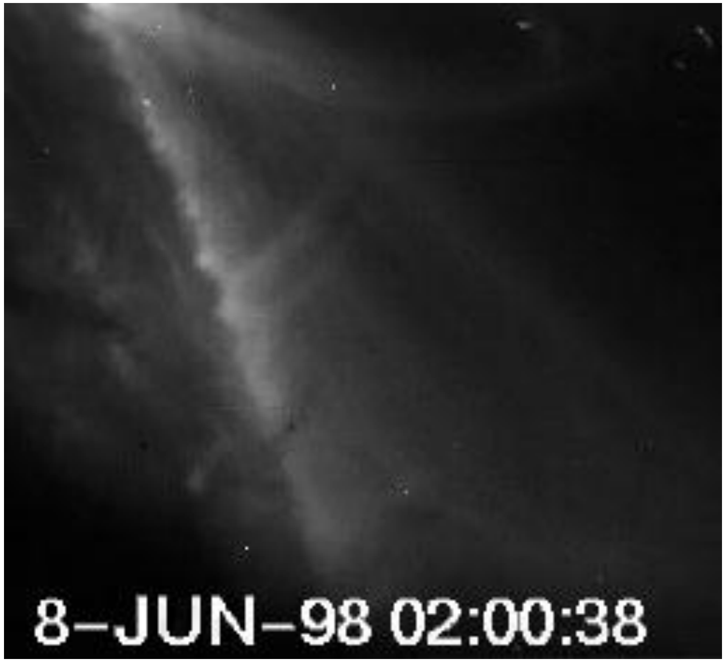
Active-region Dynamics, Flux Emergence, and Bright Points

Hiroaki Isobe (Kyoto Univ)

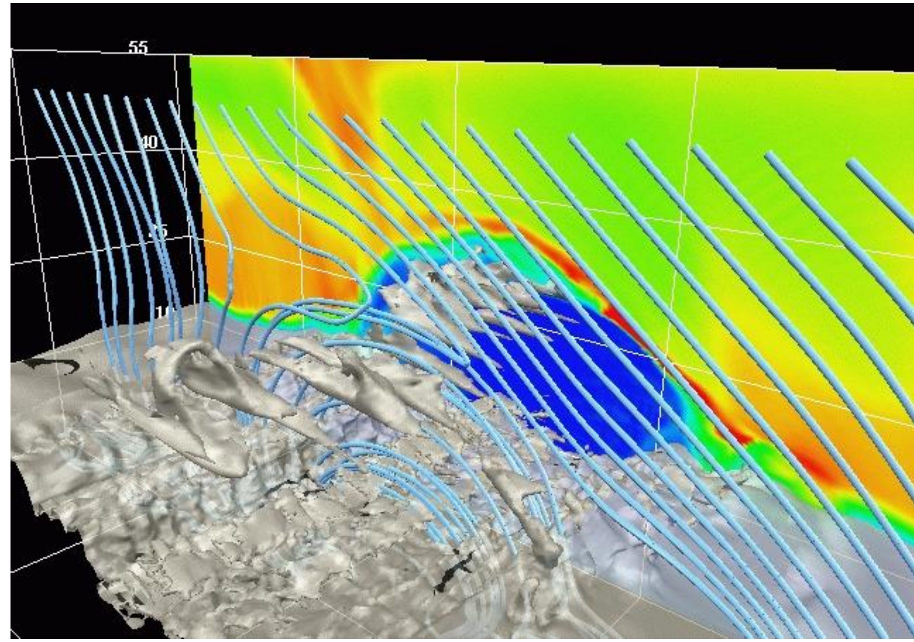
- Flux emergence
- Transient energy release events
- Challenges for cycle 24

Flux emergence

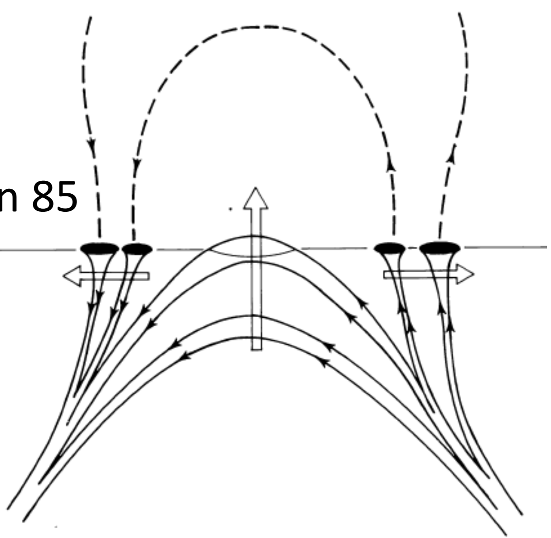
TRACE



Isobe+ 06



Zwaan 85



- Undular mode of magnetic buoyancy instability (Parker instability)
- Rise of Ω-shaped loop

Problems in current MHD simulations

- Scales too small
- Twist too much
- Effect of convection

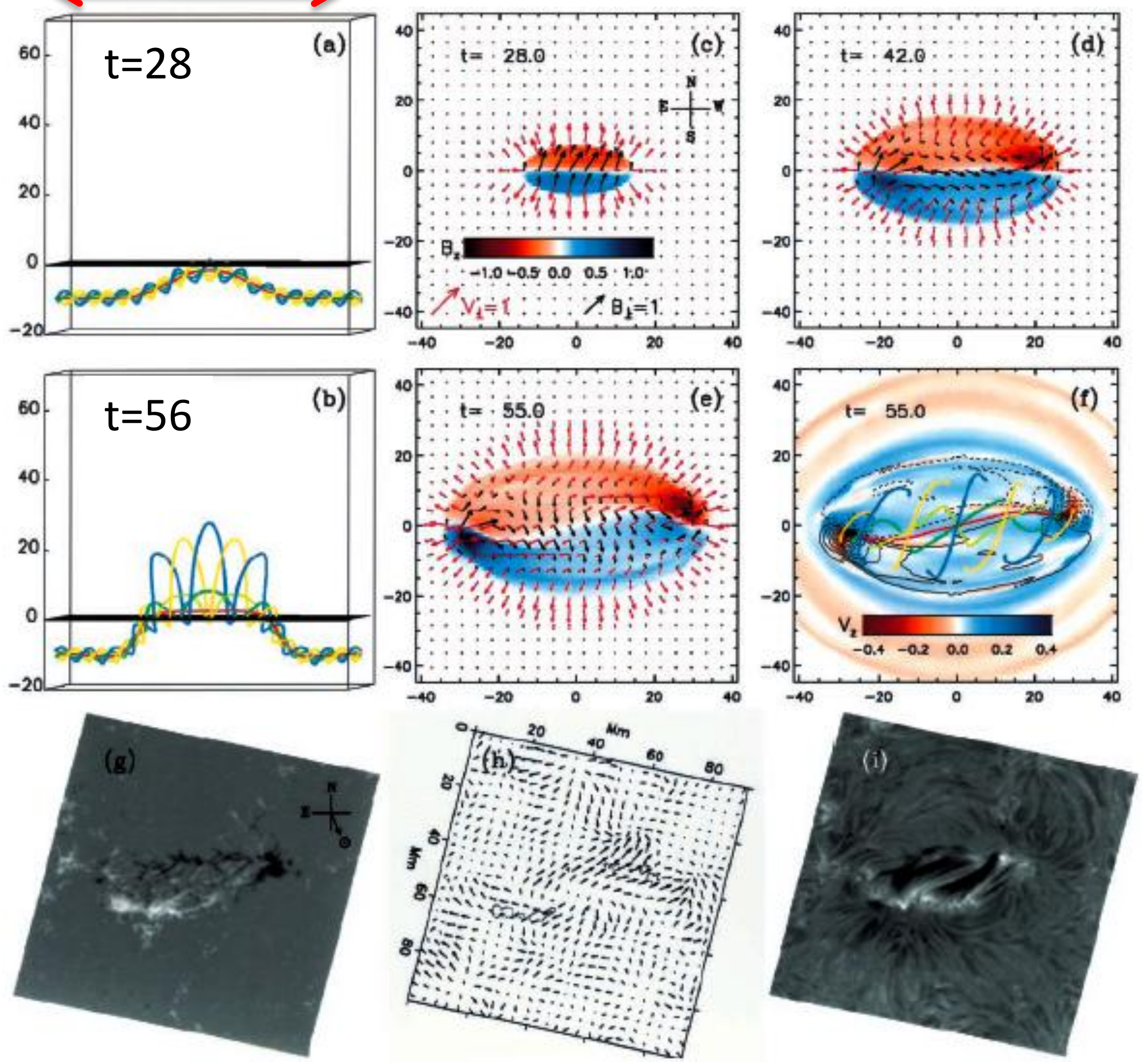
Spatial/temporal scales much smaller

- 3D MHD simulations reproduce very similar morphology

- MHD is scale-free.
- Normalized by
  - scale height H ≈ 150km
  - Sound speed Cs ≈ 10km/s
  - H/Cs ≈ 15s

- Simulations are 10 times smaller than big active regions

15,000 km ≈ 100H

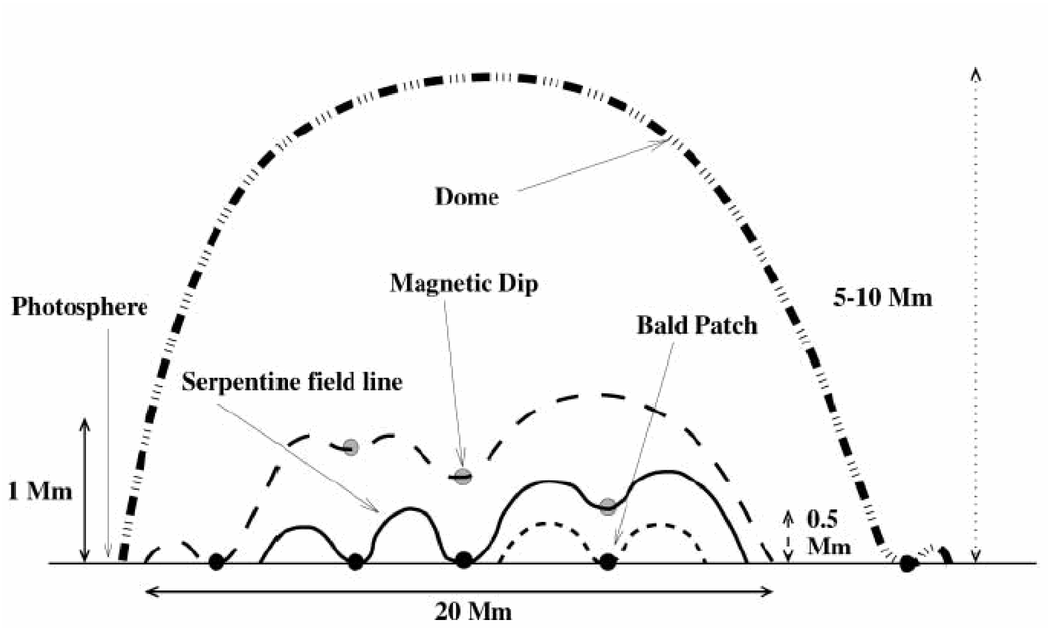


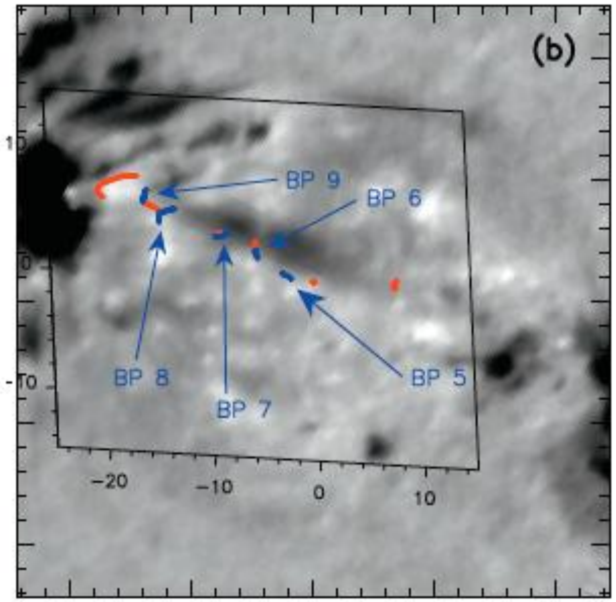
150,000 km ≈ 1000H

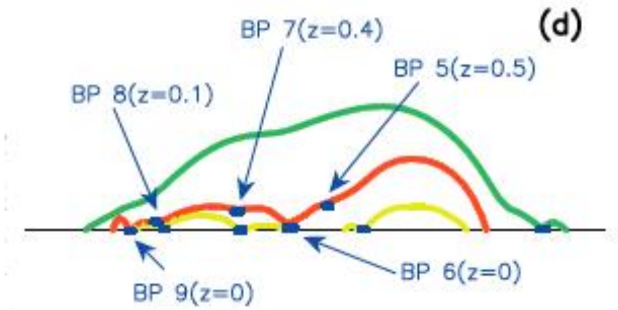
Fan 2001

Multiple loops and Ellerman bombs

- Parker instability has a characteristic length ≈ 20H ≈ 3Mm
- Emergences of multiple loops
- Reconnection between neighbouring loops







