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12th Postdam Thinkshop
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Observations and models of solar coronal jets

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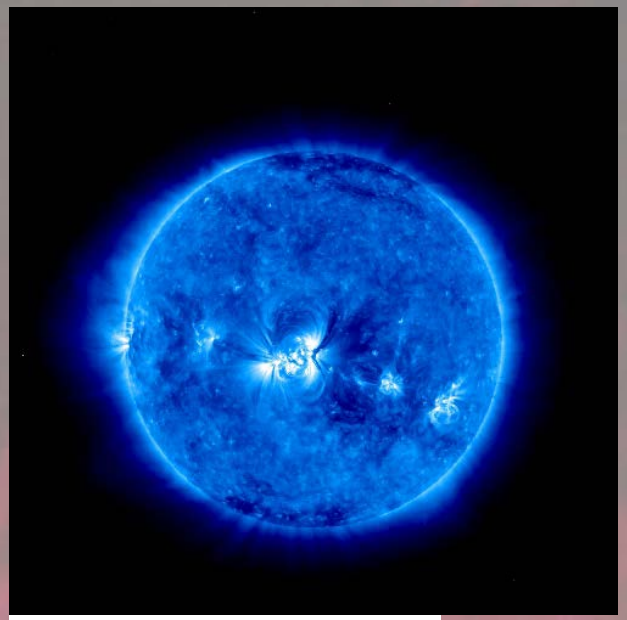
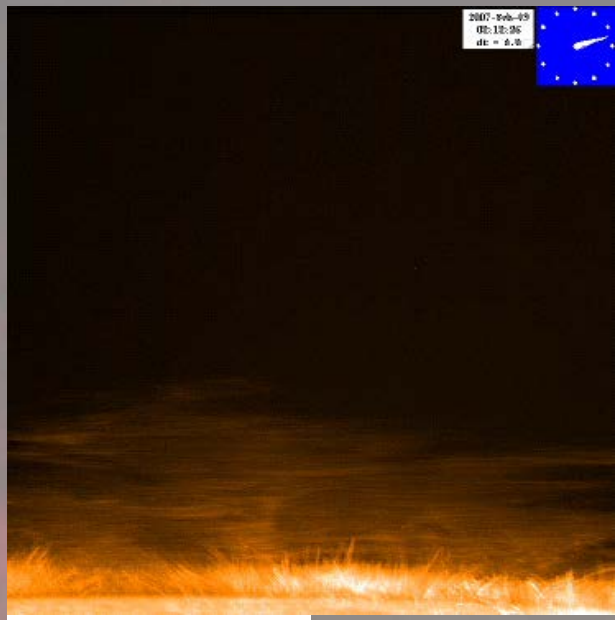
Jets: ubiquitous phenomena

- **Impulsive, collimated, sharp edged features**
- **Observed all over the atmosphere**
  - in coronal holes
  - in active regions
- **Observed over a broad range of scales**
  - Coronal jets (macrospicules) : X-ray, UV, White light
    - Length > 10^4 km
  - Chromospheric jets (surges): Ha, Ca II, UV
    - Length: ~ 10^3 km
  - Photospheric jets / spicules :
    - Length < 10^3 km
- **Homologous recurring structures**

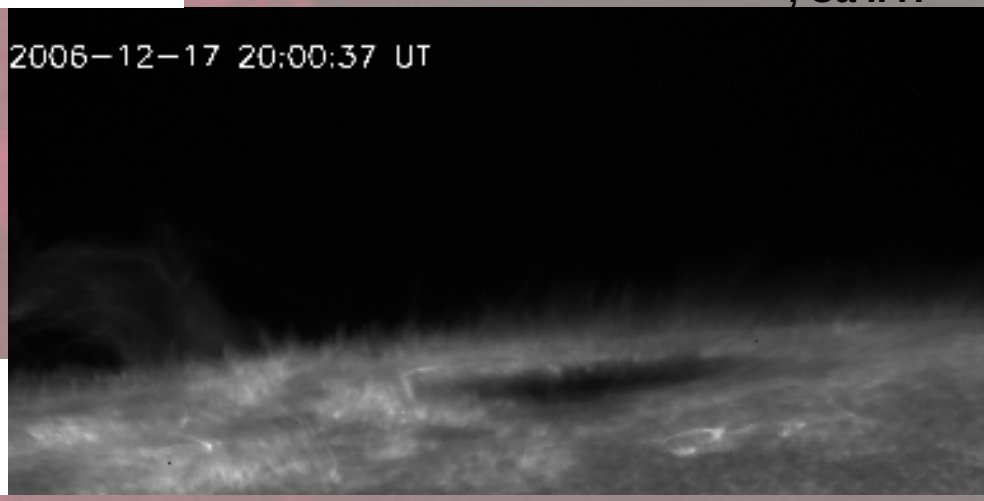


UV+White Light (STEREO) **(Patsourakos et al. 08)**



(Liu et al. 09)

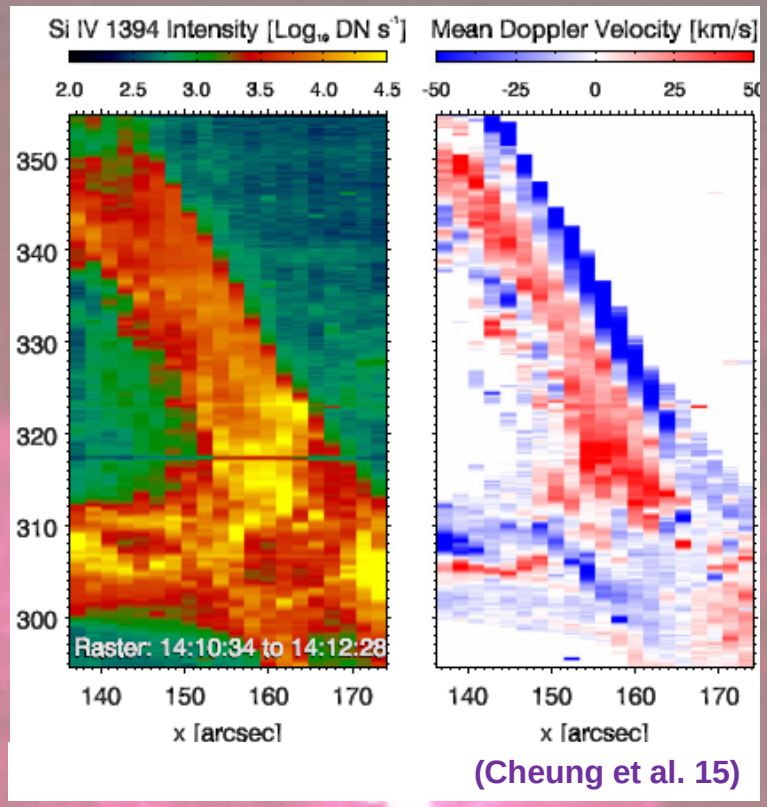
SOT/Hinode , Ca II H



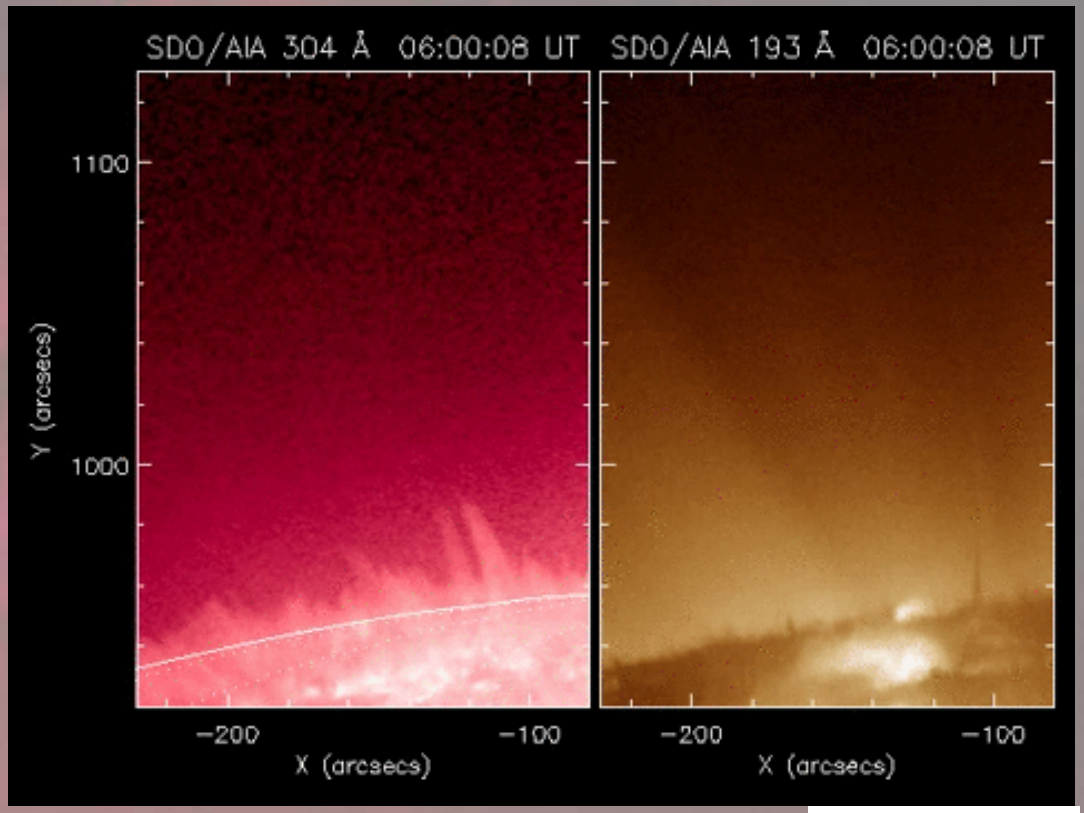
(Shibata et al 07 ; Nishizuka et al. 11)

