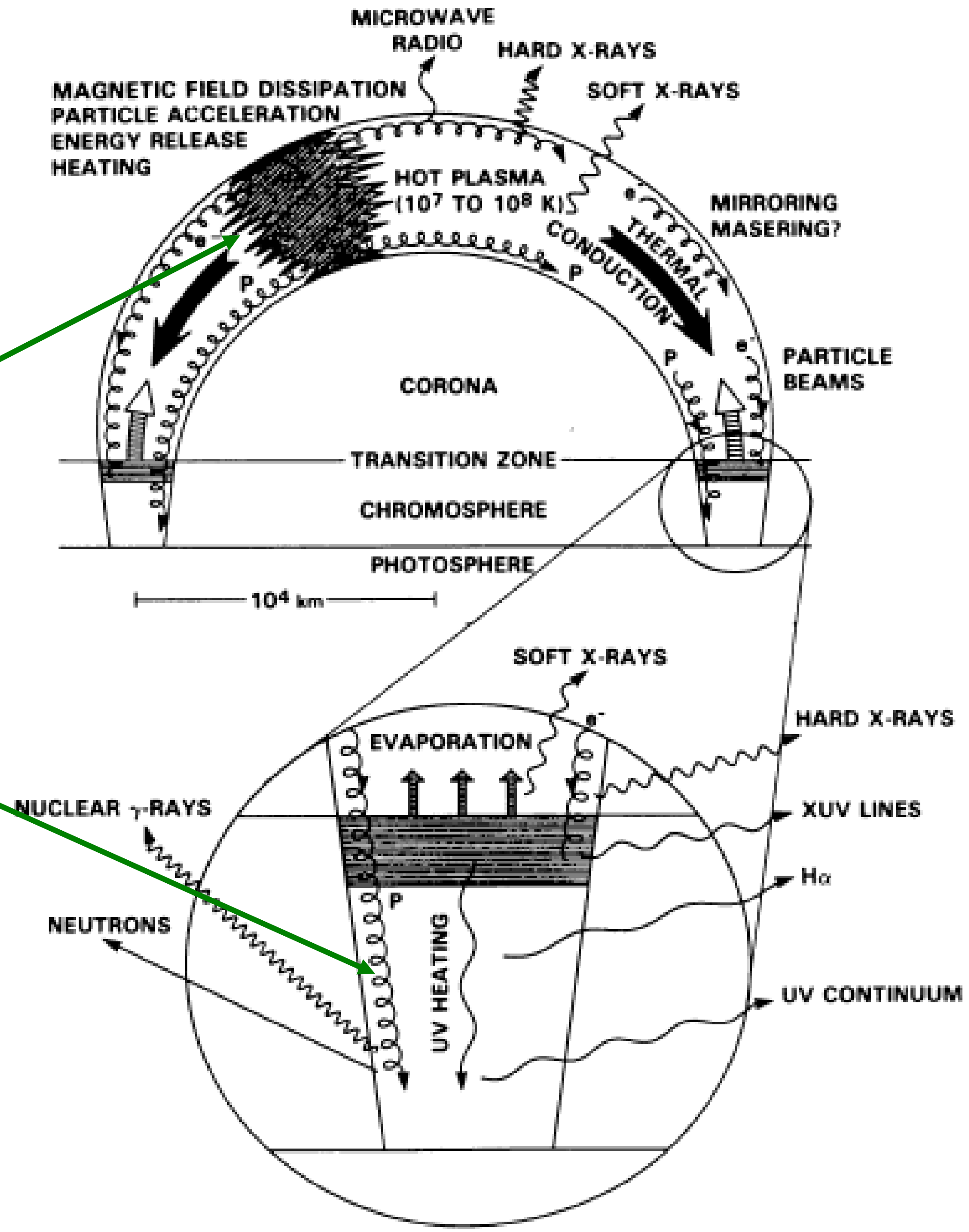
Impulsive flares (or impulsive phase)

LDE flares (or gradual phase)

Schematic model of a flaring magnetic loop (Dennis & Schwartz 1989).

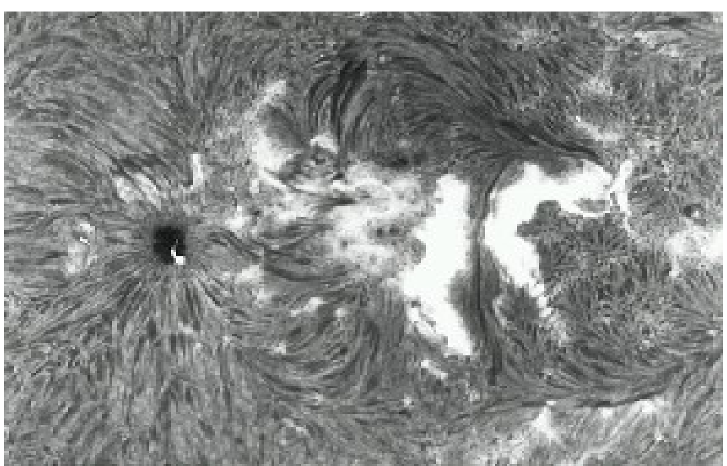
A reconnection of fields occurs along the loop length which accelerates electrons down to the chromosphere.

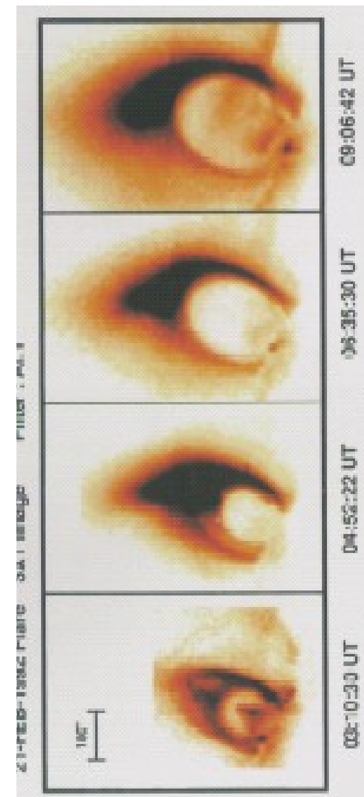
They dump their energy in the chromosphere which "evaporates" upwards