Pariat+ 04

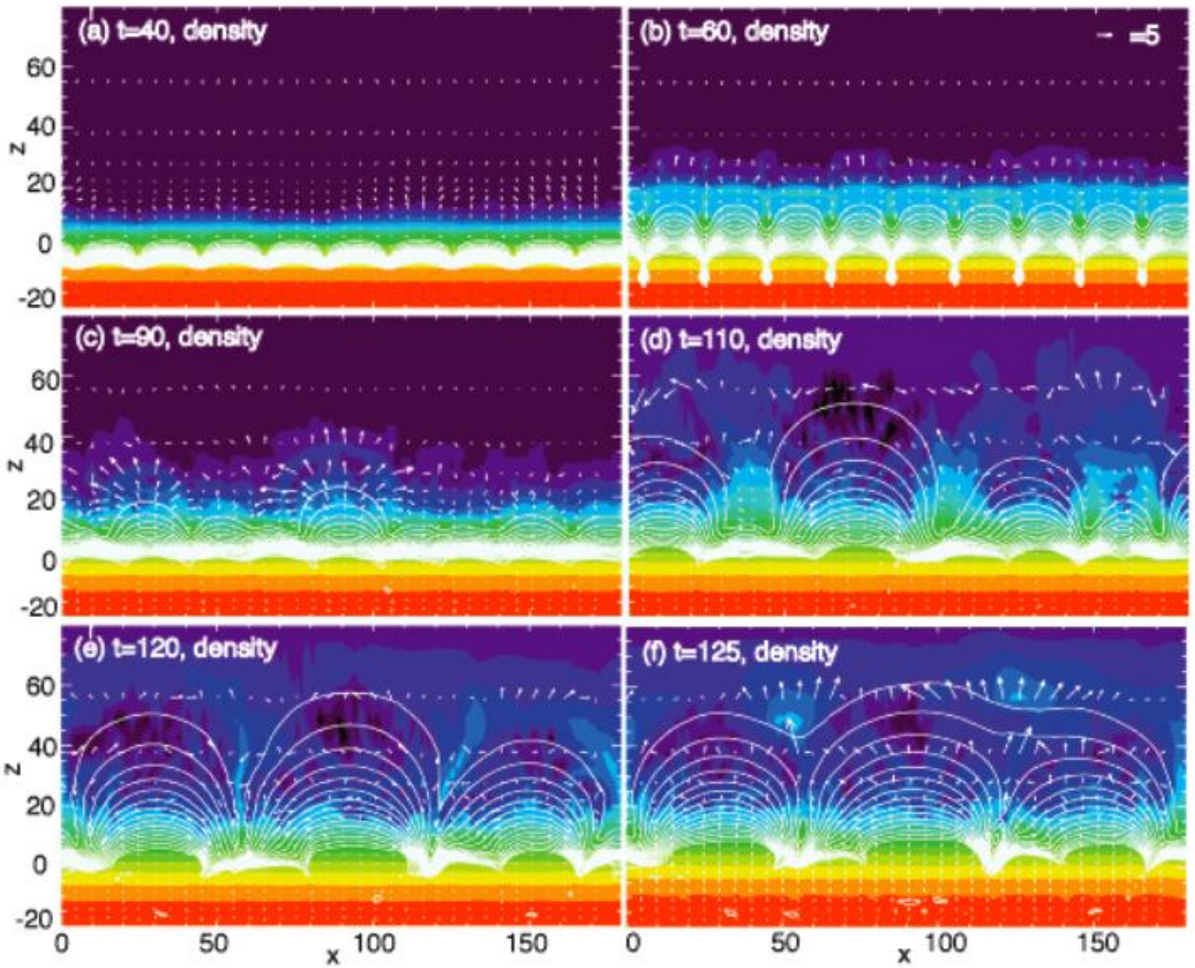
MHD simulation

Isobe, Tripathi & Archontis 07

- 2D flux sheet in CZ
- Box size ≈ 200H

- Emergence of Parker-size (≈ 20H) loops
- Reconnection in phtosphere
  =>EBs

- Secondary instability
- Reconnection in corona
  => jets

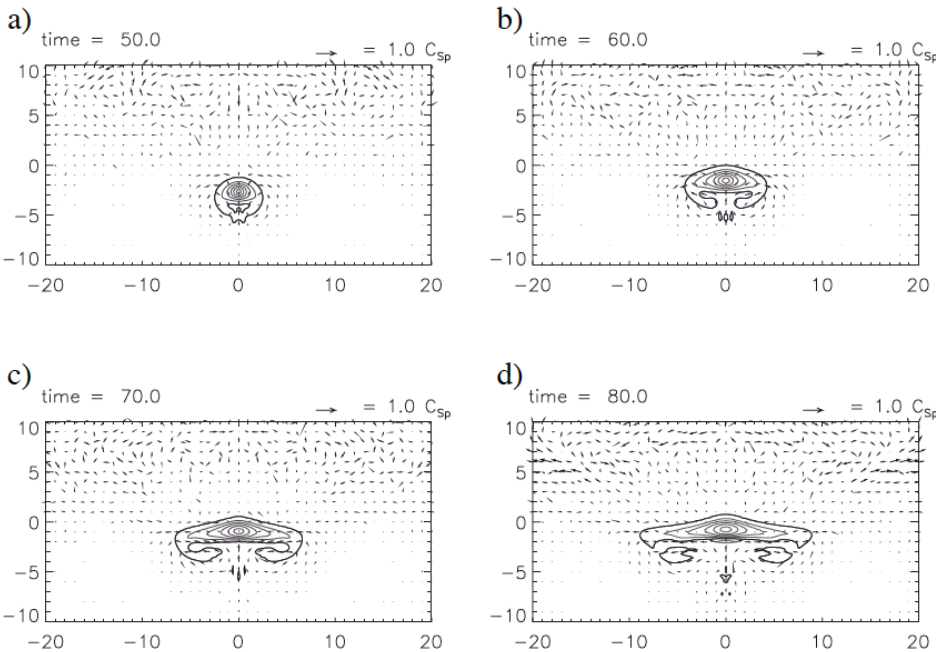


- Essential process to unload the dense plasma from field lines
- Current sheets and reconnections are natural and inevitable consequences

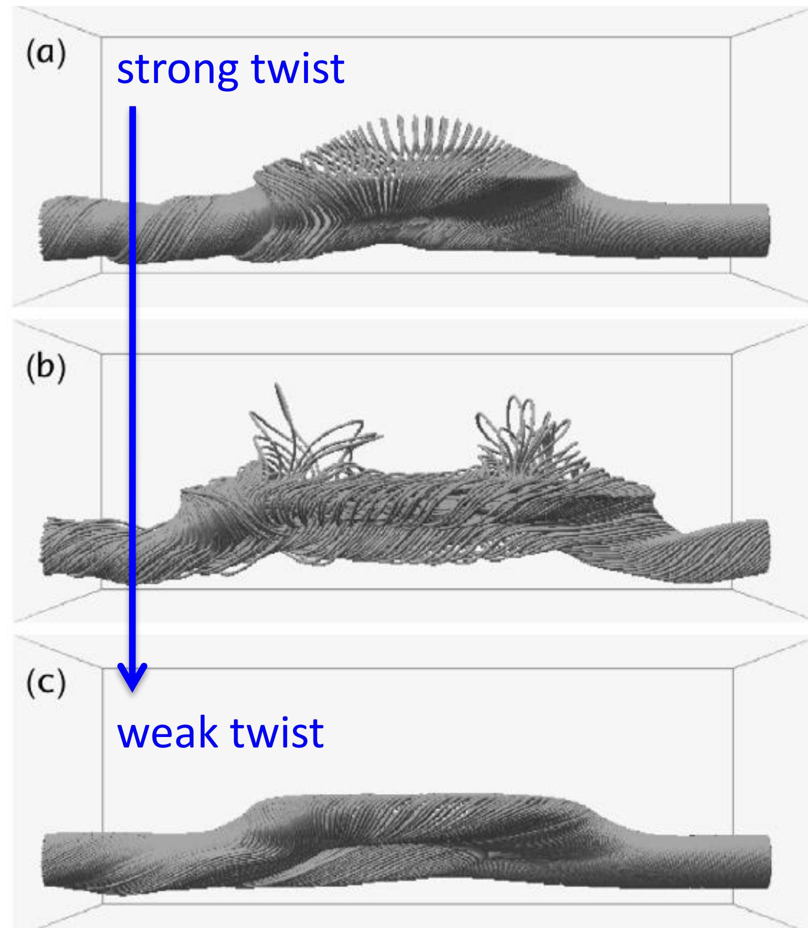
If twist is week

(say, <one turn along emerging part)

Murray+ 06



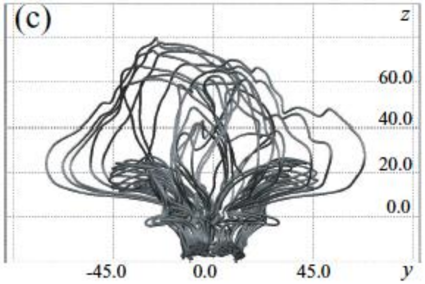
Magara 01

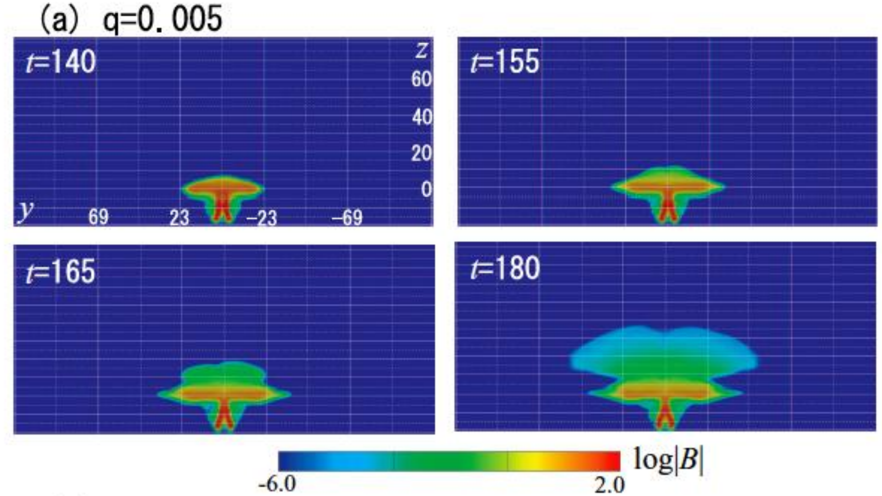


It expands in the photosphere and does not emerges immediately.