Helical properties of jets

- **Helical structure commonly observed**
  - Morphology **(e.g. Shibata et al. 92, Canfield et al. 96,, Liu et al.10,11, Shen et al. 11, …)**
  - Doppler (imaging) **(Harrison et al. 01, Jibben et al. 04, Young et al. 14,15, Cheung et al. 15)**
  - Stereoscopy **(Patsourakos et al. 08, Kamio et al. 10, Matsui et al. 12)**
- **Twisting motion observed at all scales** **(e.g. Liu et al. 09,11, Curdt et al. 11, 12, DePontieu et al. 12)**



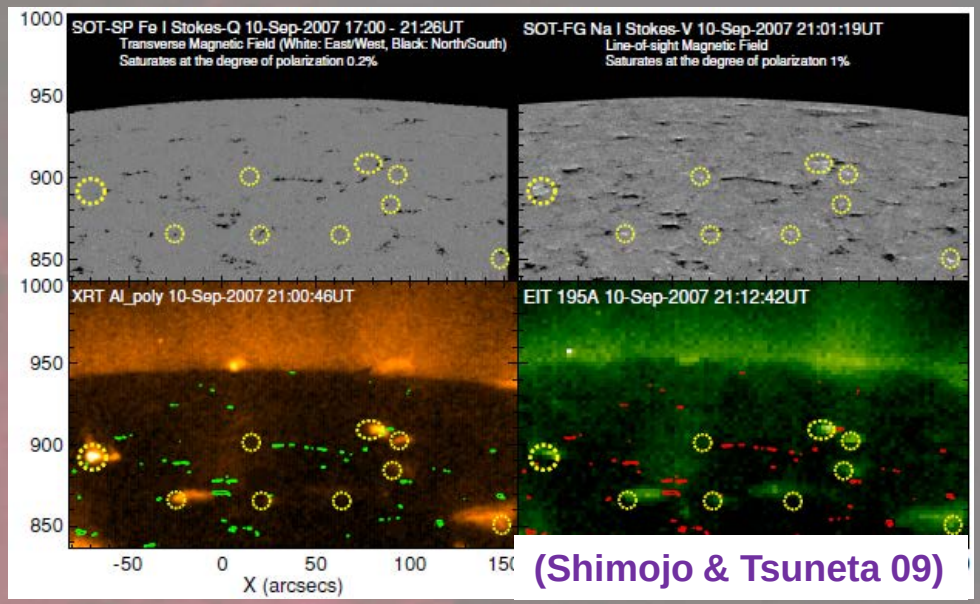
(Cheung et al. 15)



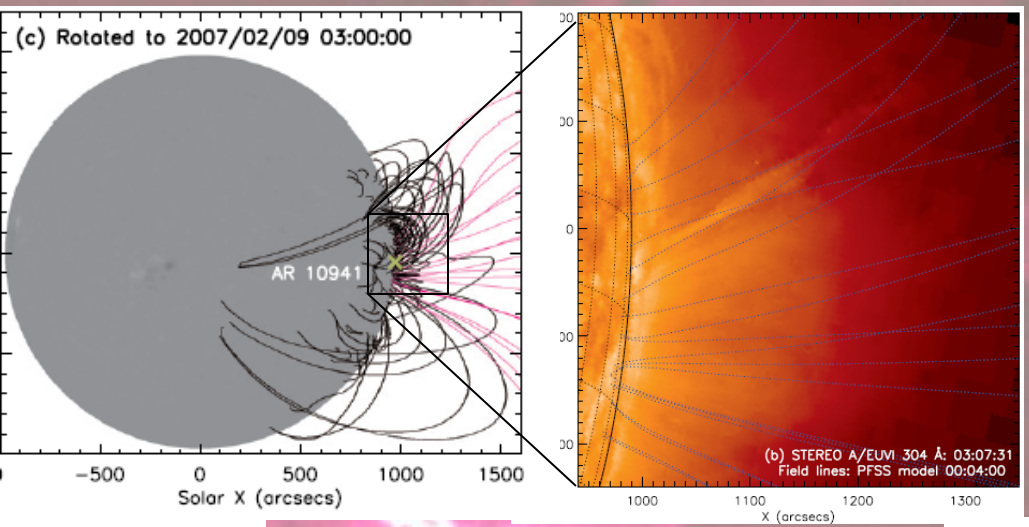
(Shen et al. 11)

Magnetic field properties

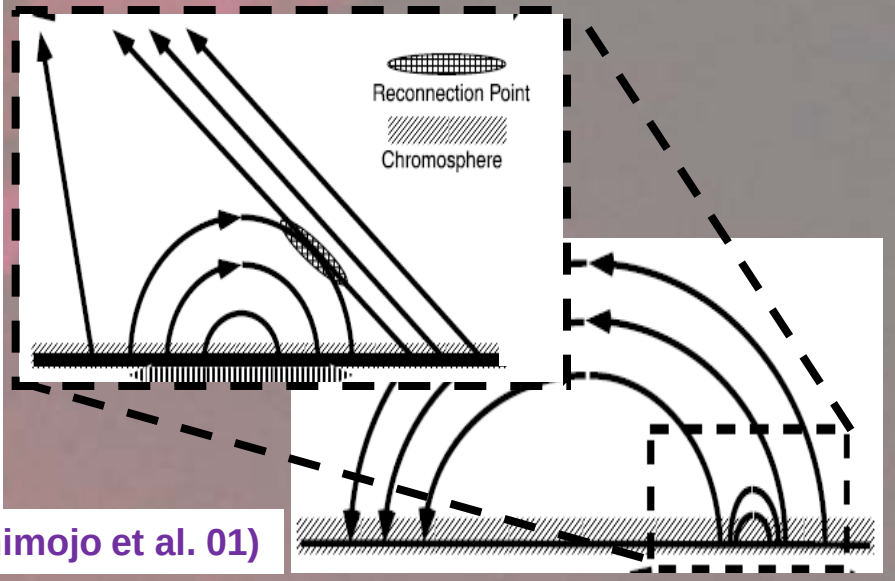
- Jets generally (~90%) associated with multipolar fields. **(Shimojo et al, 98,09)**
- Jet collimated along “open” **B** lines:
- **Jets occur at the interface of two connectivity domains:**
- close & “open” = two different characteristic length of **B** gradients
  - **Necessary ingredients for jets**



(Shimojo & Tsuneta 09)



(Liu et al. 11)

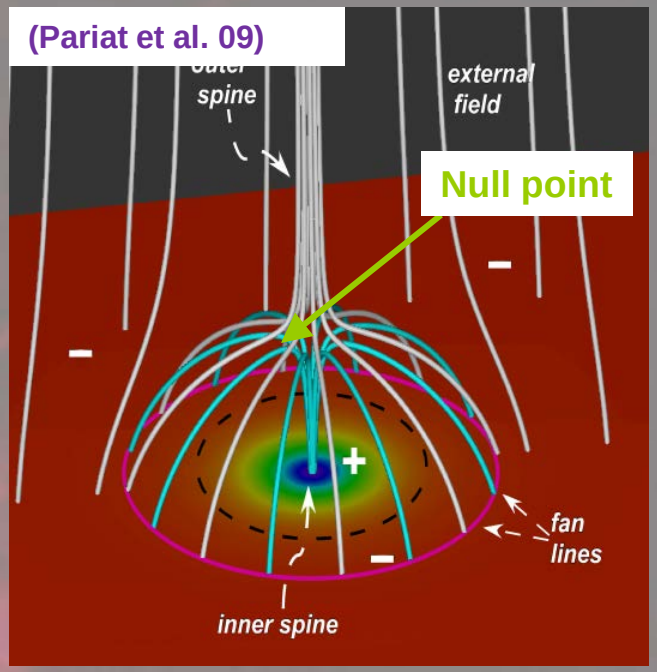


(Shimojo et al. 01)