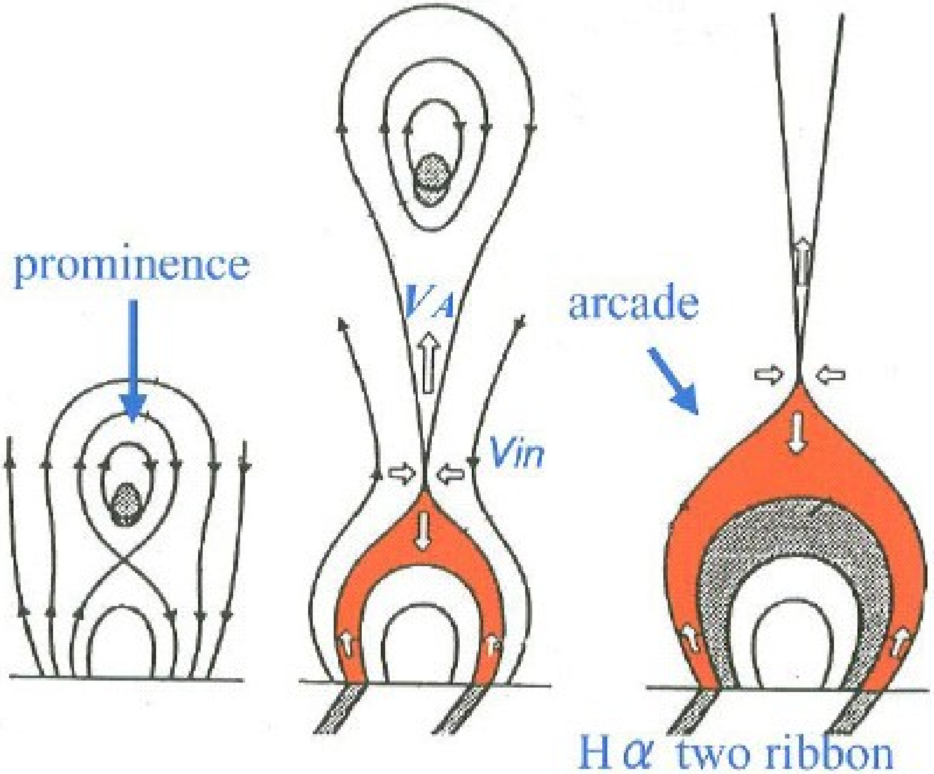
Flare Model

- Post-eruption loop arcade appears successively high, because of the reconnection site rises with time
- The ribbon separates with time because of the increasing distance between footpoints due to higher loop arcades