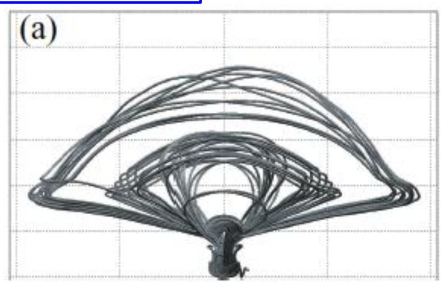
Miyagoshi, Isobe, Yokoyama & Shibata 09

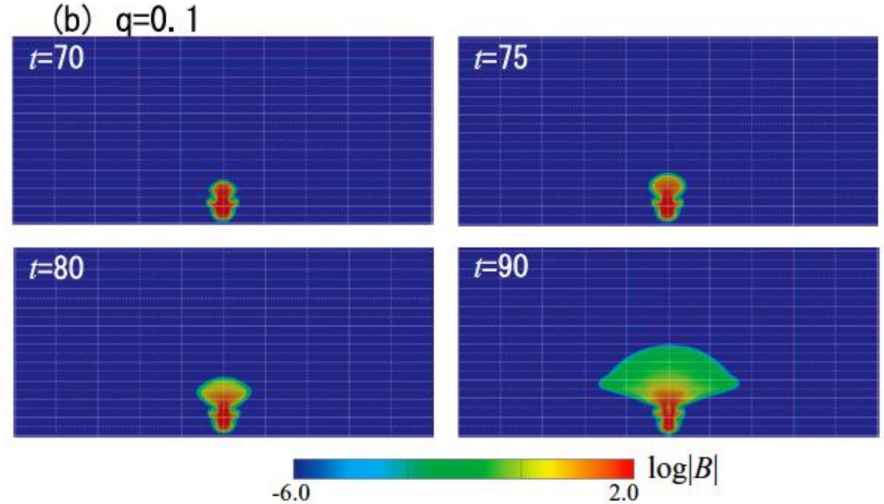
Weak twist





Strong twist





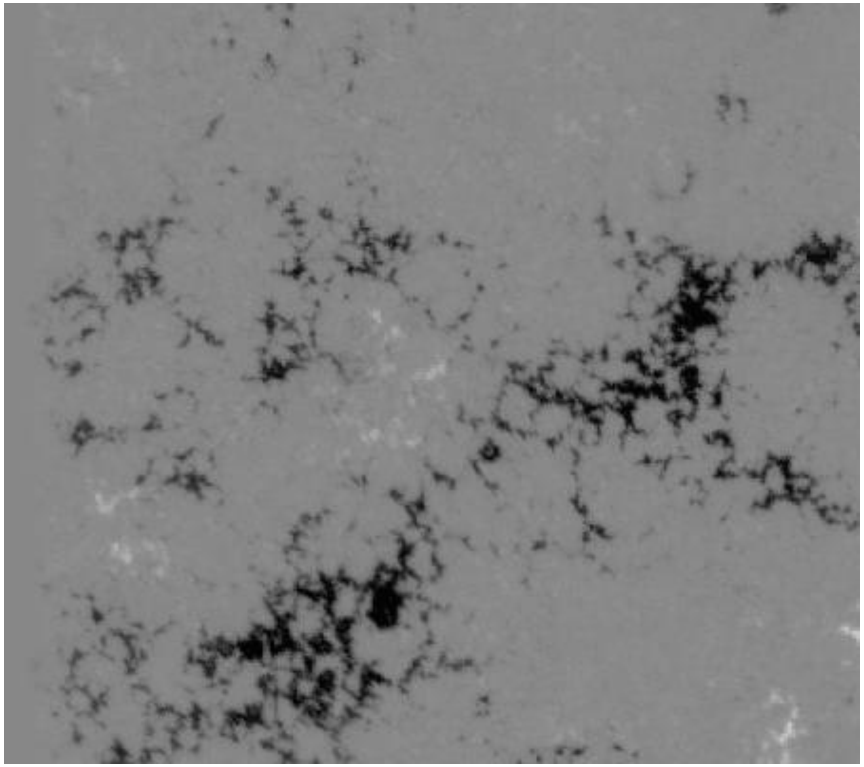
Emergence scenario of weakly twisted tube:

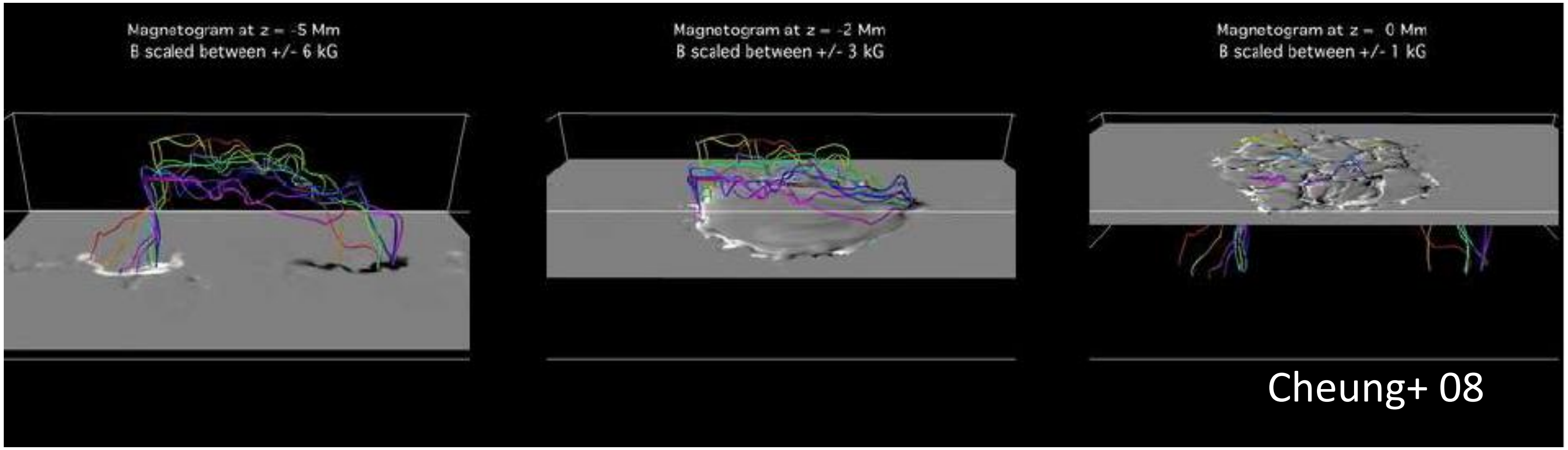
1. Expands horizontally in photosphere
2. Stay there while flux supply from below continues
3. Starts to rise again when secondary instability sets in (Acheson 79)

$$-H_{\rm p}\frac{\partial}{\partial z}(\log B) > -\frac{\gamma}{2}\beta\delta + \tilde{k}_{\|}^{2}\left(1+\frac{\tilde{k}_{\perp}^{2}}{\tilde{k}_{z}^{2}}\right)$$

Schmieder+

Sea of mixed polarity





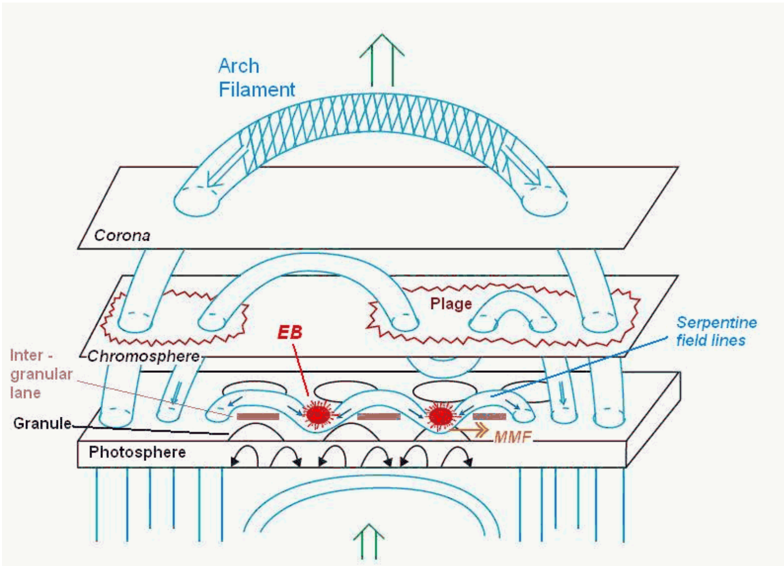
Cheung+ 08

Modern scenario of flux emergence

1. Omega-loop come from below to sub-adiabatic photosphere
2. Expands horizontally, fragmented by convection
3. Secondary instability in photosphere => multiple loop emergence
4. Reconnection between neighbours => EB, larger loops
5. Repeat the same processes in several stages

•Convection and Parker instability produces small scales and current sheets => heating events

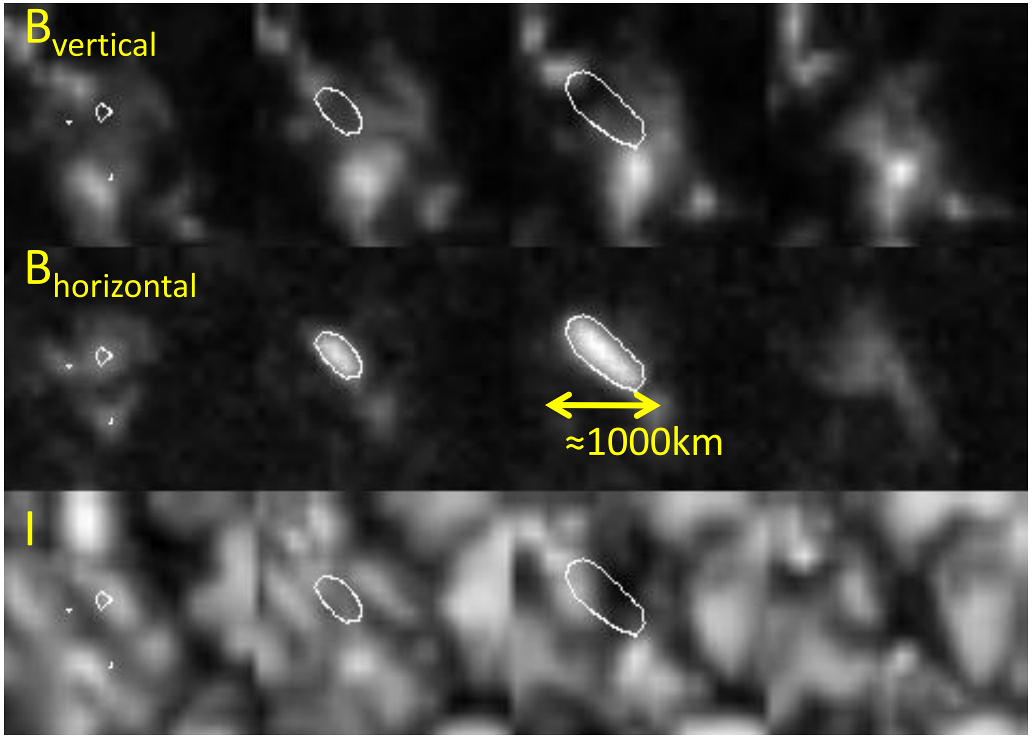
•Sub-surface structure still poorly understood



Schmieder 08

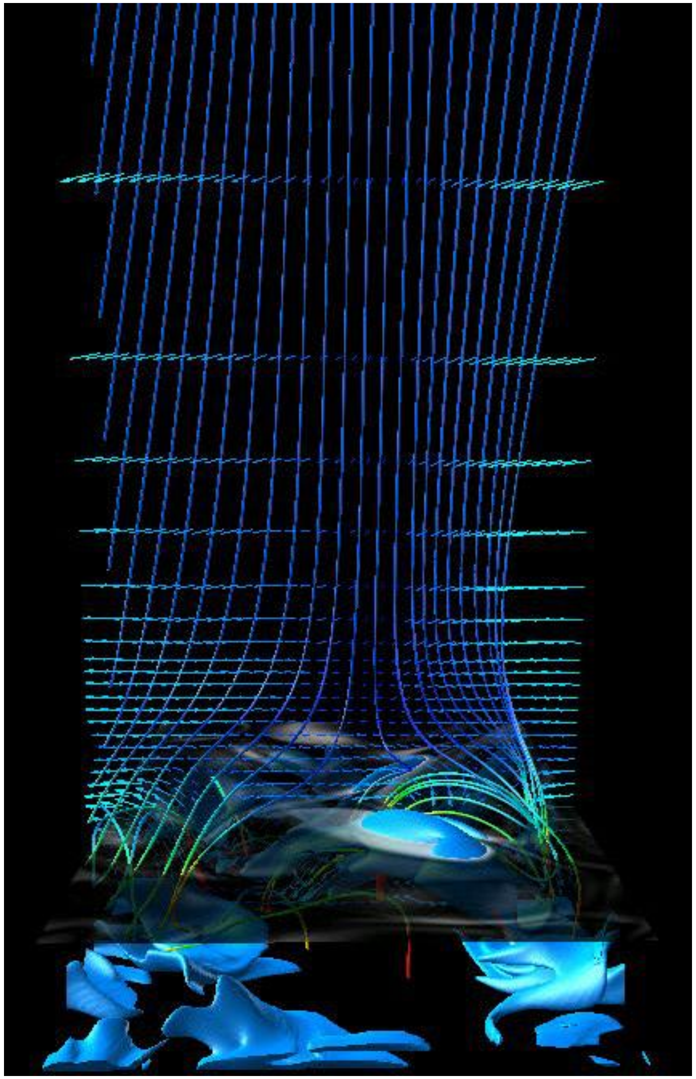
Granular-scale emergence

- Ubiquitous small-scale horizontal fields found by Hinode/SOT (Lites+ 2007)
- Granular scale emergences everywhere (Centeno+ 07, Ishikawa+ 08)
- Size < Parker length. Driven by upward convective flow.