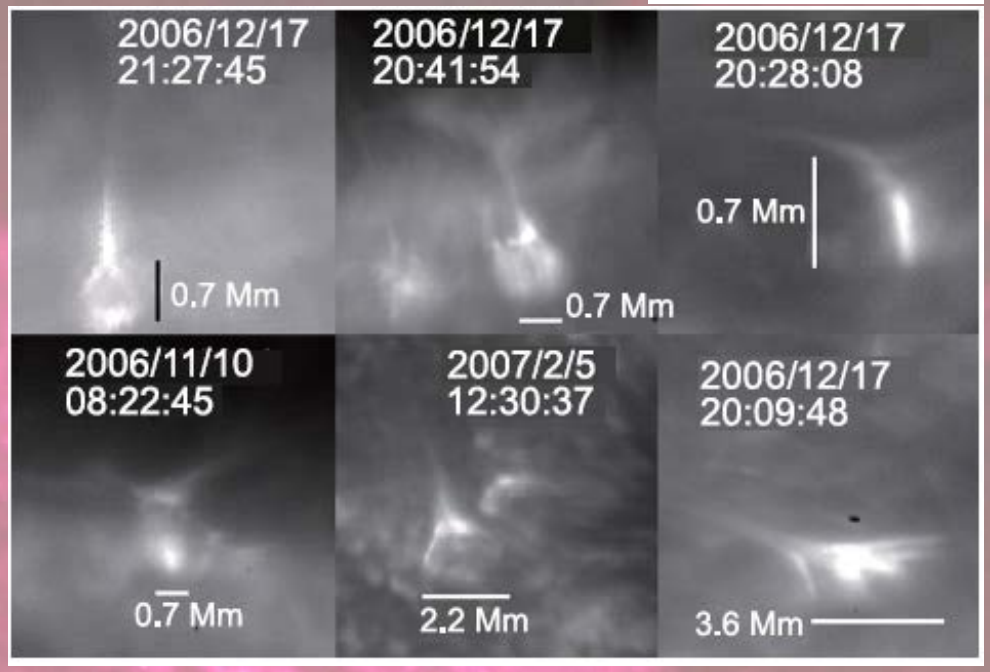
Magnetic field topology

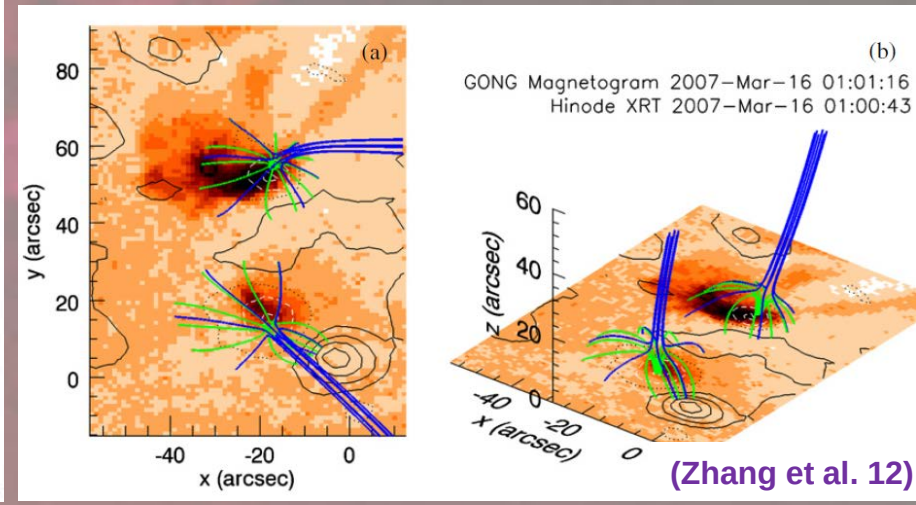
- **Jets usually associated with 3D null points**
  - "Anemone" morphology **(e.g., Shibata et al. 92, Liu et al.11)**
  - Few extrapolation cases **(Fletcher et al. 01, Moreno-Insertis et al. 08, Liu et al. 11, Zhang et al. 12)**
- More complex topologies: **Guo et al. 13, Schmieder et al. 13**

(Pariat et al. 09)



(Nishizuka et al. 11)





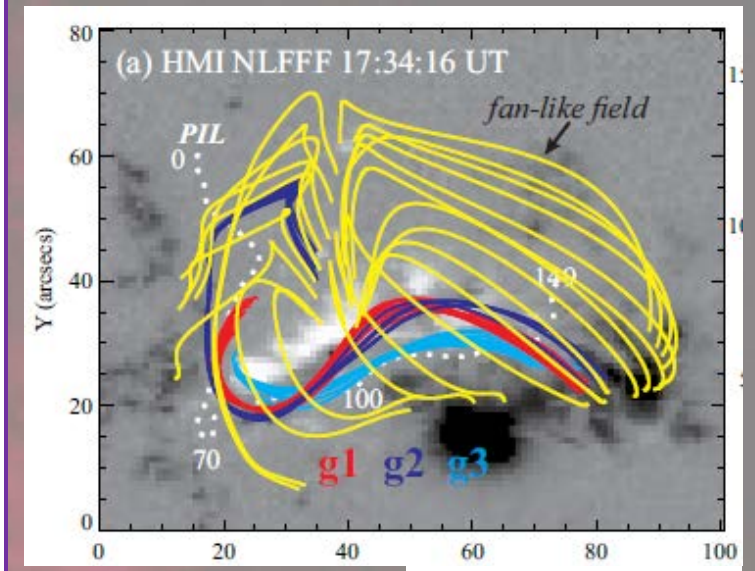
(Zhang et al. 12)

Jet progenitor and trigger

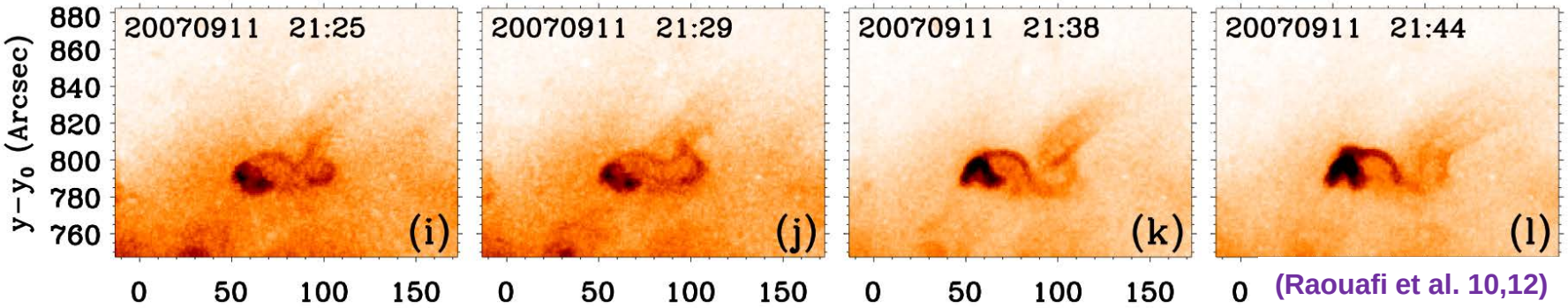
- Observations of sigmoid structure (Raouafi et al. 10, 12) and of small scale filaments (Kayshap et al. 13, Sterling et al. 15) prior to the jet

➔ **indication for pre-jet twisted flux rope in the closed field domain**

- Flux rope recently found bellow null points (Jiang et al.14, Kai et al. 15, Liu et al. 15, Masson et al. 16)
- Pre-jet photospheric motions generally convergent, i.e. magnetic cancellation filaments (Chen et al. 08, Chifor et al. 08, Guo et al. 13, Young et al. 14, Muglach et al. 15)
  - Flux emergence earlier (and necessary) but not directly linked with jet trigger



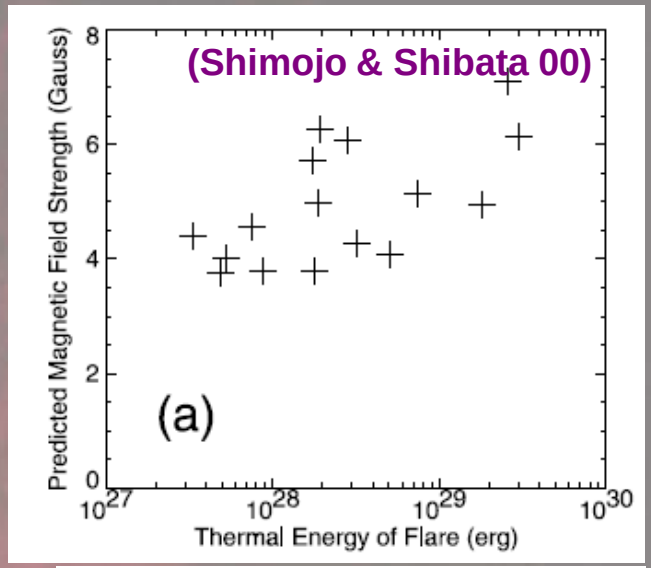
(Liu et al. 15)