2D view of reconnection (CSHKP) model



⇒should be observed in Soft-Xrays

Recent Space Observations of Solar Flares and Coronal Mass Ejections

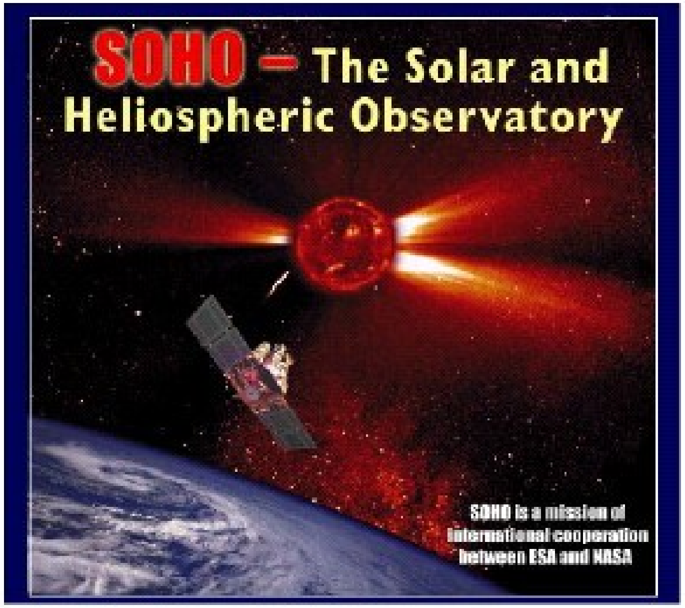
- Yohkoh, SOHO, TRACE

increasing evidence of magnetic reconnection and plasmoid ejections

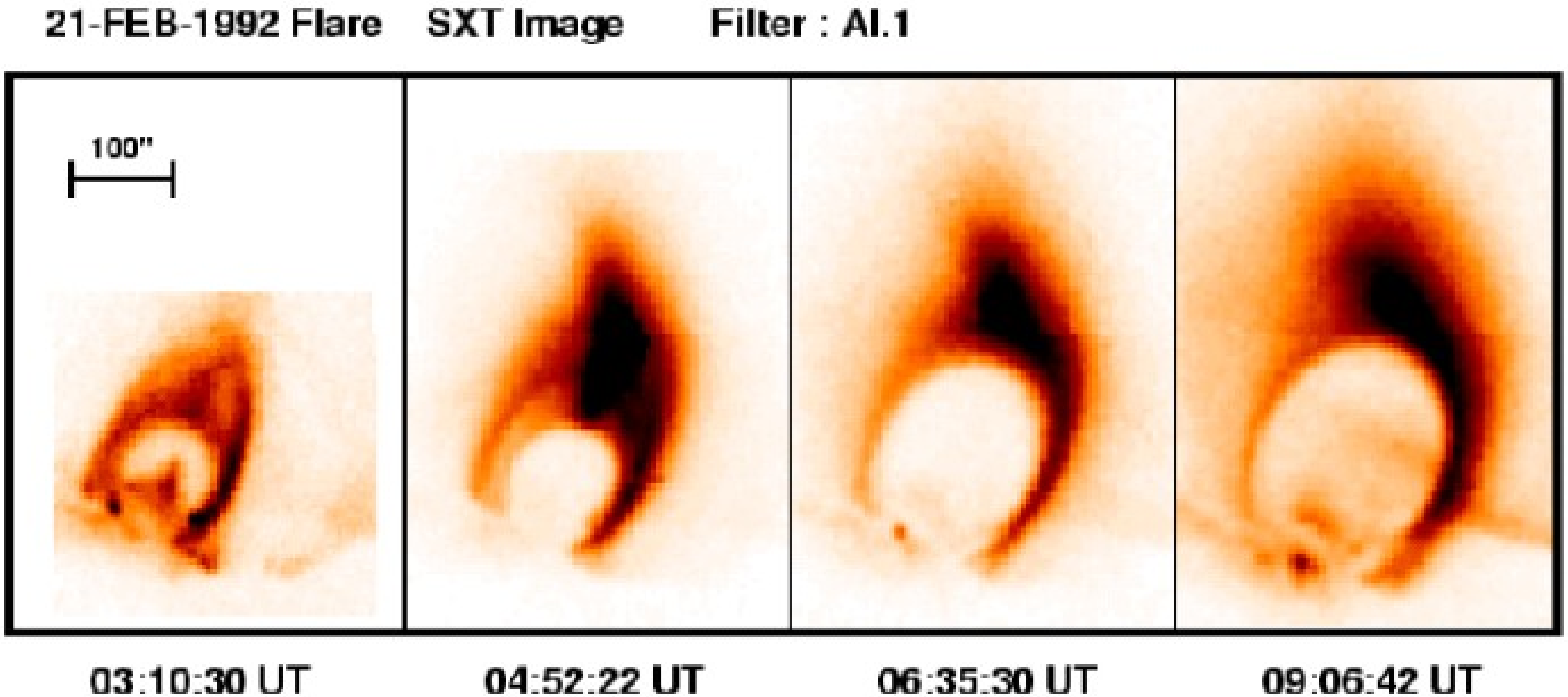
Yohkoh 1991

SOHO and TRACE

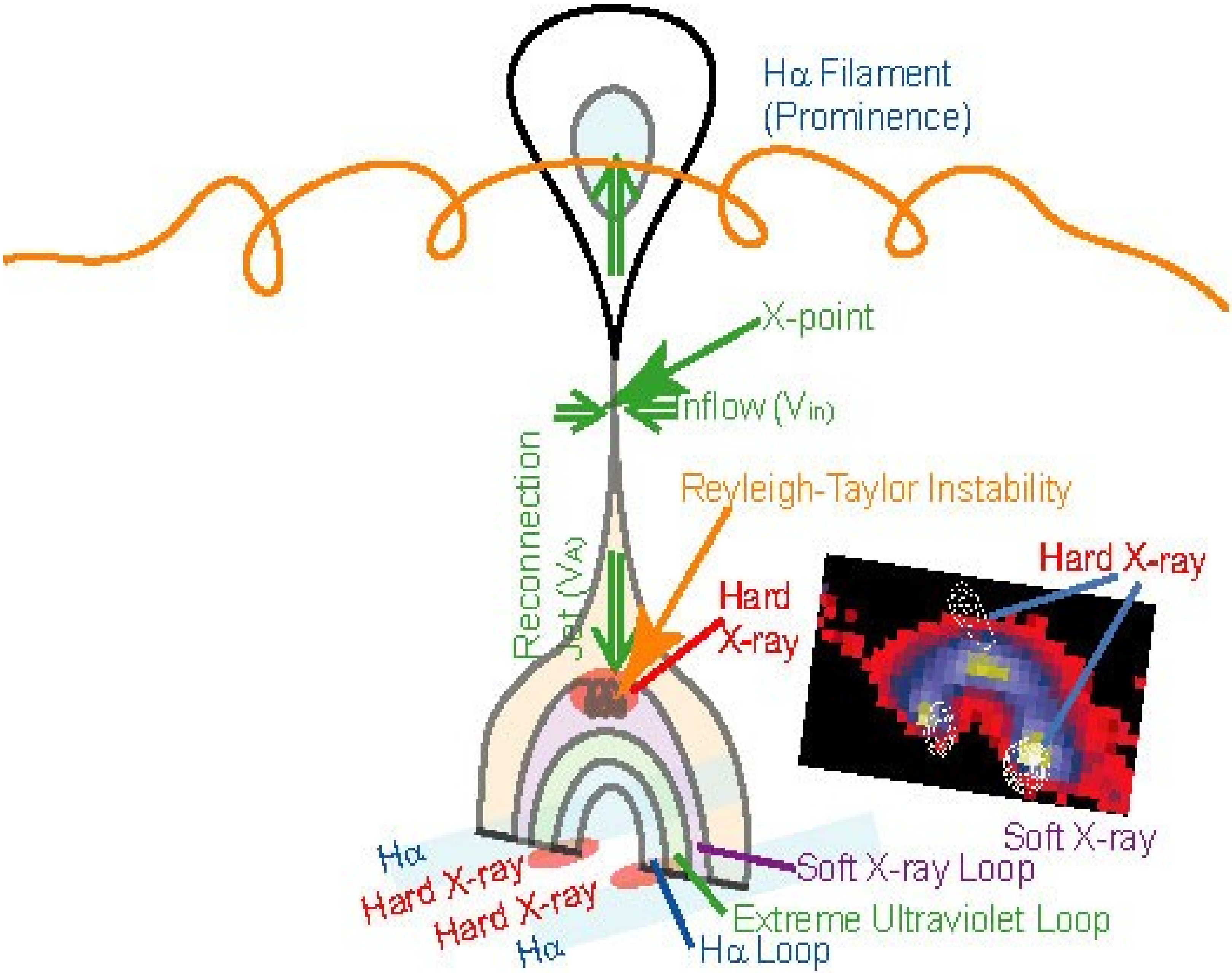
- 「SOHO」 launched 1995 Dec
  - Extreme Ultravilet Imaging Telescope (EIT)
  - Space coronagraph (LASCO)
  - SUMER, CDS, MDI, etc.
- 「TRACE」 launched 1998 Apr
  - EUV telescope



LDE (long duration event) flare (SXT, ～１keV、 Tsuneta et al. 1992)