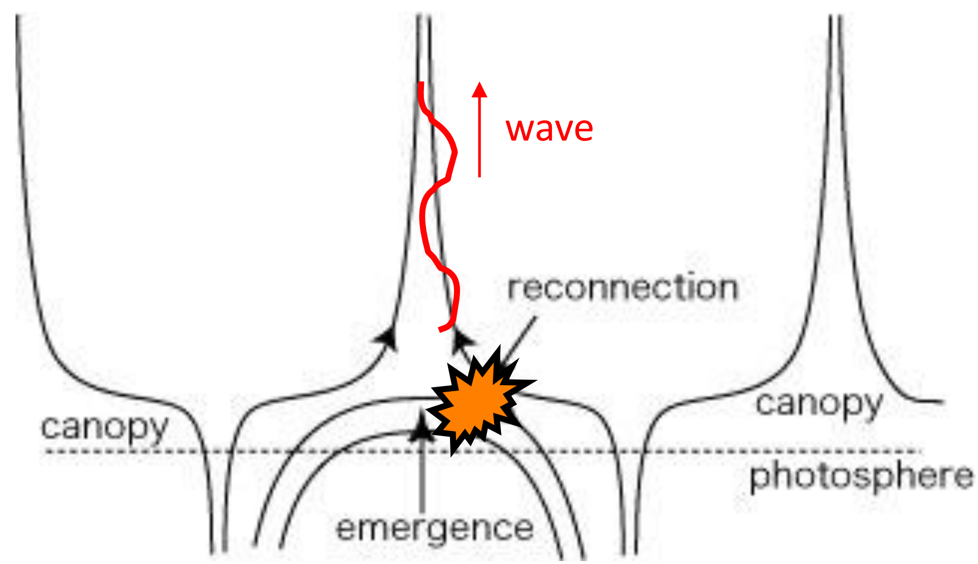
They have significant upward Poyinting flux $\approx 10^{6\text{-}7}$ erg cm^{-2} s^{-1};
(Ishikawa & Tsuneta 2009)

Granular-scale emergences and corona/solar wind

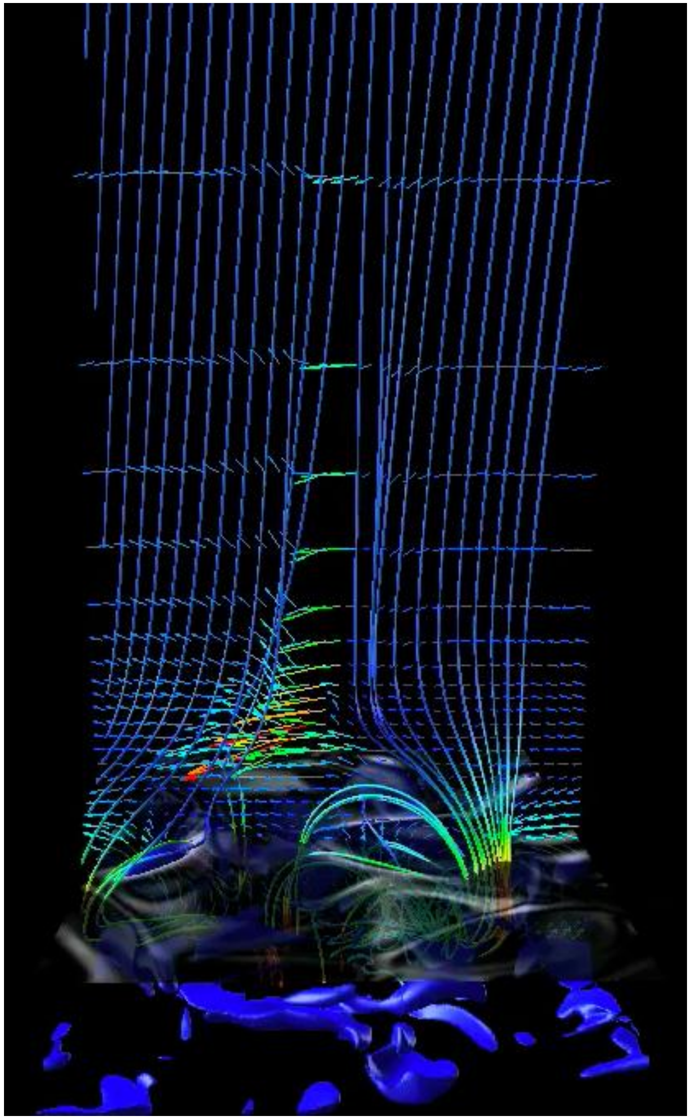


Isobe, Proctor & Weiss 2008

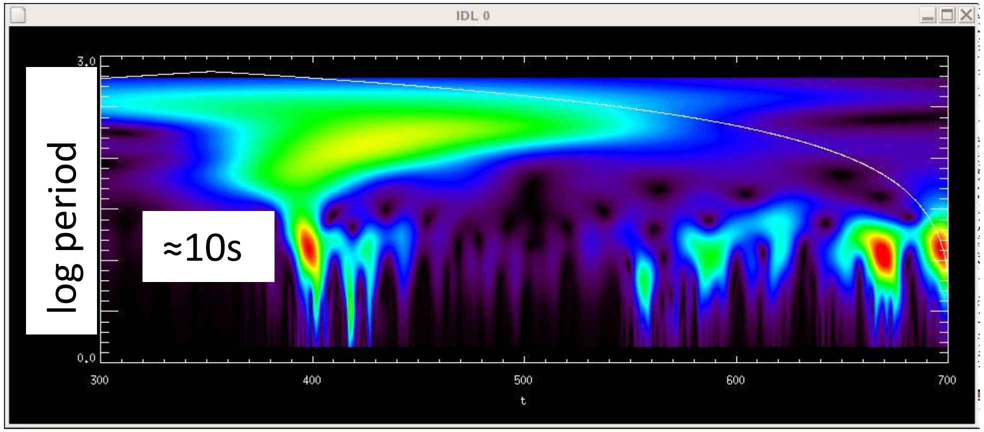
- Cannot reach the corona by itself
- Energy can be transported via interaction with vertical flux



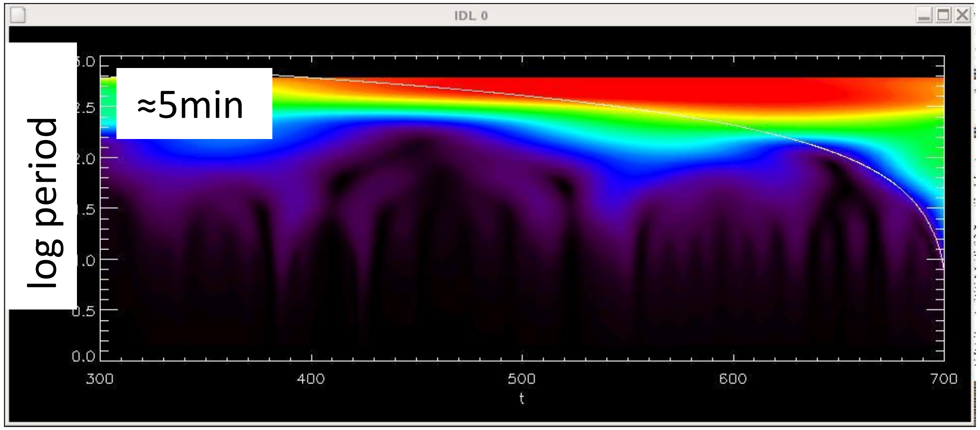
Chromospheric reconnection produces high-frequency waves



Wavelet spectrum of Vx in corona

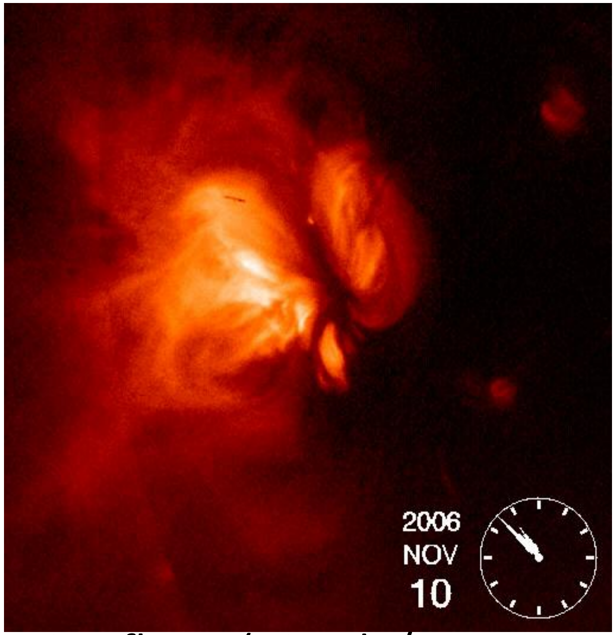


Wavelet spectrum of Vx in photosphere

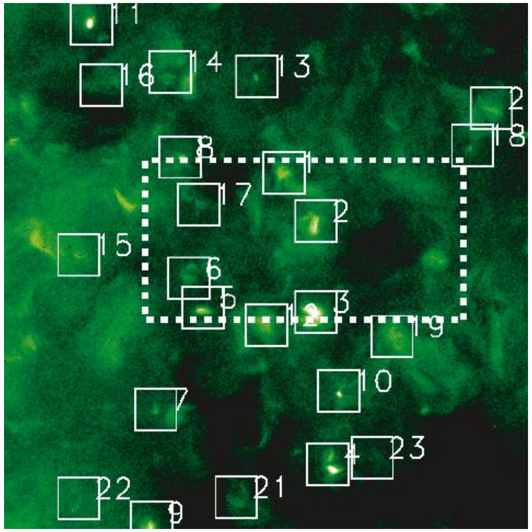


Frequency of wave depends on detail of reconnection

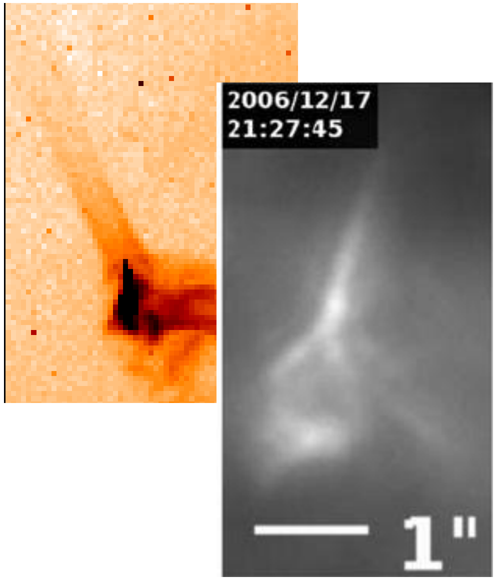
Transient energy release events



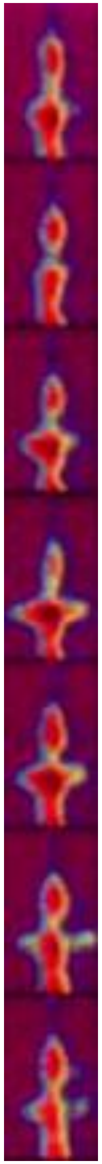
Microflares (Hinode/XRT; Kano+)



XBPs (Kotoku+ 07)

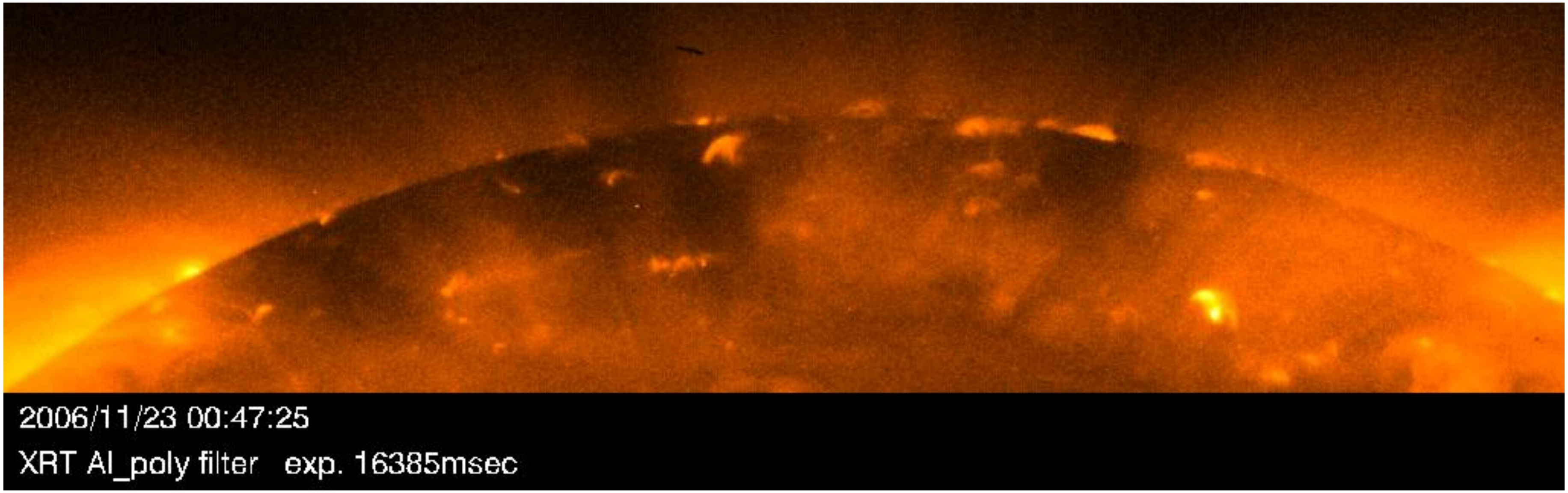


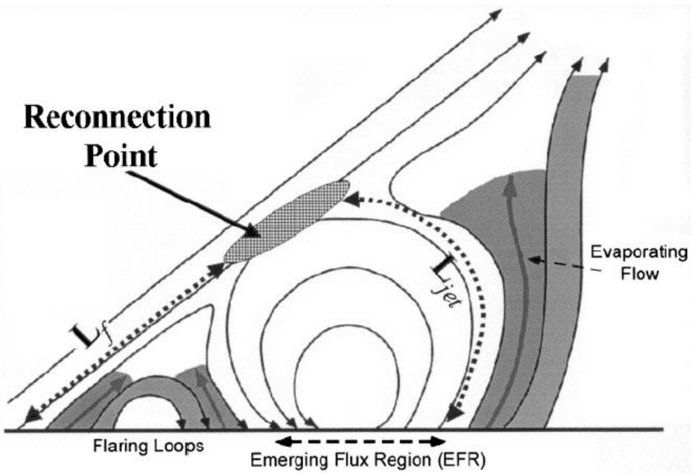
Jets (Shibata+ 92, 07)