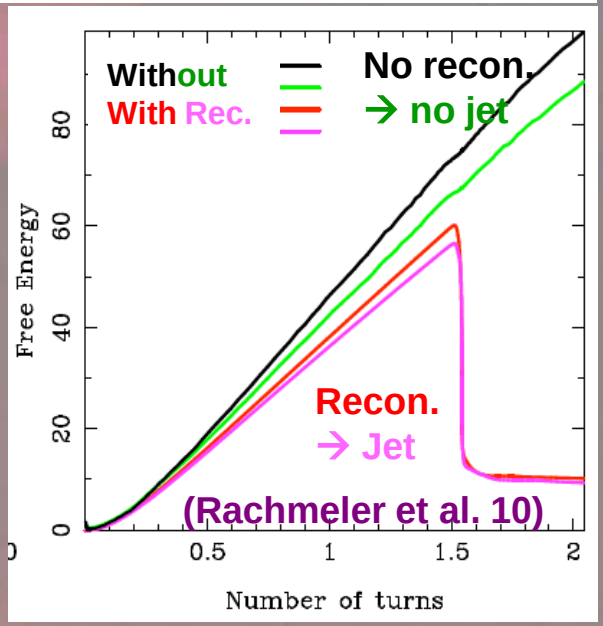


(Raouafi et al. 10,12)

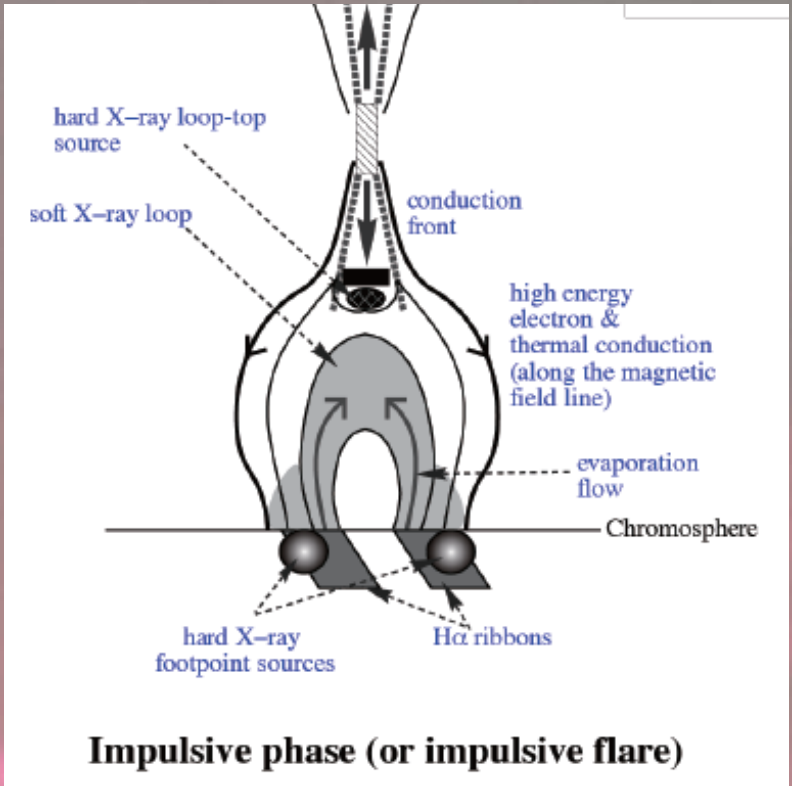
Evidence for magnetic reconnection

- X-ray jets: energetic events (10^{20}-10^{22}J).
  - **Energy source must be magnetic**
- Transient impulsive events:
  - Violent energy release
- **Obs. of non-thermal particles** **(Bain et al. 09)**
- X-ray jets associated with small flares: X-ray bright points **(Shibata et al. 1992, 1994, …):**
  - Correlation between energies and plasma temperatures of the jet and of the flare
  - Area of footpoint flare corr. jet temperature
- Change of the coronal loops connectivity
- **Null points are preferential recon. sites**
- **Numerous numerical simulations involving reconnection producing jets**

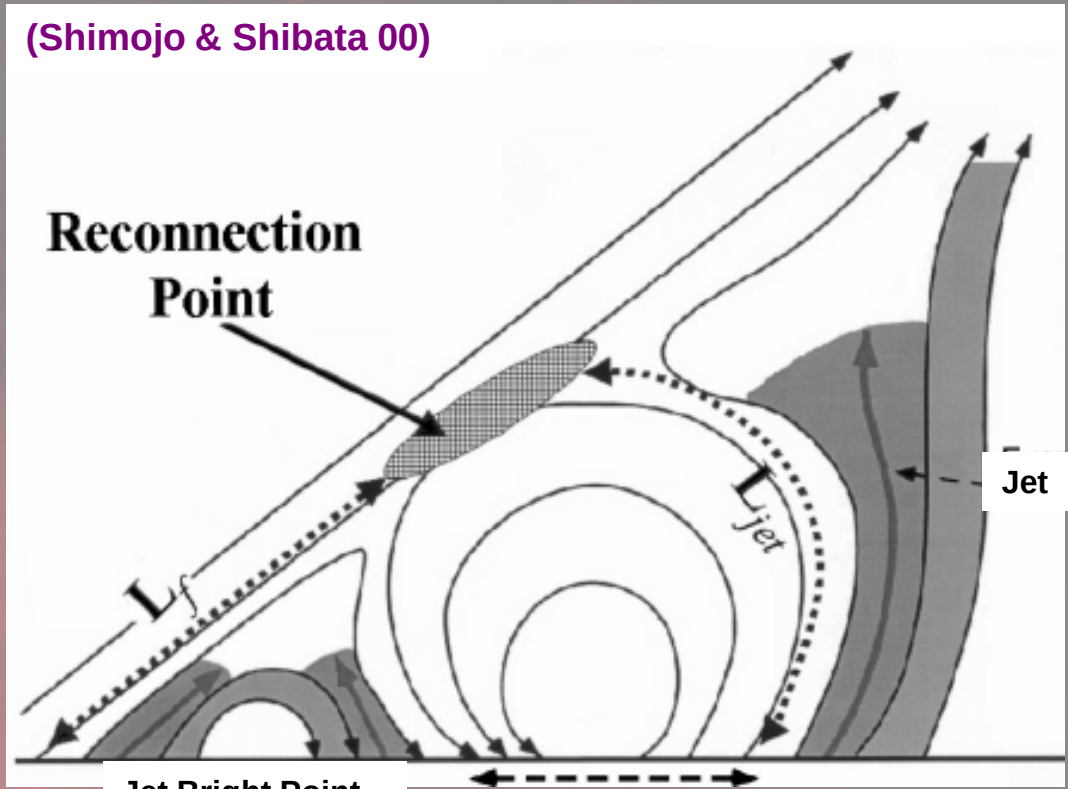




Mechanism for jets (in 2D)



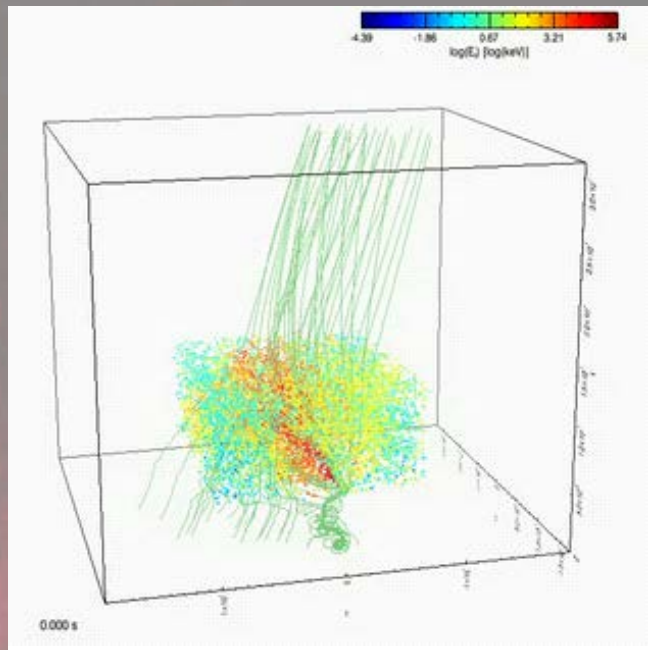
(Shimojo & Shibata 00)