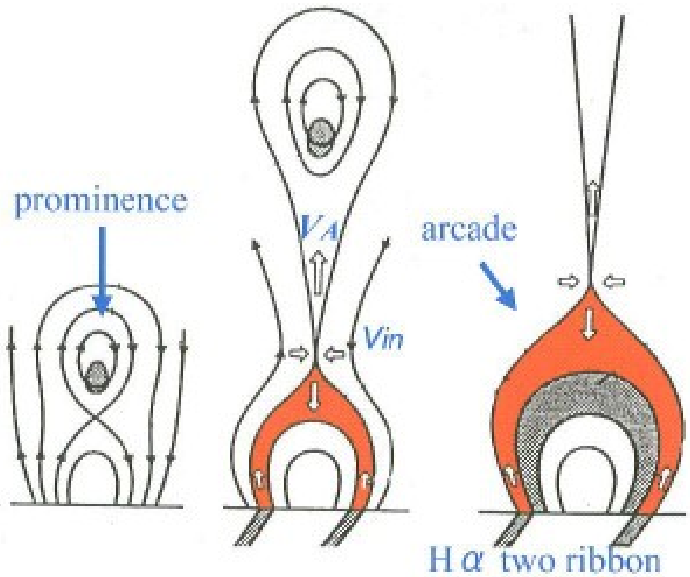


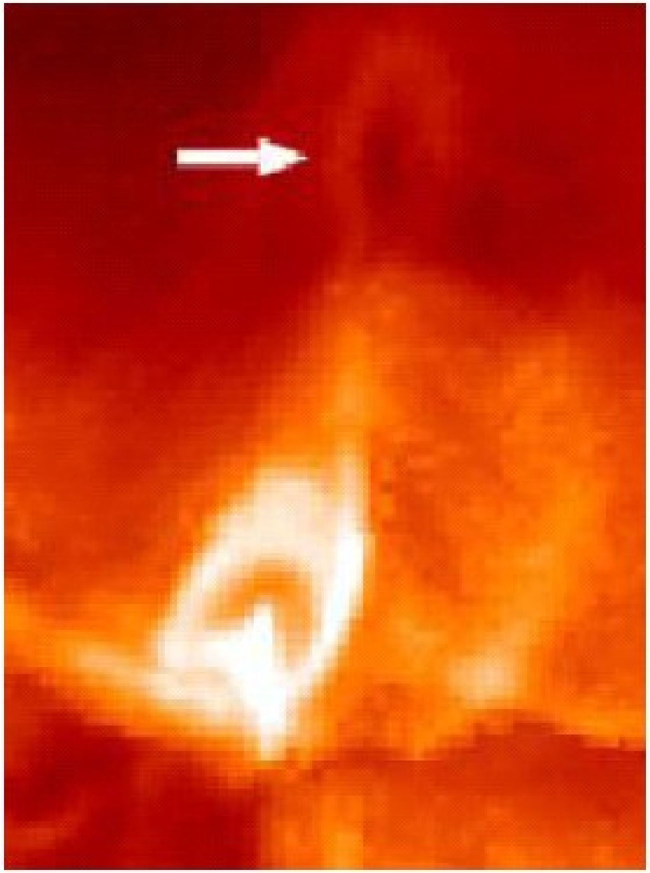
electron temperature ～１０＾７ K、
electron density～１０＾（１０）ｃｍ＾（－３）



Hα Filament
(Prominence)
X-point
Inflow (Vin)
Reconnection
Jet (VA)
Reyleigh-Taylor Instability
Hard
X-ray
Hard X-ray
Soft X-ray
Hα
Hard X-ray
Hard X-ray
Hα
Soft X-ray Loop
Extreme Ultraviolet Loop
Hα Loop

Plasmoid ejection associated with LDE (long duration) flare (Yohkoh/SXT)

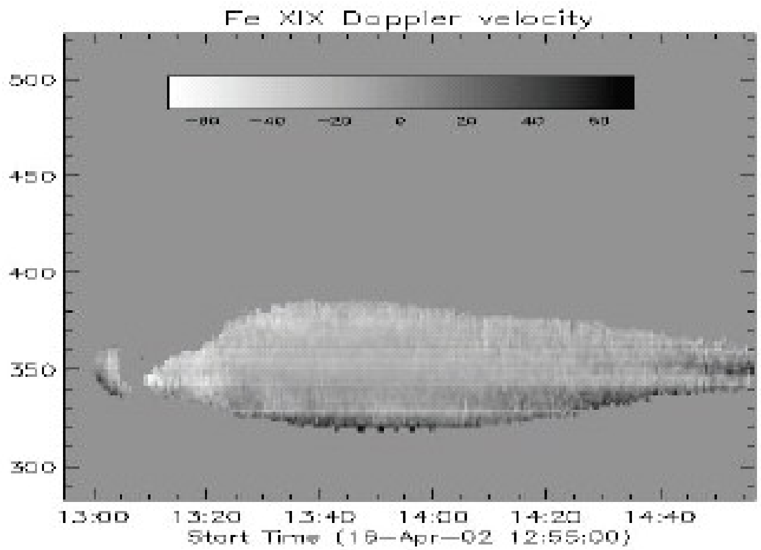




Note: there was no prominence eruption. Plasmoid speed is about ３００ｋｍ／ｓ

Evidence of erupting flux rope

Goff et al., 2005 found evidence for a flux rope leaving the Sun followed by a flare. The flux rope shows evidence of twist



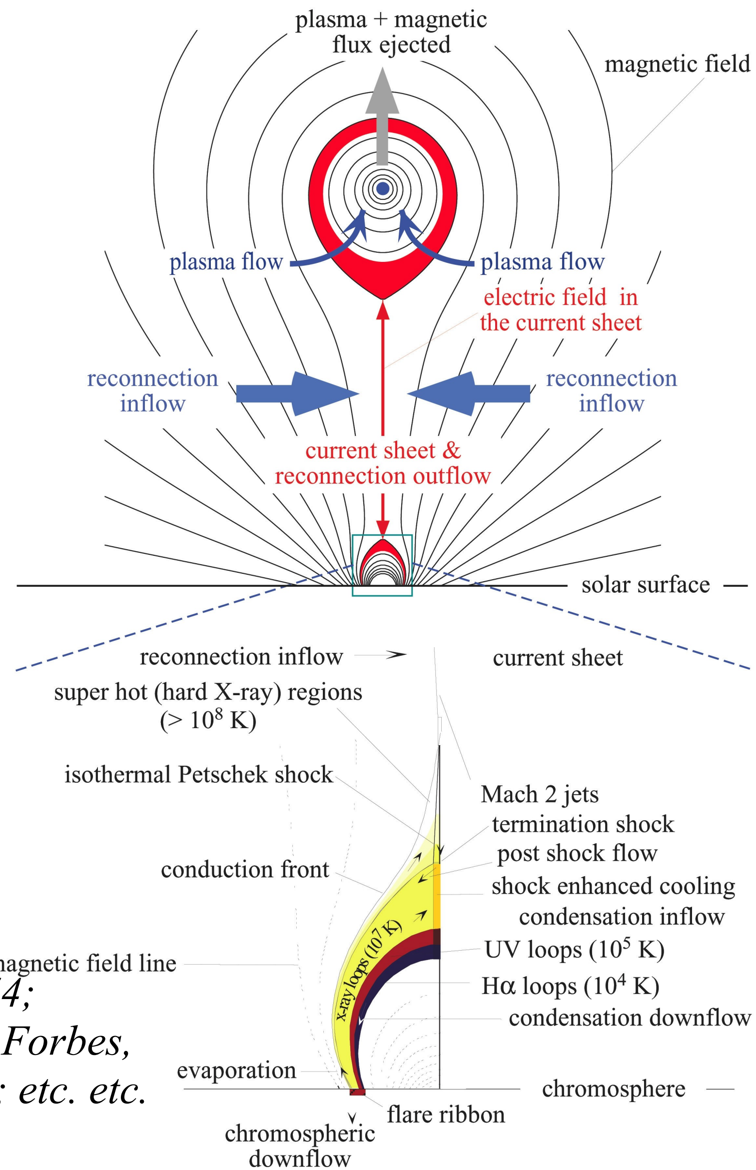
Basic questions about coronal mass ejections (CMEs)