TR explosive event (Innes+ 97)

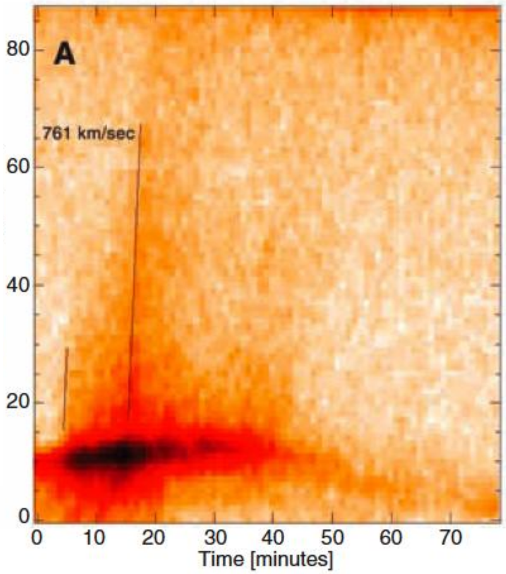
- Diverse morphological/spectral features
- Most (almost all) models invoke magnetic reconnection
  - driven by flux emergence, flux cancellation and shear motion

Coronal jets



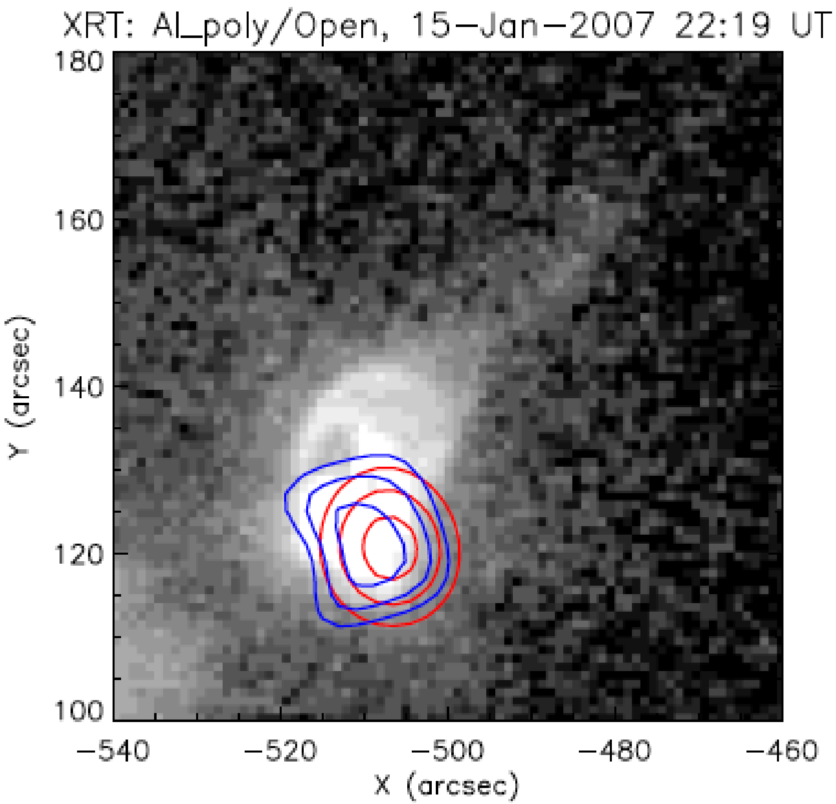


Shimojo & Shibata 00

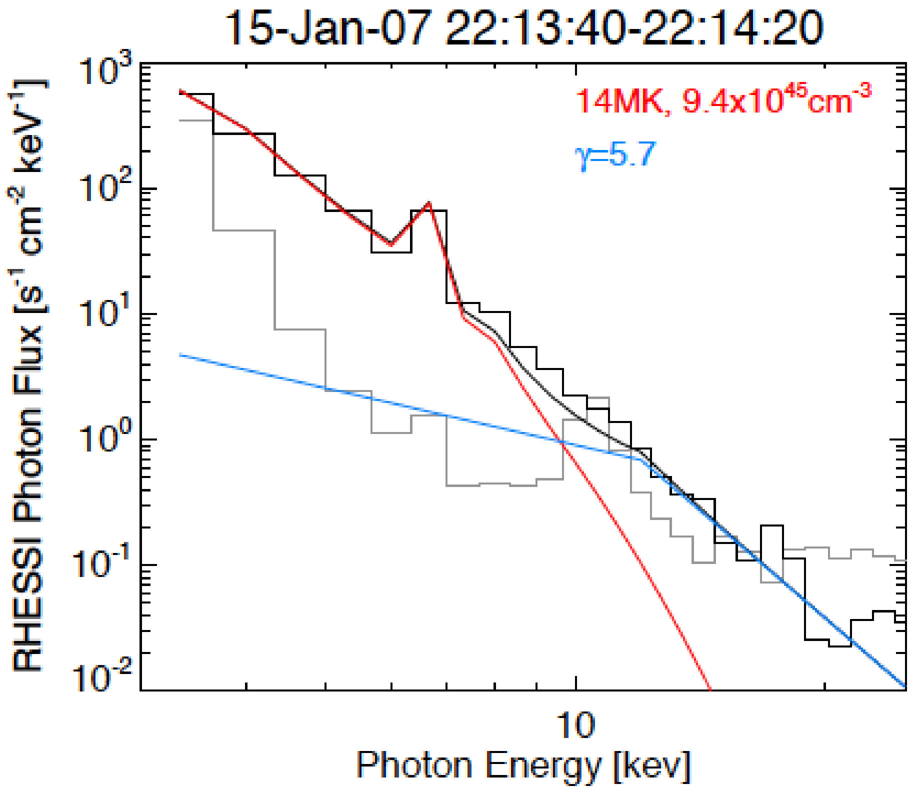


- Two compornents: Alfvenic jet (≈800 km/s) and evaporation jet (≈ sound speed ≈ 200 km/s)
  (Cirtain+ 07)

Multi-wavelength obs: HXR

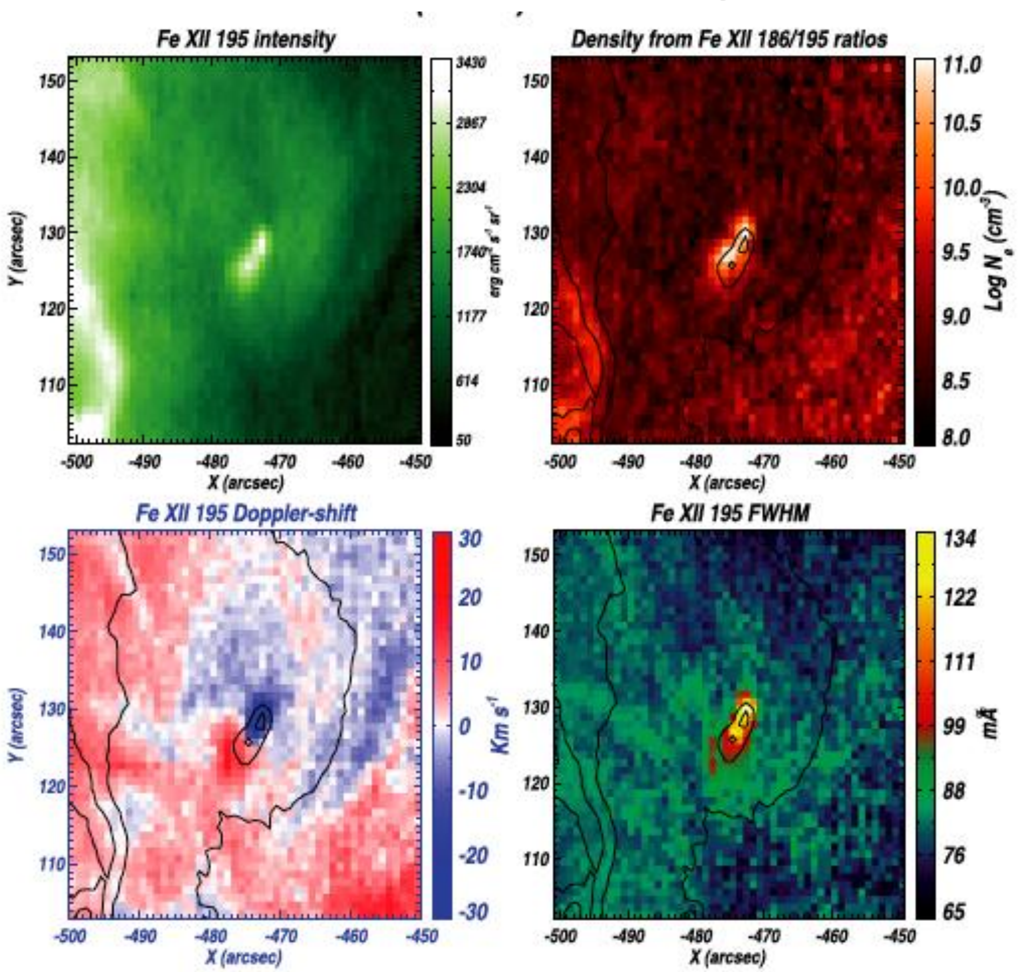


RHESSI 4-6keV 12-16keV

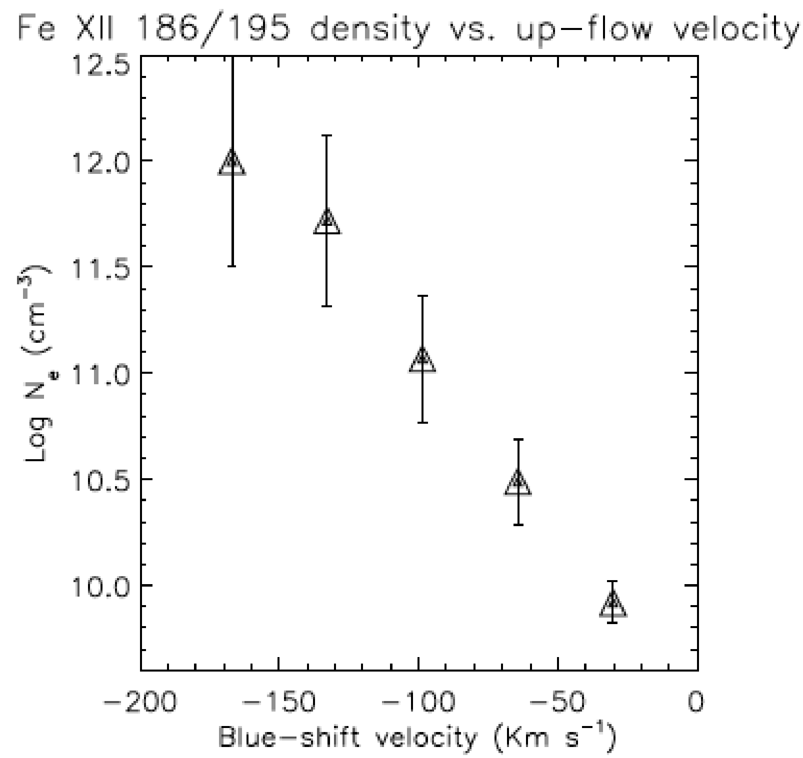


- High energy, possibly non-thermal component
- Reconnection point is in corona

Multi-wavelength obs: EUV spectroscopy



Hinode/EIS



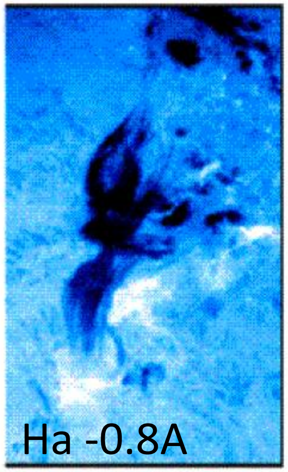
Positive correlation between jet velocity and density

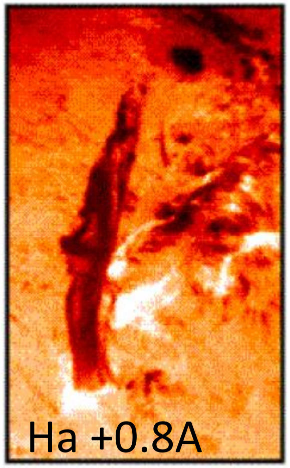
✖ Alfvenic reconnection jet

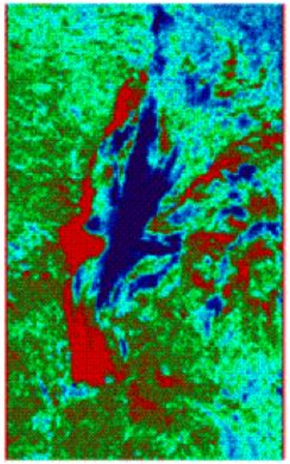
○ Evaporation jet (Shimojo+ 01)