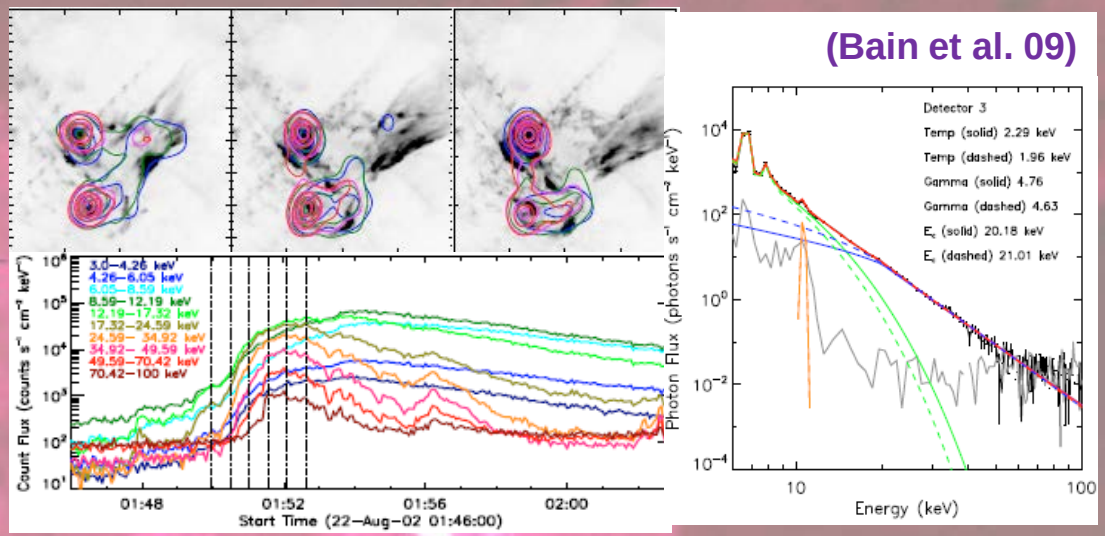
- **Jet = flare involving strongly asymmetric field lines**
- **Jet bright point: standard post flare loop**
- **Jet: non-standard post flare loop**
  - Energy deposit close to base of a extended loop
  - Transfer of energy along the extended loop

Jets and particles acceleration

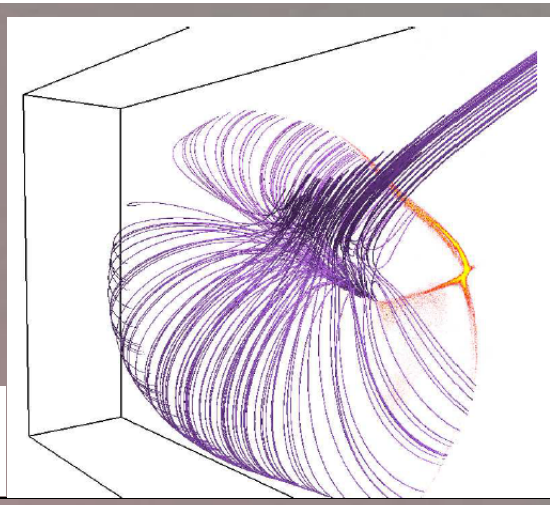
- **Evidences of non-thermal e- beam during (large) jet events** (Aurass 94, Raulin 96, Bain et al. 09, Krucker et al. 11,)
- Test particle simulations (B fixed)
  - at 3D null point (Dalla & Browning 05,06,08)
  - with relativistic e- (Rosdahl & Galsgaard 10)
- **Toward self-consistent model: PIC** (Baumann et al. 13)
  - Important tool to follow particle injection in the heliosphere and ribbon formation



(Rosdahl & Galsgaard 10)



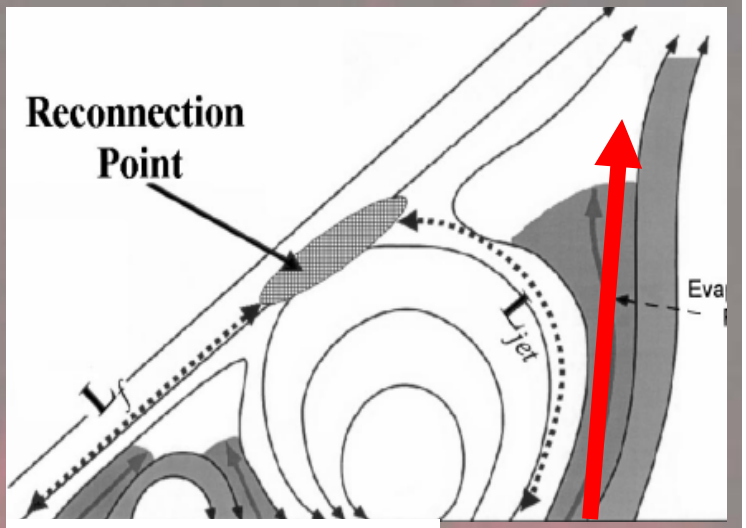
(Bain et al. 09)



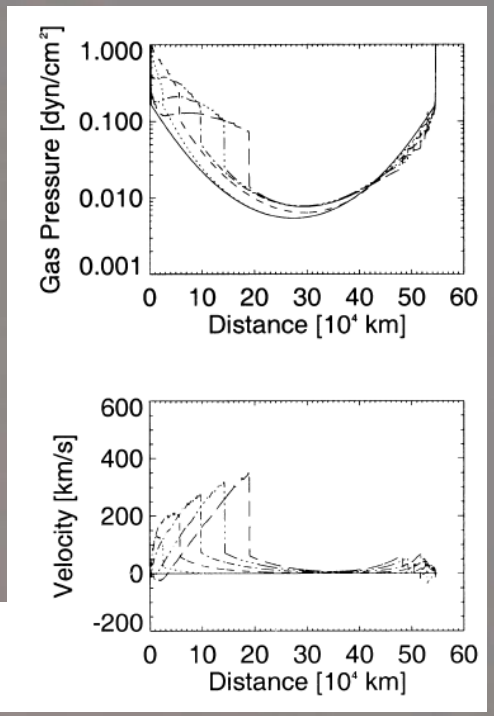
(Baumann et al. 13)

Evaporation flows

- **Evaporation flows**
  - Deposition of energy following reconnection
  - ➔ Upflow of material: $V_{Jet} \propto Cs$
  - **Driver: additional gas pressure and thermal conduction**