- Are CMEs more important than flares ? (Gosling 1993)
- What is the relation between CMEs and flares ? Are CMEs different from flares ?
- Is reconnection important in CMEs ?

+ CME model

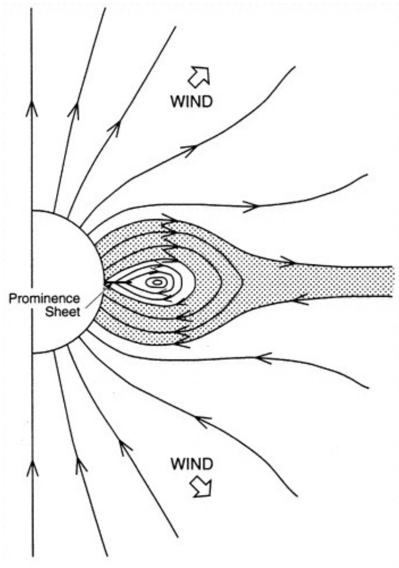
Unified CME-flare model

- CME: flux rope
- Flare
  - Coronal loop arcade
  - Hα flare ribbon
- Magnetic reconnection
  - Underneath the flux rope
  - Above the loop arcade
  - Current sheet
  - Reconnection inflow

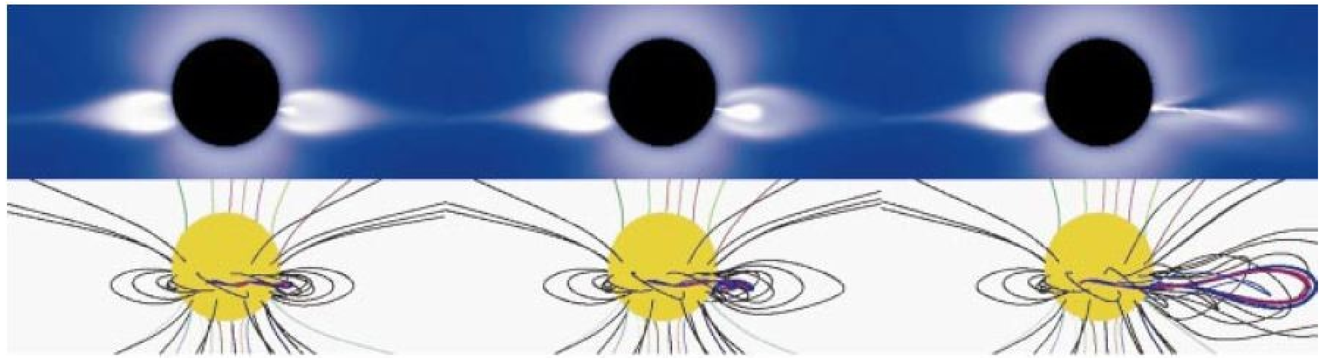


Carmichael, 1964; Sturrock, 1966; Hirayama, 1974; Kopp and Pneuman, 1976 and later by Priest and Forbes, 1990; Moore et al, 1992-2000; Shibata et al. 1999; etc. etc.

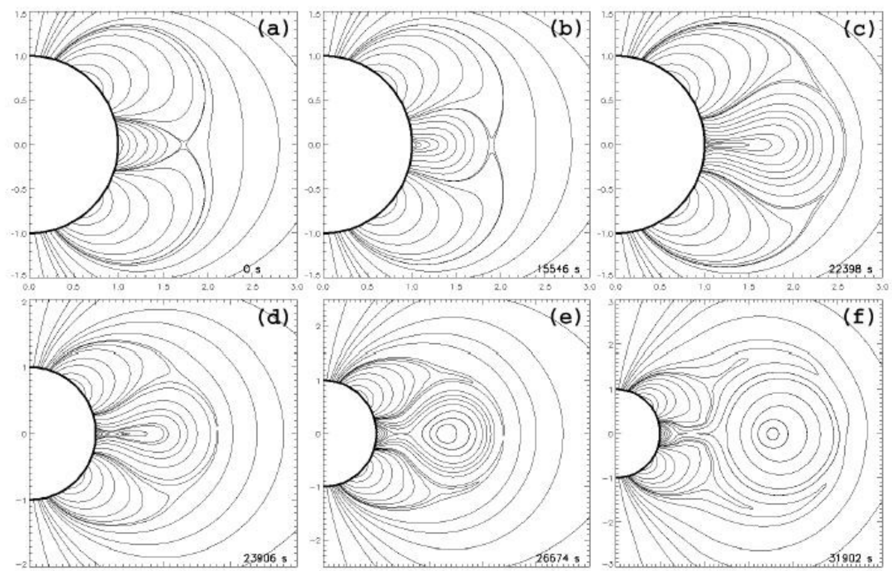
Uniting theme: Magnetic flux rope -- the question is, when does it form?