Twisting jets: Observations

H-alpha (Hida/DST; Kurokawa+ 84)

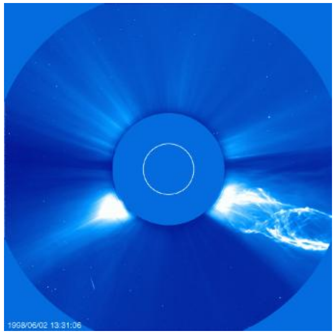




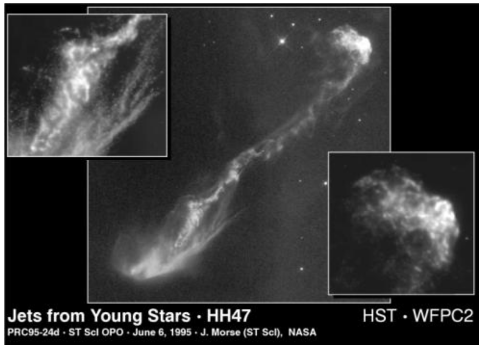


TR (CDS, OV; Pike & Mason 98)

Corona (FeXII, STEREO/EUVI; Patsourakos+ 08)



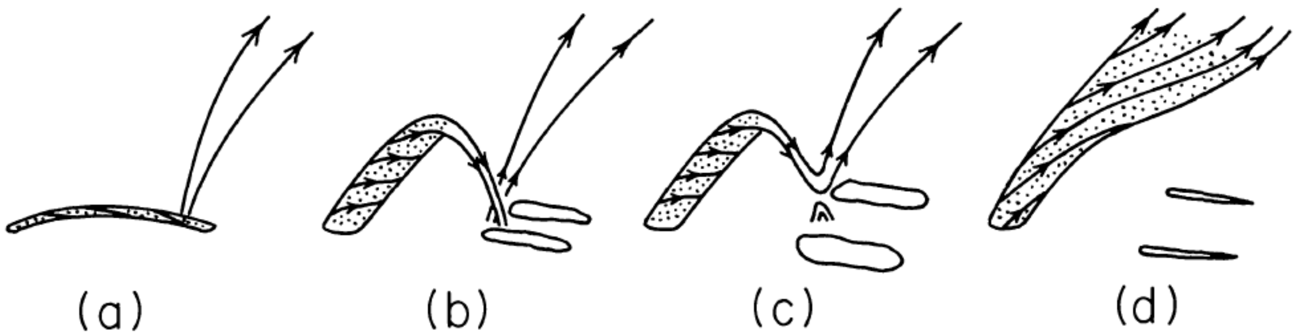
CME (LASCO)



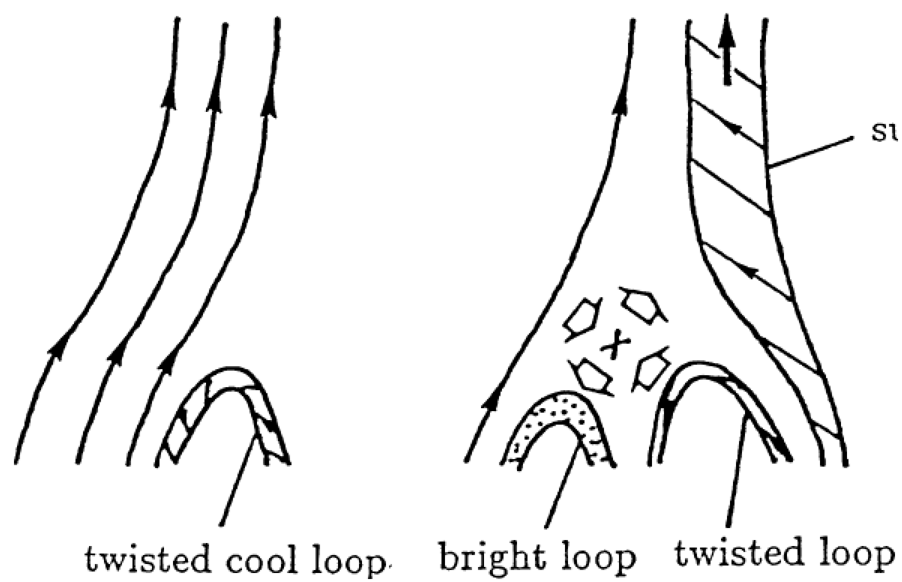
YSO jet (HST)

Twisting jets: Cartoon models

Reconnection between twisted (emerging) tube and open field



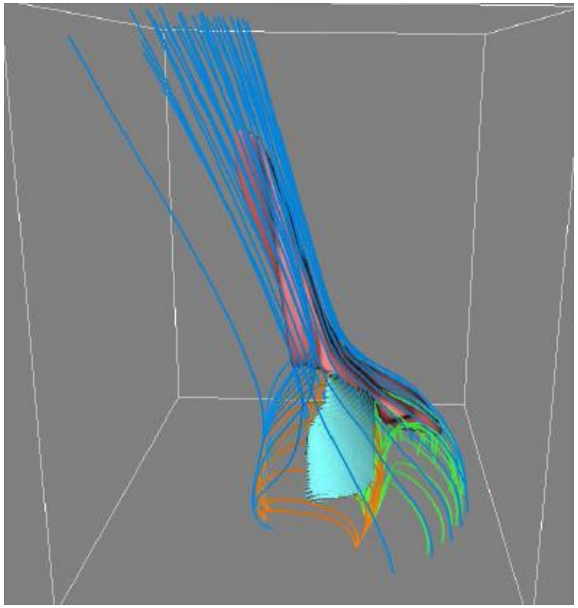
Shibata & Uchida 86



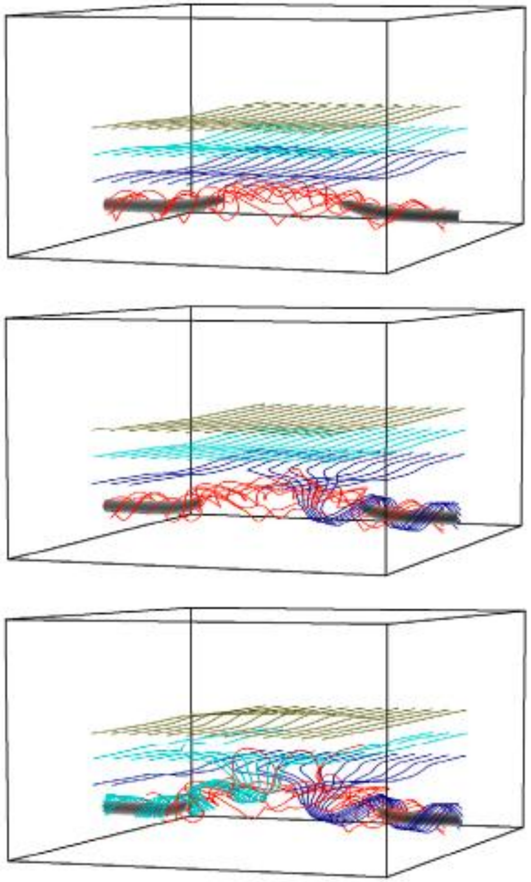
Schmieder+ 95

Twisting jets: MHD simulations

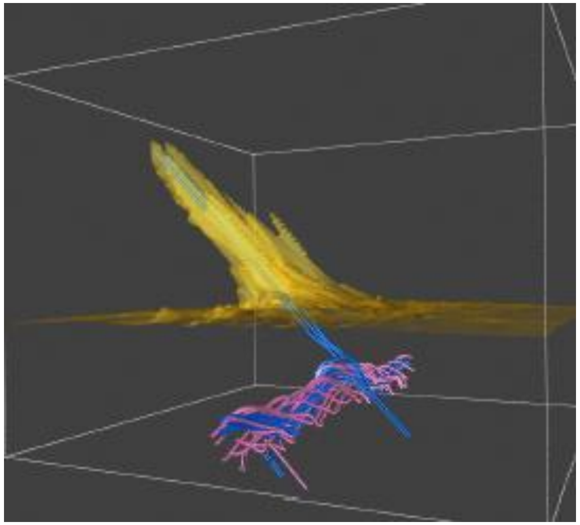
Moreno-Insertis+ 08



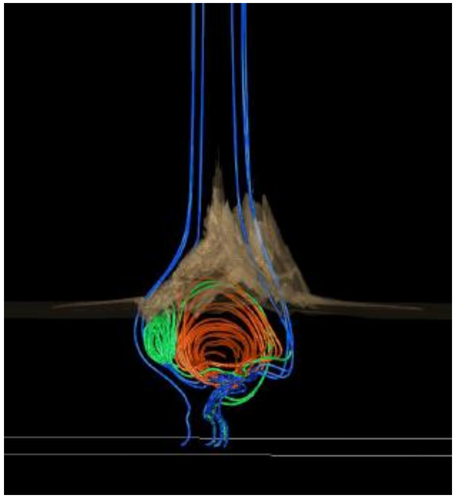
Archontis+ 2004



Miyagoshi+ 2004



Nishida+ in prep.



No helical jets!

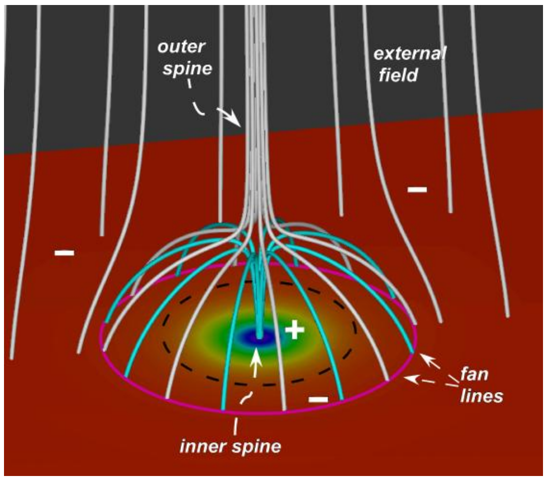
Why?

- Reconnection proceeds at most $V_{rec} \approx 0.1\text{-}0.2V_A$.
- Twist cannot be transported instantaneously
- Magnetic shear transported through reconnection will escape rapidly with Alfven velocity