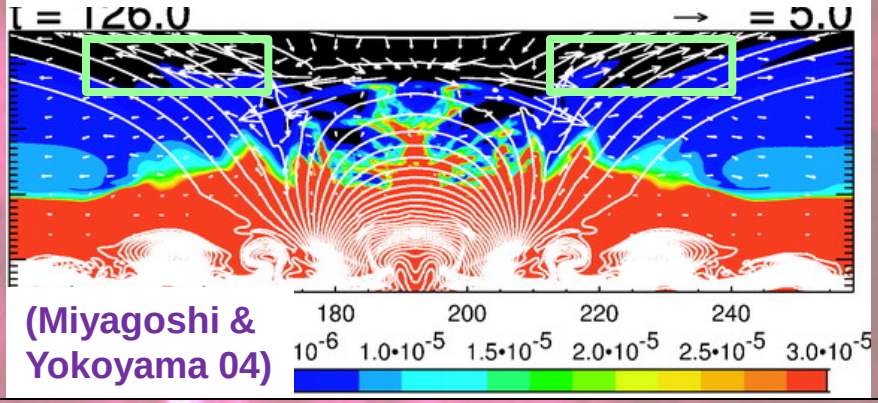


Shimojo & Shibata, 00



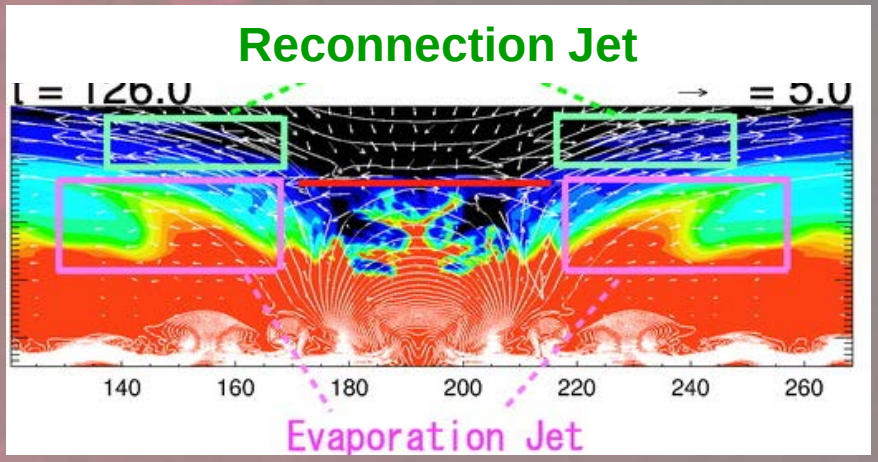
Shimojo et al. 01

No heat conduction



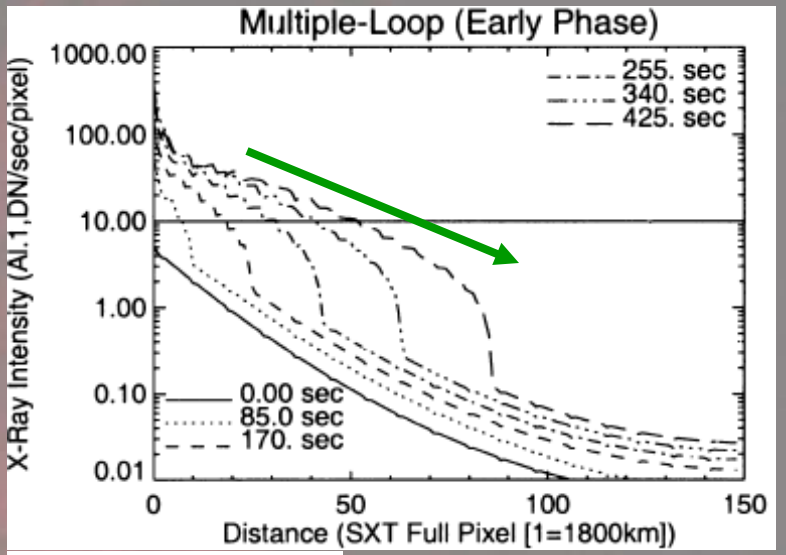
(Miyagoshi & Yokoyama 04)

Reconnection Jet



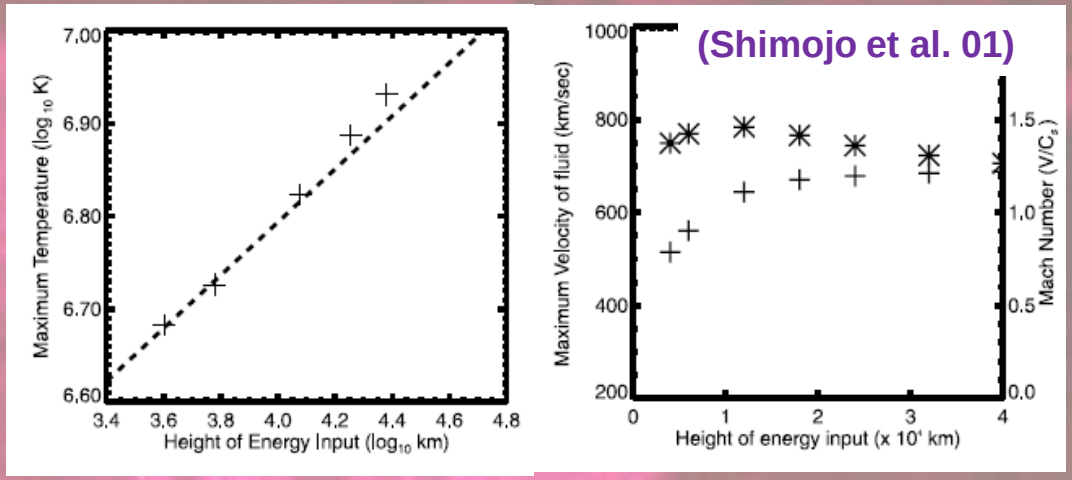
Evaporationflow

- **Relative good fits (V,ρ,T) with observations**
  (e.g. Shimojo et al 01, Chifor et al .08, Matsui 12)
  - Velocity agreement at high Temp. **(Matsui 12)**
    - **No good fit at lower temperature**
  - Exponential intensity decrease with height in X-ray
- Jet properties depends on the energy deposit height, i.e., reconnection evolution
  - Mechanism different in the corona and in the chromosphere

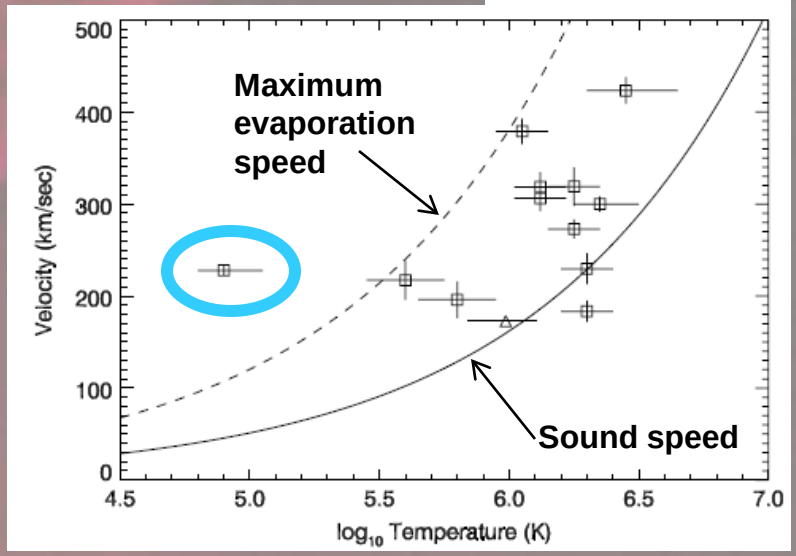


Shimojo et al. 01

Matsui et al. 12

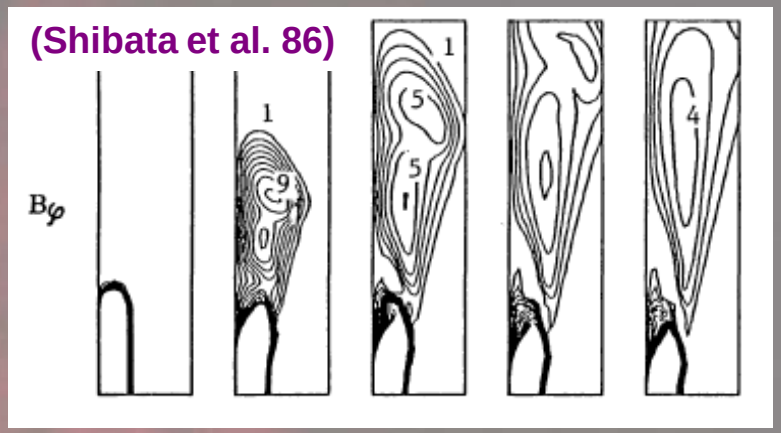


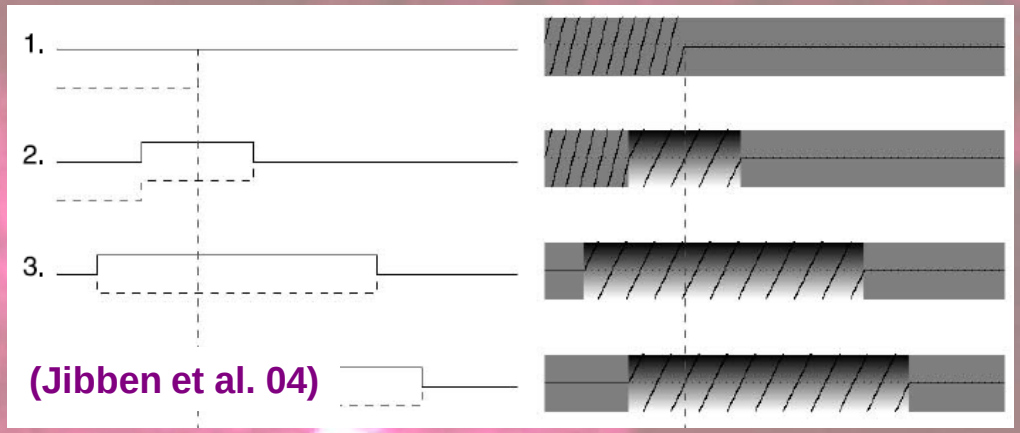
(Shimojo et al. 01)

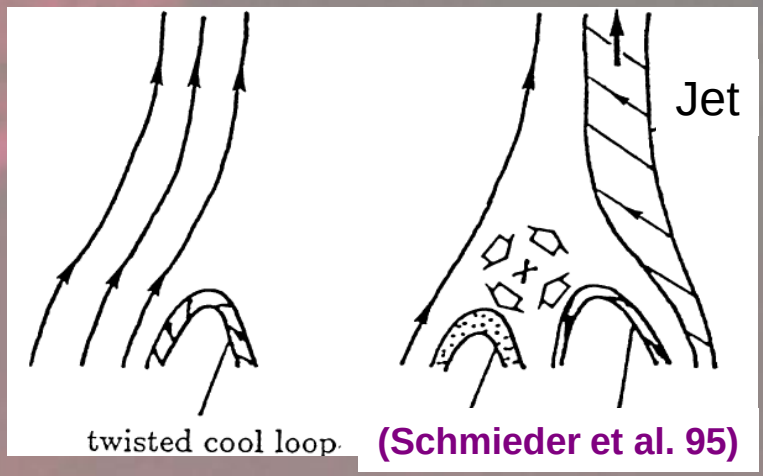


Magnetic untwisting flows

- **Magnetic Twist flows**
  - Recon. of twisted/sheared and untwisted/unsheared loops
  - **Release of the shear ➔ non linear Alvénic wave**
  - Driver: Kink-type wave magnetic pressure