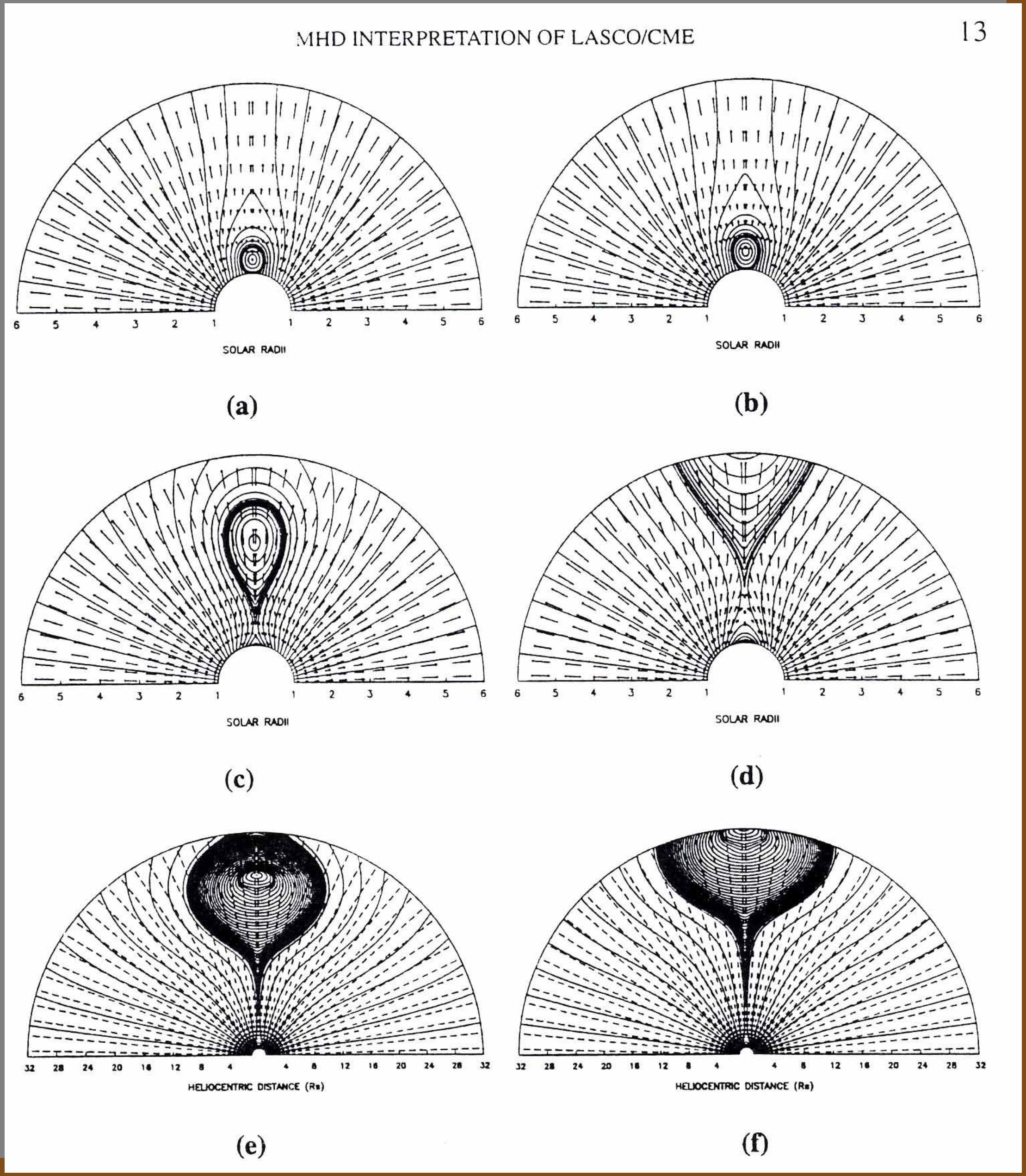
Low and Hundhausen, 1995



Linker et al., 2003



Lynch et al., 2004



2.5 D numerical simulations did quite well reproduce this type of classical CME.

The « ballooning » is due to the

***MAGNETIC BUOYANCY* effect.**

The CME is occuring above the line of polarity reversal

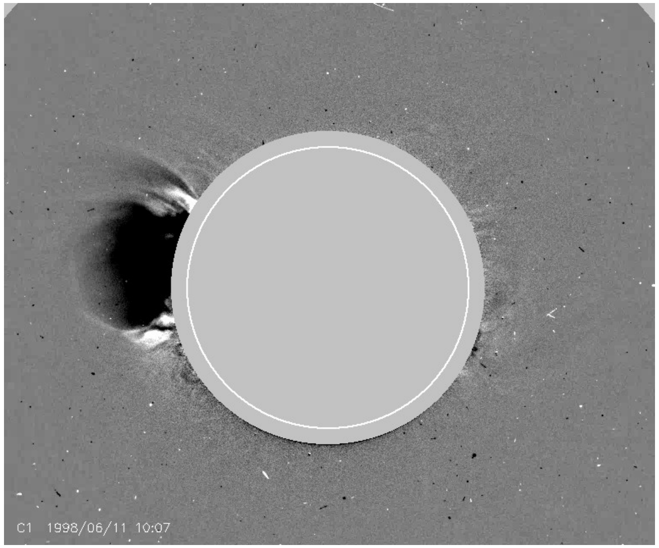
From Wu, Gao, Dryer et al. 1994- 98 ; Plunkett et al. 2000

CME

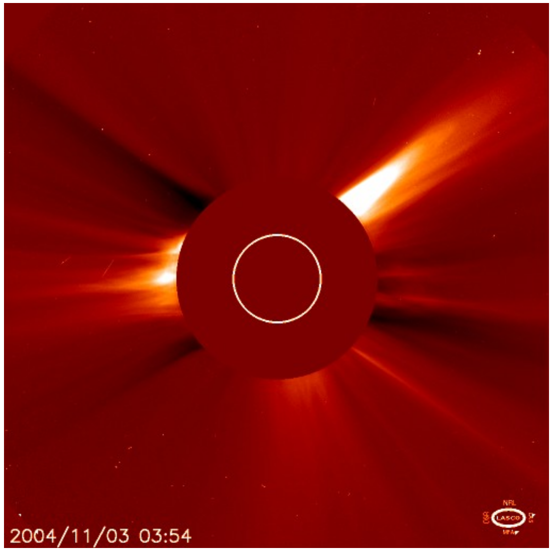
- A CME is a large scale coronal plasma and magnetic field structure ejected from the Sun
- A CME propagates into interplanetary space. Some of them may intercept the earth orbit if it moves toward the direction of the Earth
- CME eruptions are often associated with filament eruption