- Bottom of the flux tube does not emerge anyway

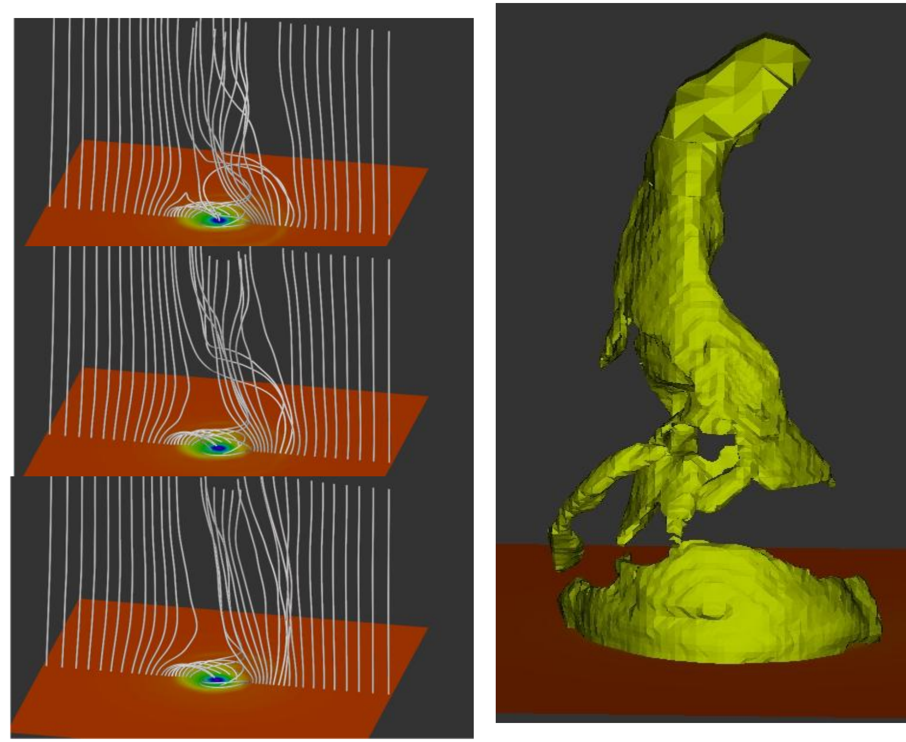
Store => release

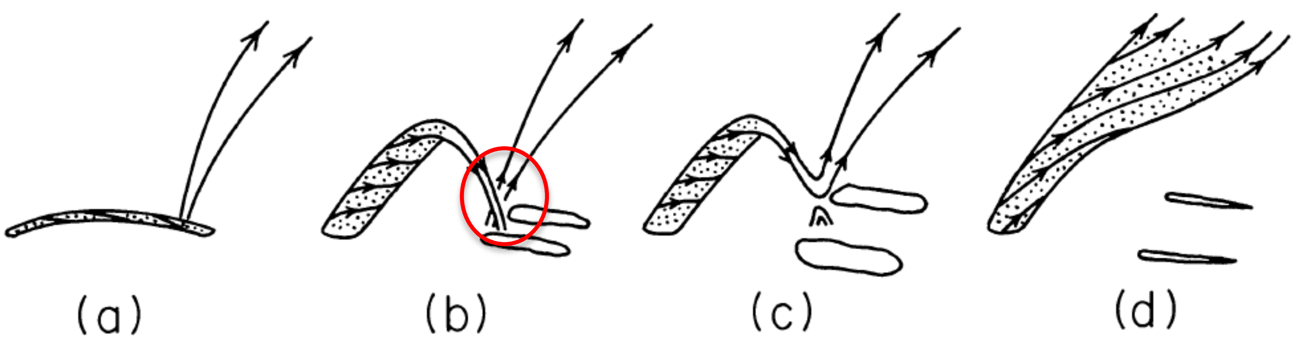
Pariat+ 08



Rotation of sunspot

kink instability

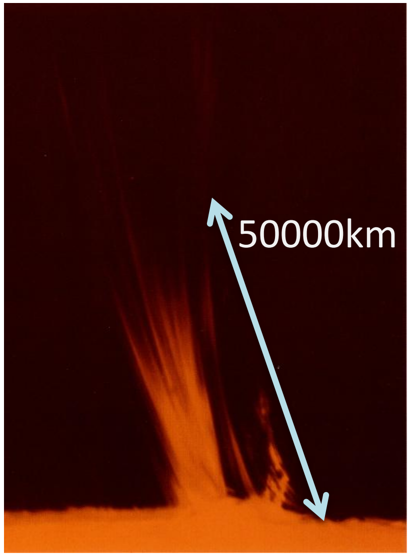




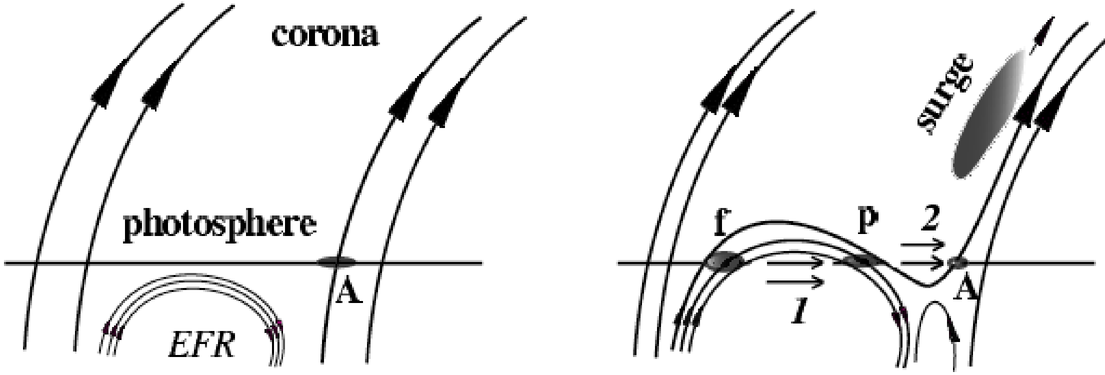
Shibata & Uchida 86

Chromospheric jets

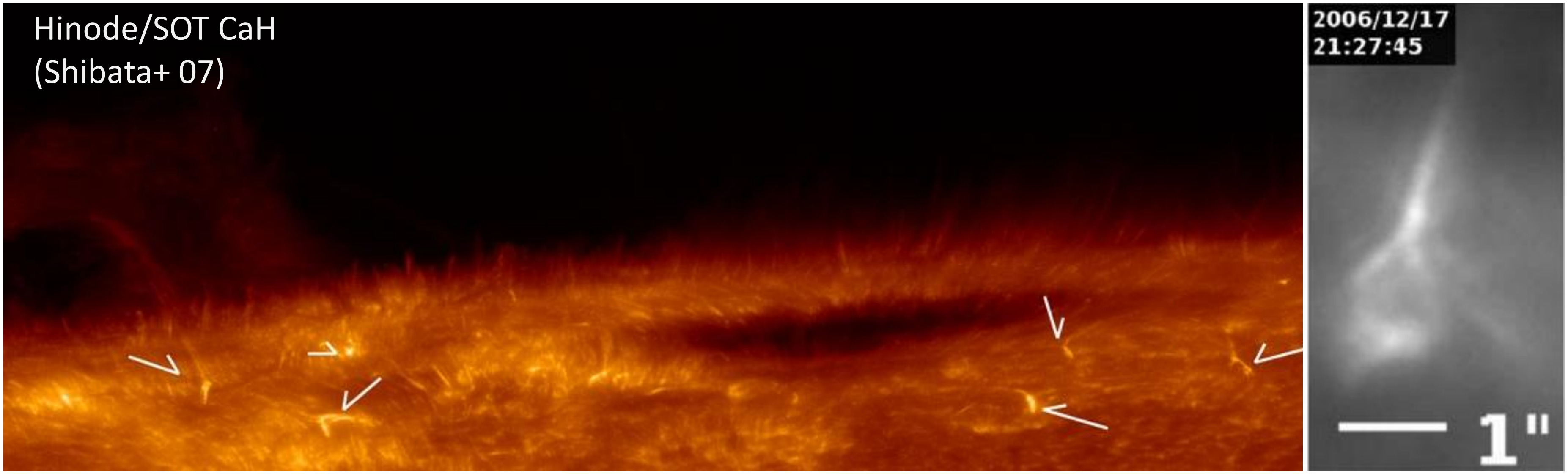
H-alpha surge (spray)
Hida observatory



Models invoke reconnection in chromosphere.



Liu & Kurokawa 04



Can chromo-reconnection produces high jets?

Available magnetic energy $B^2/8\pi \approx \rho g h$ (potential energy)

$$\Rightarrow h \approx (B^2/8\pi)/\rho g$$

$$\approx (B^2/8\pi)/\rho RT^*(RT/g)$$

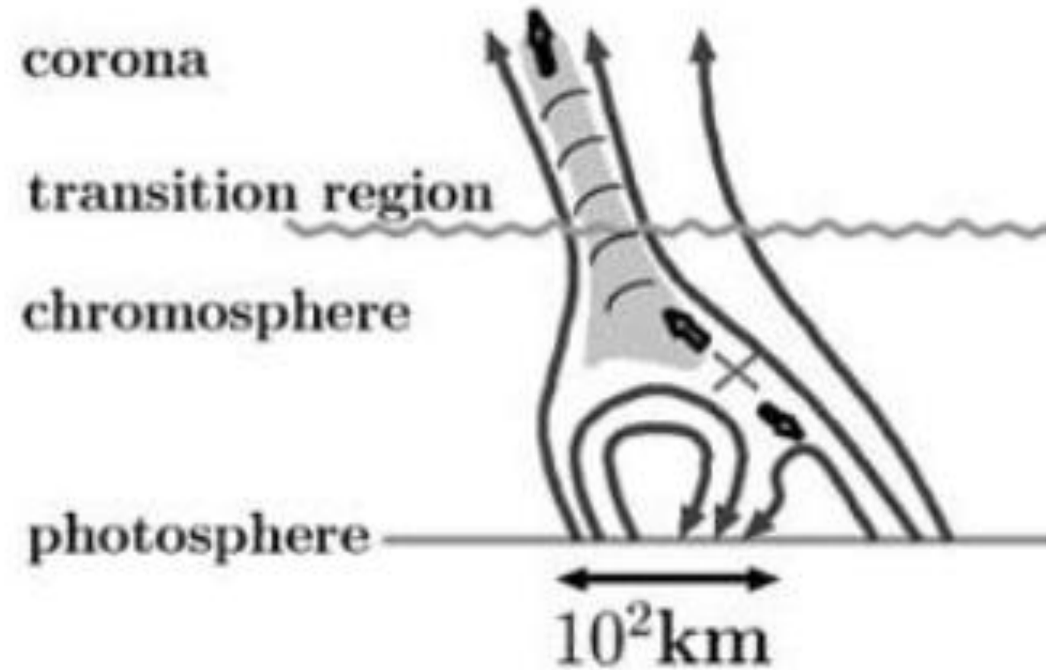
$$= H/\beta$$ (H: scale hight, β: plasma beta

- If $\beta \approx 1$, reconnection jet (or any magnetic driver) can ascend only $H \approx 300$ km.

- Needs a clever way to accelerate only a selected plasma.

Reconnection => wave => acceleration?

Shibata+ 07



- May also work for flares? (L. Fletcher, this morning)
- Needs more numerical/observational studies

Particle acceleration

- Microflares are also accelerating electrons (Krucker+ 03, Christe+ 08, Hannah+ 08), but not as strongly as flares

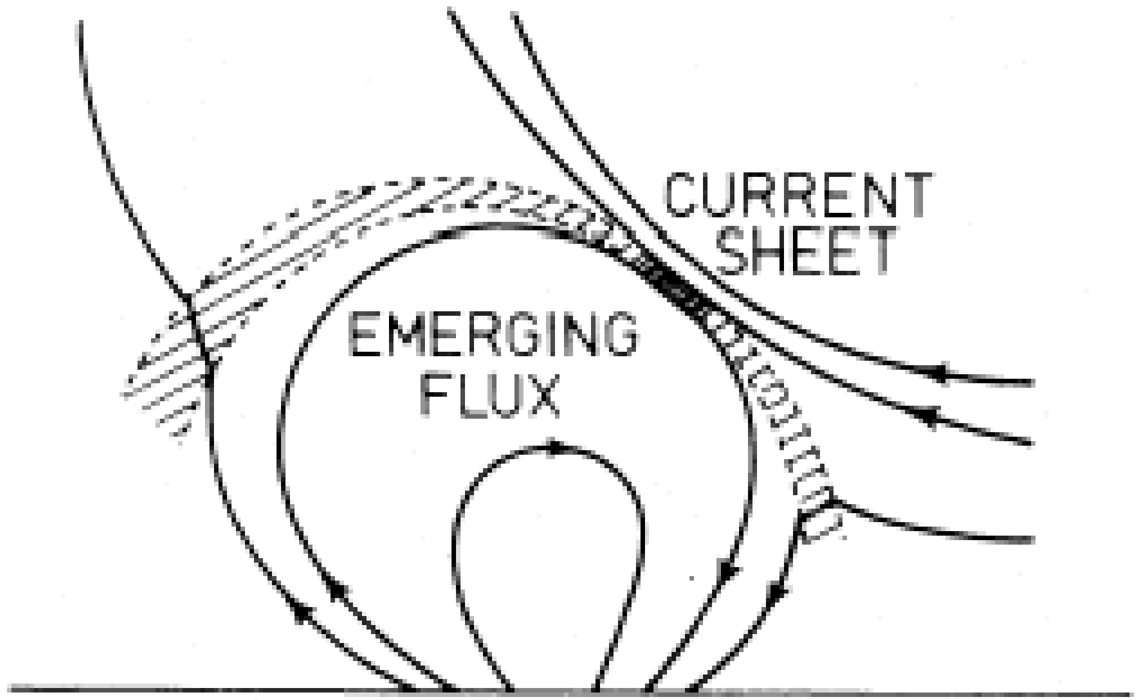
- What about explosive events in transition region or chromosphere?
  - Too dense?
  - From which height does electron acceleration starts?

- What about eruptive events in quiet sun?
  - no HXR above noize
  - Magnetic/electric fields too weak?
  - but magnetospheric substorms accelerate electrons ($B \approx 10^{-4}$G)
  - and solar wind reconnection does not! (Gosling+ 05)
  - what are the controlling parameters? See our poster on Thursday.

Summary

- Significant progresses in last cycles.
- Still many open questions.
- Let’s go ahead.

Why do we care about more than this?



Heyvaerts, Priest, & Rust 1977

I was born in 1977!

We desperately want to know every single detail of our sweet-heart (e.g., jets)

Is it so important? Perhaps love makes us blind?

No, the forefront of physics and astrophysics is there.

How fast can magnetic field dissipate?
- fundamental process in astrophysics -

- Dissipation in fully ionized (collisionless) plasmas
  - high energy phenomena in astrophysics (GRB, AGN, Blackhole accretion disks, magnetors…)
- Dissipation in weakly ionized, collisional plasmas
  - flux removal of collapsing molecular clouds => origin of stars
  - MRI and dynamo in protoplanetary disks => origin of planets (and life)
- Experimental determination of reconnection rate as a function of plasma parameters by solar observation

- “In solar and astro physics, reconnection is used as a synonym for energy release”

  (H. Hudson 2006, at Harry Petschek Symp. on Magnetic Reconnection)

- key problems
  - what is and what determines the reconnection rate
  - origin of (anomalous) resistivity
  - cross scale coupling
  - particle acceleration

In astrophysics…

Uzdensky (2006, astro-ph/0607656)

… the most important reconnection mechanism in Astrophysics invokes waves, a certain type of waves, in fact. Called *handwaves* (See Fig 1).