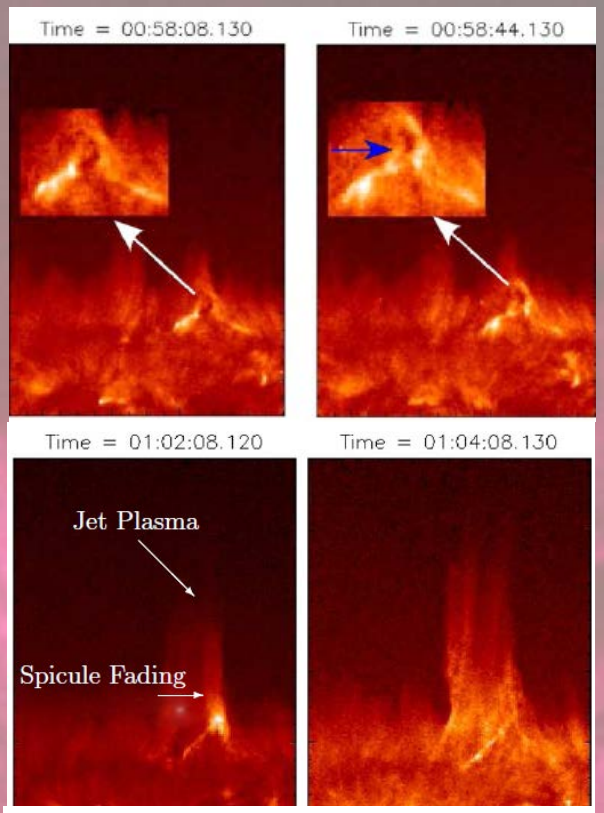




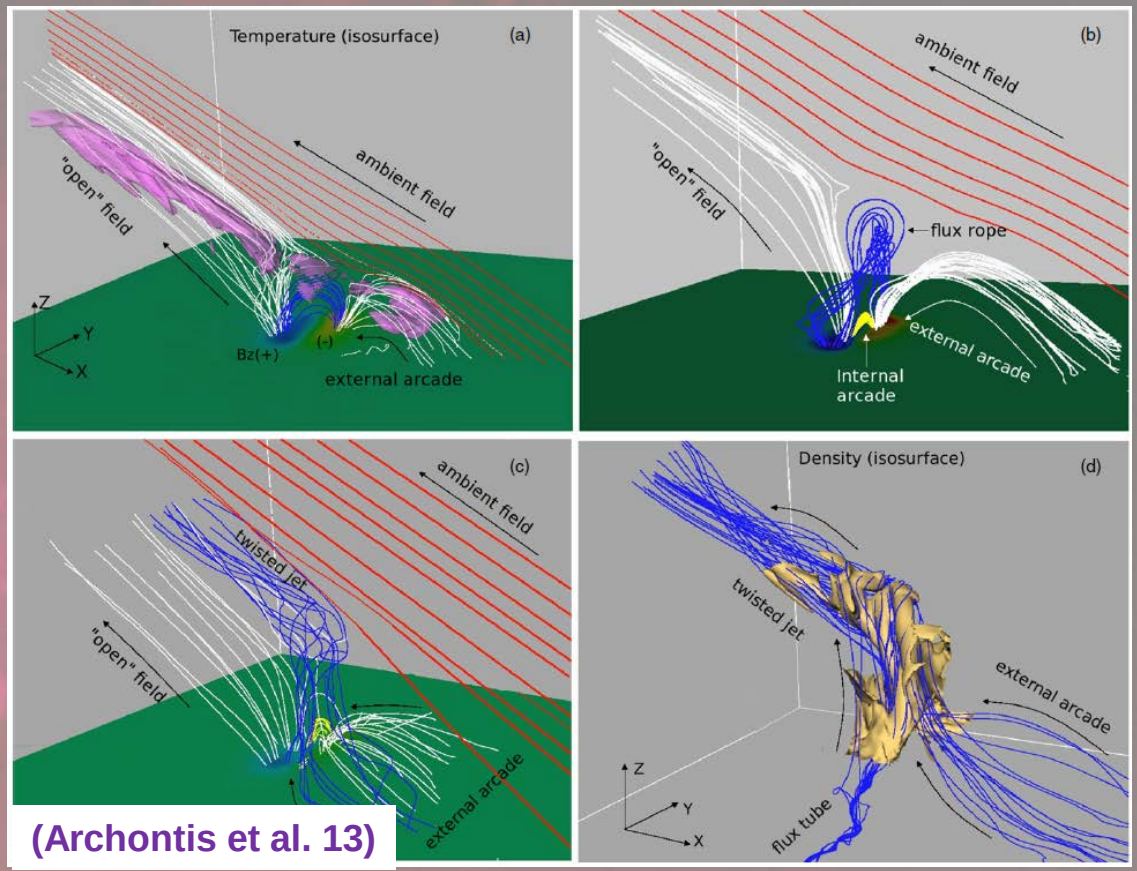


Helical jet = destroyed erupting flux rope

- **Helical jets corresponds to destroyed erupting flux rope** (Moore et al. 10, Raouaffi et al. 12, Moreno-Insertis et al. 13, Archontis et al. 13, Kayshap et al. 13, Fang et al. 14, Lee et al. 15, Pariat et al. 15)
- Jet driver: untwisting of the reconnected field lines of the disrupted flux rope (Pariat et al. 09,10,15, Török et al. 09, Moore et al. 10,13)
- **Trigger of helical jets = trigger of coronal mass ejection**



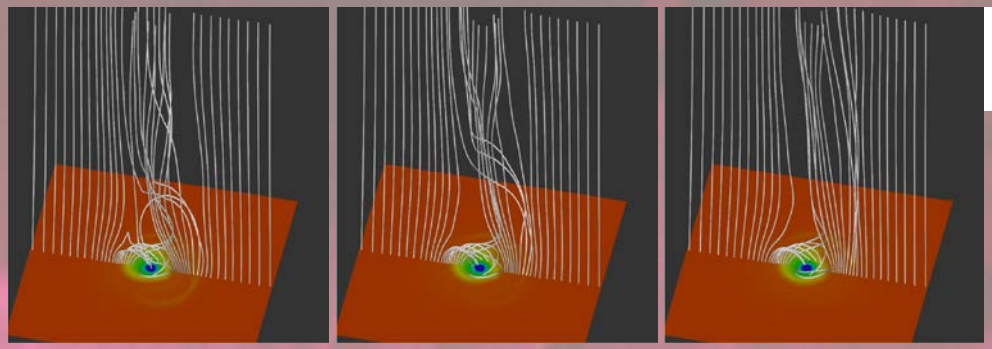
(Kayshap et al. 13)



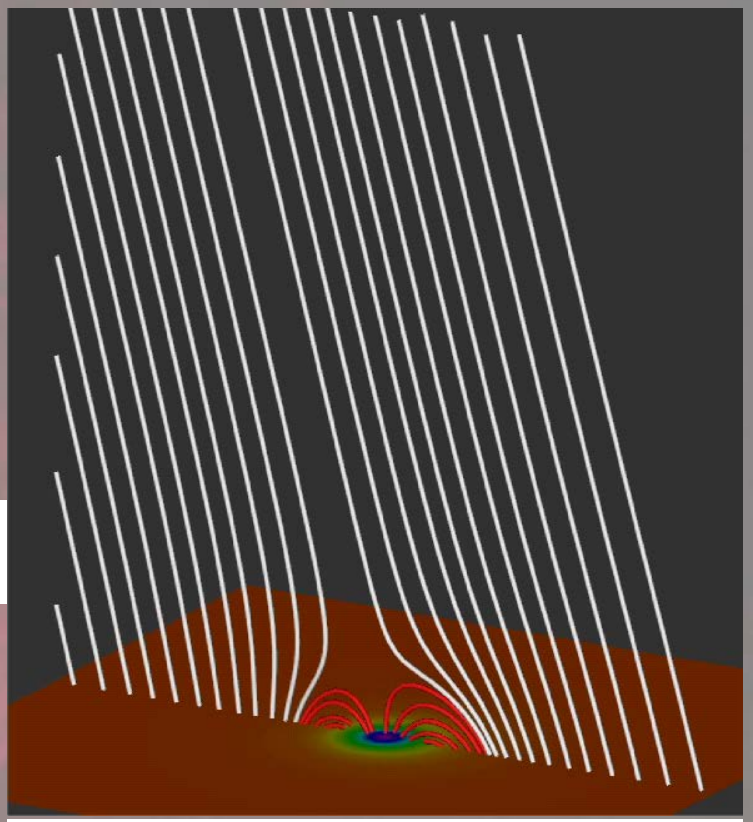
(Archontis et al. 13)