Coronagraph: LASCO

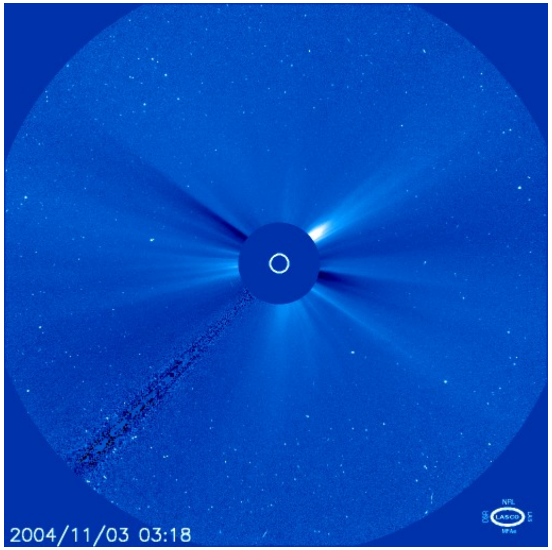
- C1: 1.1 – 3.0 Rs (E corona) (1996 to 1998 only)
- C2: 2.0 – 6.0 Rs (white light) (1996 up to date)
- C3: 4.0 – 30.0 Rs (white light) (1996 up to date)



C1



C2

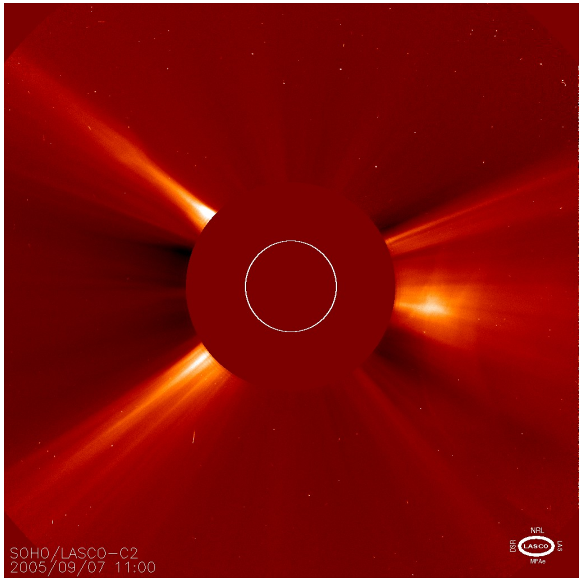


C3

- LASCO uses a set of three overlapping coronagraphs to maximum the total effective field of view.

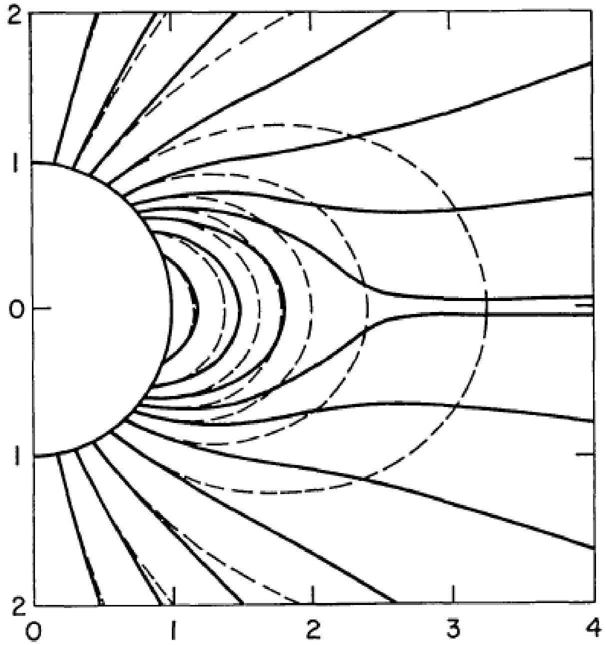
Streamer

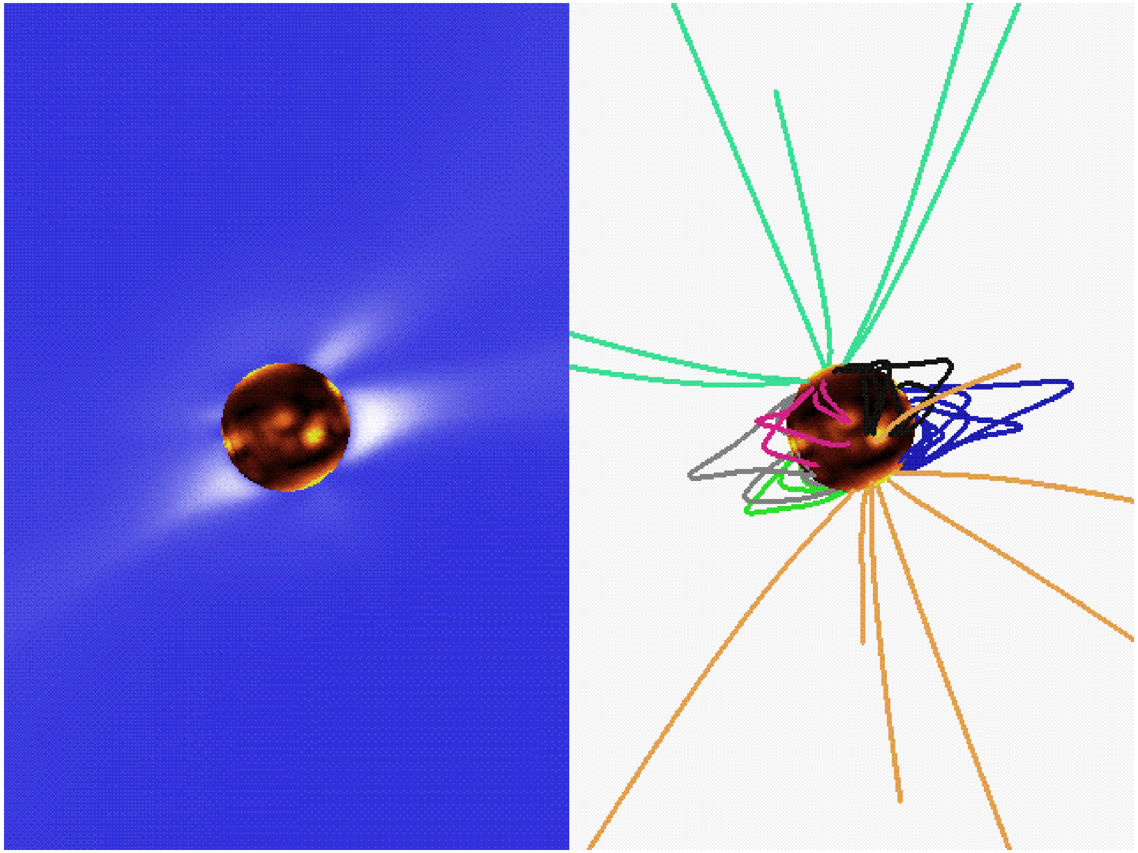
- A streamer is a stable large-scale structure in the white-light corona.
    - It has an appearance of extending away from the Sun along the radial direction
    - It is often associated with active regions and filaments/filament channels underneath.
    - **It overlies the magnetic inversion line in the solar photospheric magnetic fields**.