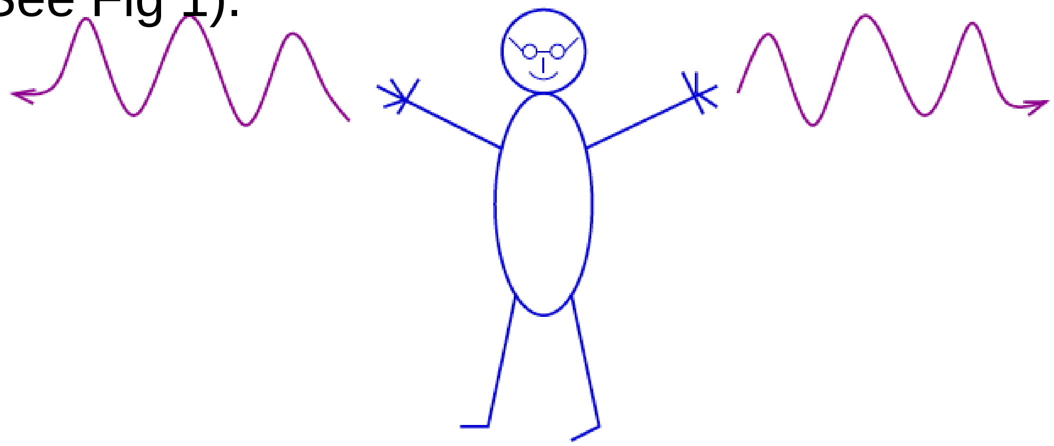


Fig. 1.— Main Reconnection Mechanism in Astrophysics.

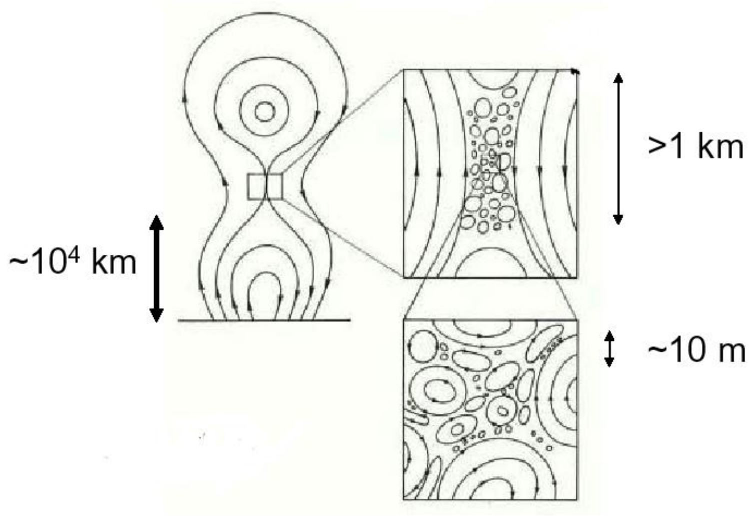
The mechanism works like this: *Well, we know that fast reconnection happens in the Solar corona, and in the Earth magnetosphere. So it should also happen in OUR astrophysical system.*

Problems in reconnection physics: corona

- Coronal is fully ionized, almost collision less
- Micro: anomalous resistivity by kinetic effects (wave-particle interaction)
- Macro: plasma ejection, slow shock

- Micro scale: ≈ 10^2 cm (Ion intertia length, Larmor length)
- Macro sale ≈ $10^{9\text{-}10}$ cm

- Cross scale coupling



Tajima & Shibata 97

- Common problem with magnetosphere.
- But macro/micro ratio is ≈ 10^2.
- Are connecting 10^2 and connecting 10^7 same?

Problems in reconnection physics: lower atmosphere

- Chromo/photosphere is fully collisional and weakly ionized
  - But magnetic Reynolds # is still large: $S = V_A L/\eta \approx 10^5$
  - Reconnection seems bursty
  - Classical Sweet-Parker reconnection perhaps too slow (e.g., Chae et al. 2002)
  - Hall/ambipolar effects?

Hall and Ambipolar effects

Induction equation of weakly ionized plasma

Hall term
(Ion-electron)

Ambipolar term
(Ion-neutral)

Ambipolar/Hall = ω_{ci}/ν_{in}

ω_{ci} : Ion-cyclotron freq $\propto B$

ν_{in} : Ion-neutral collision freq $\propto n$

Chromosphere: Ambipolar > Hall, resistive
Photosphere: Hall > ambipolar, resistive

Important only in small scale, e.g., current sheets and high-frequency waves.

When Hall/Ambipolar become significant

Hall > Advection => $$t < \frac{1}{\omega_{ci}} \frac{n_n}{n_i} \frac{V_{na}^2}{V^2}$$

0.1〜1 s in photosphere

Ambipolar > Advection => $$t < \frac{1}{\nu_{in}} \frac{n_n}{n_i} \frac{V_{na}^2}{V^2}$$

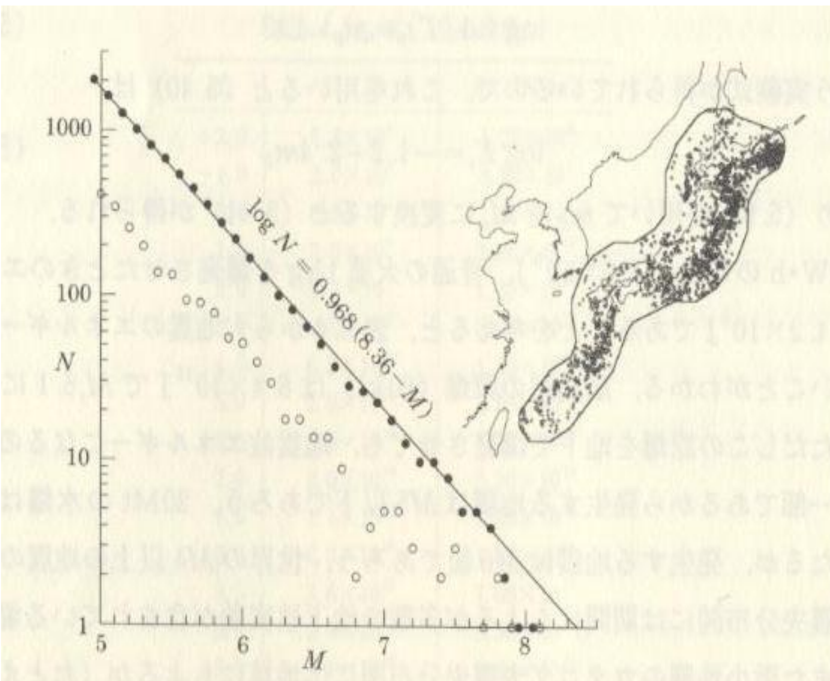
0.1〜1 s in chromosphere

Length scale ≈ $tV_{na} = c/\omega_{pi}\,(n_n/n_i)^{1/2}$ ≈ 1-10km (c/ω_{pi} : inertia length)
=> Detection more likely in temporal variation

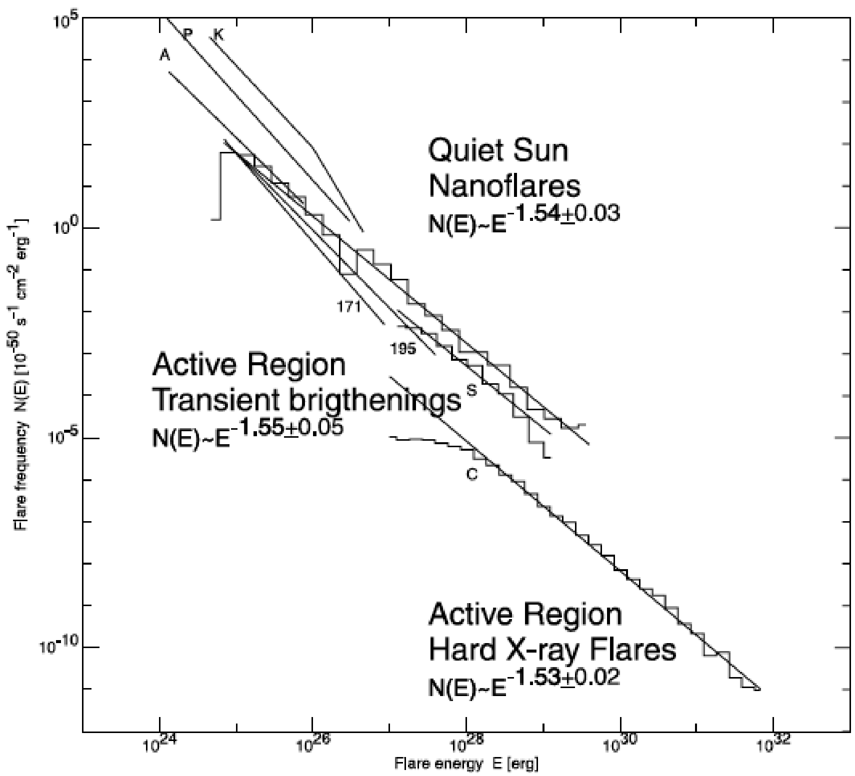
* Possibly important in local dynamo, too (Krishan & Gangadhara 2008)

Energy storage problem

Histgram of earthquake near Japan

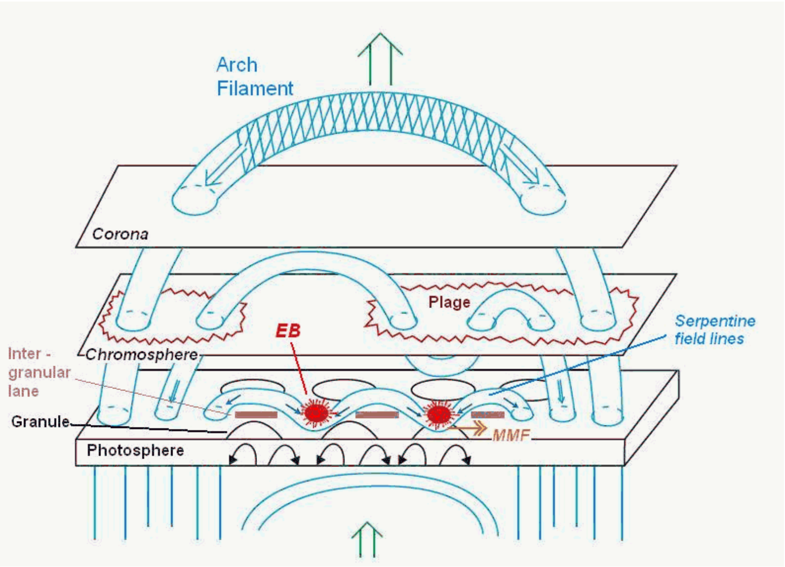


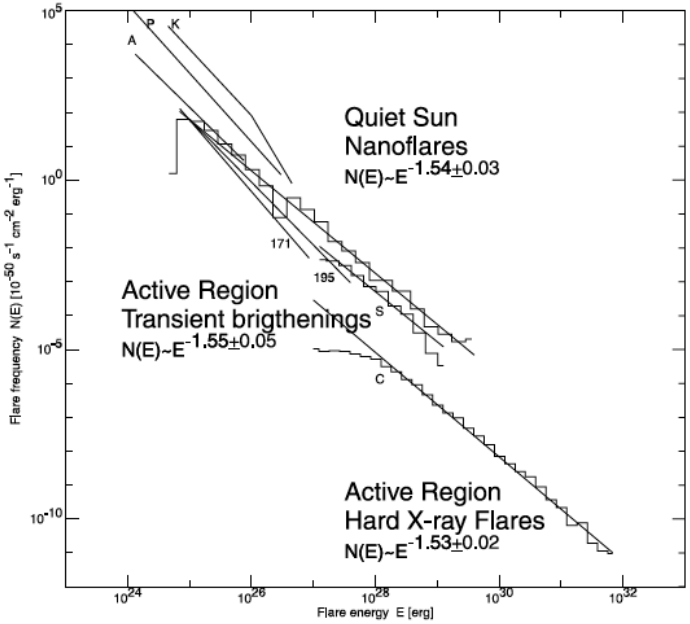
Aschwanden & Parnell 02



- Power law => no characteristic scale
- Self-Organized Criticality?

• Energy supply and cascade processes self-organize the system to power-law (SOC)
• How?





• Investigating the details of topology and dynamics of individual events is still necessary to make progress
• But should be done in more systematic manner

Scientific challenges in cycle 24

- Where and how the energy is stored?
  - why power law?
  - understand the diversity of topology/dinamics as a self-organization of an integrated system
  - continuous observation essential
- How fast the magnetic dissipation?
  - determine scaling with plasma parameters
    => basis for astrophysics
  - height and rate of reconnection and acceleration
  - probing diffusion region => scale coupling