Streamer Structure

- Magnetic configuration
    - Open field with opposite polarity centered on the current sheet
    - Extends above the cusp of a coronal helmet
    - Closed magnetic structure underneath the cusp





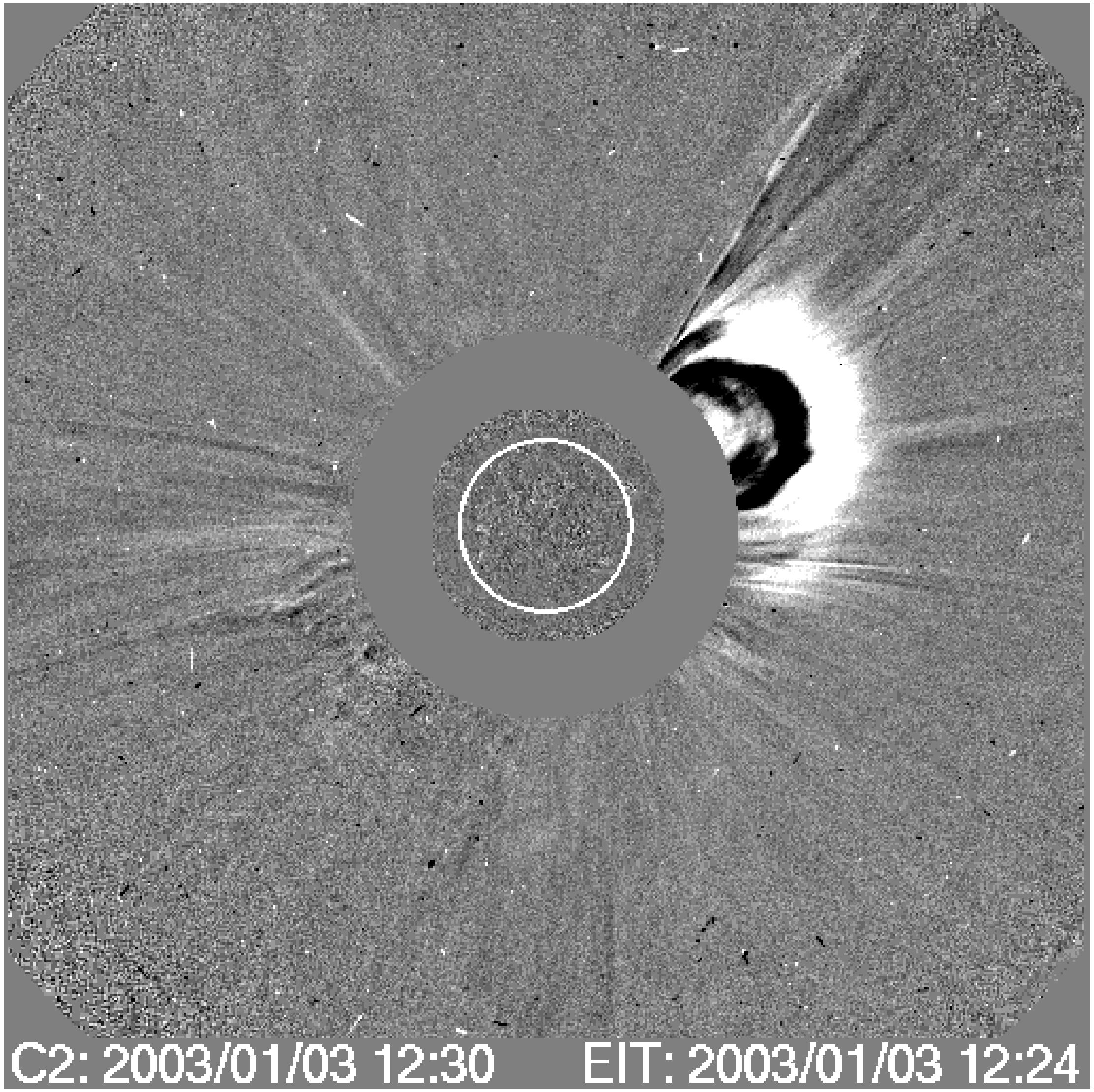
CME Properties

H (height, Rs)

PA (position angle)

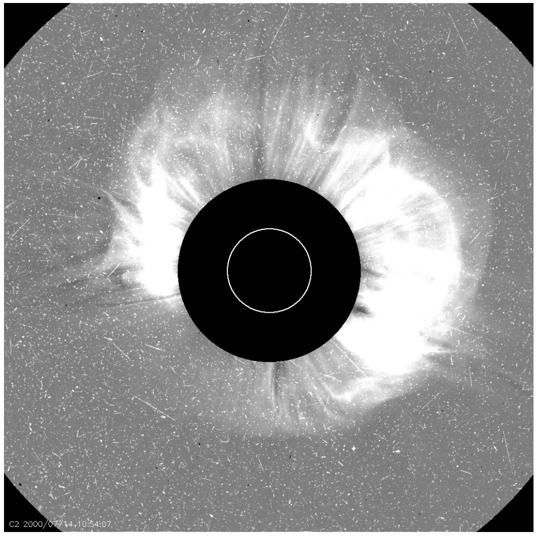
AW (angular width)

M (mass)



CME Properties

- Whether a CME is able to intercept the Earth depends on its propagation direction in the heliosphere.
- A **halo CME** (360 degree of angular width) is likely to have a component moving along the Sun-Earth connection line
- A halo is a projection effect; it happens when a CME is initiated close to the disk center and thus moves along the Sun-Earth connection line.
- Therefore, a halo CME is possibly geo-effective.



2000/07/14

C2 EIT