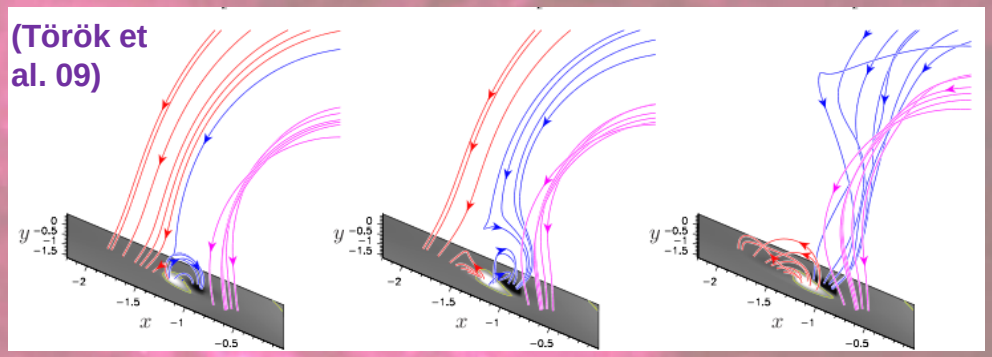
3D model of magnetic untwisting flows

- **Helical jet formed by the sequential reconnection of field lines** (Pariat et al.09,10,15; Török et al. 09; Dalmasse et al.12, Fang et al. 15, Lee et al. 15)
  - ➔ **3D helical structure**
  - Pref. obs. at lower temp. (e.g. 304A)
- 2 types of concomitant flows
  - Untwisting flows (low/warm temperature)
  - Evaporation flows (hot temperature)

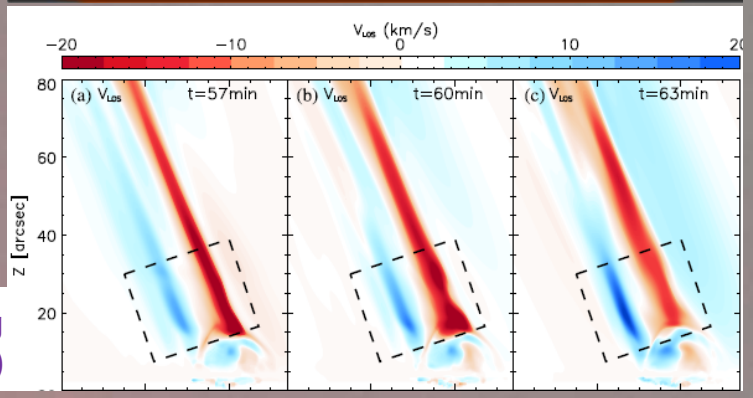


(Pariat et al.09)





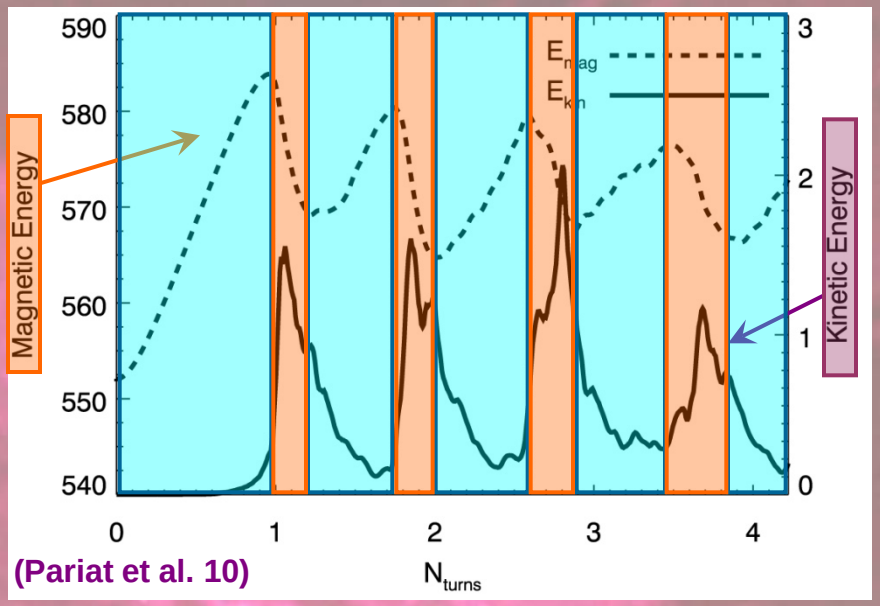
(Török et al. 09)



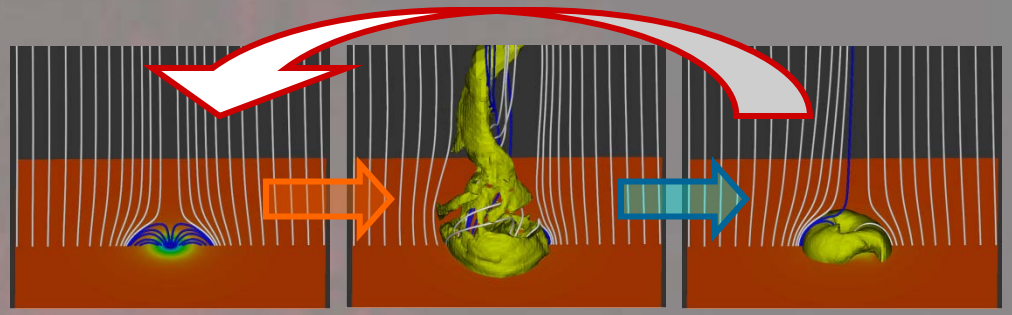
(Fang et al.14)

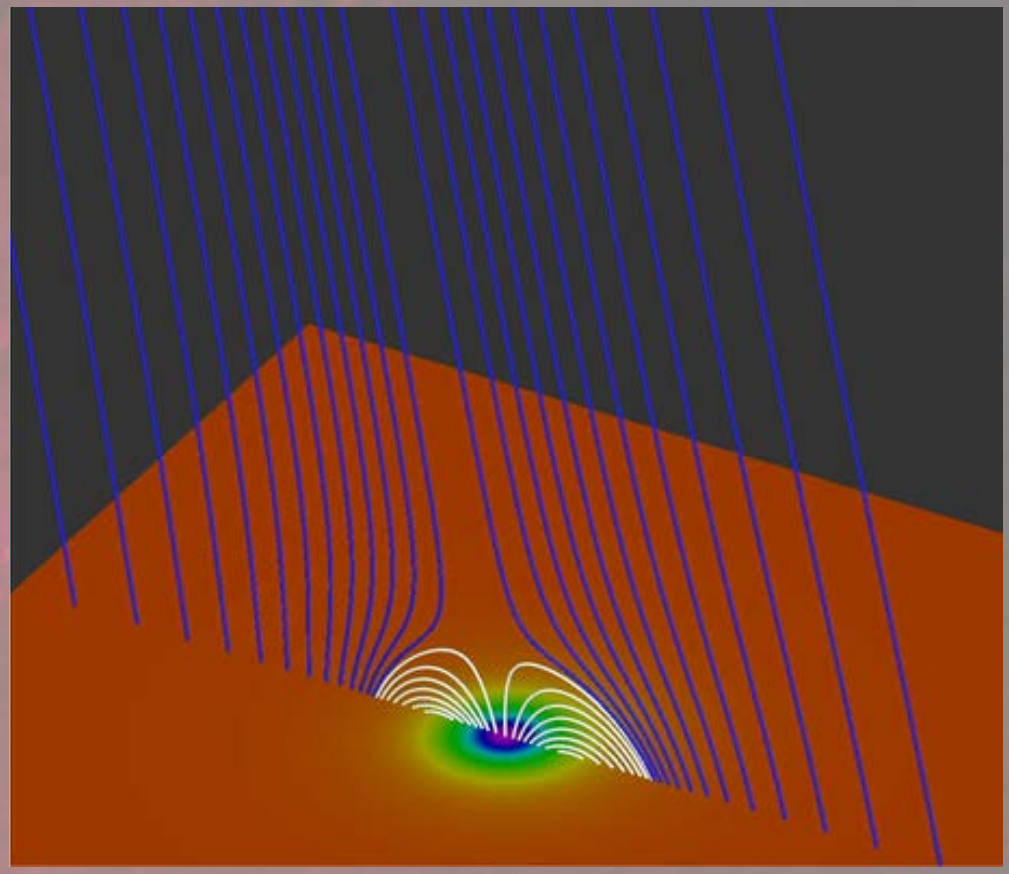
Homologous property

- **Magnetic system quasi relax to its initial potential state**
- Continuous energy injection
- **Null point configuration can simply produce multiple jets**
  - Homologous system
    - **Helicity release: jets**
    - **Relaxation & energy storage**



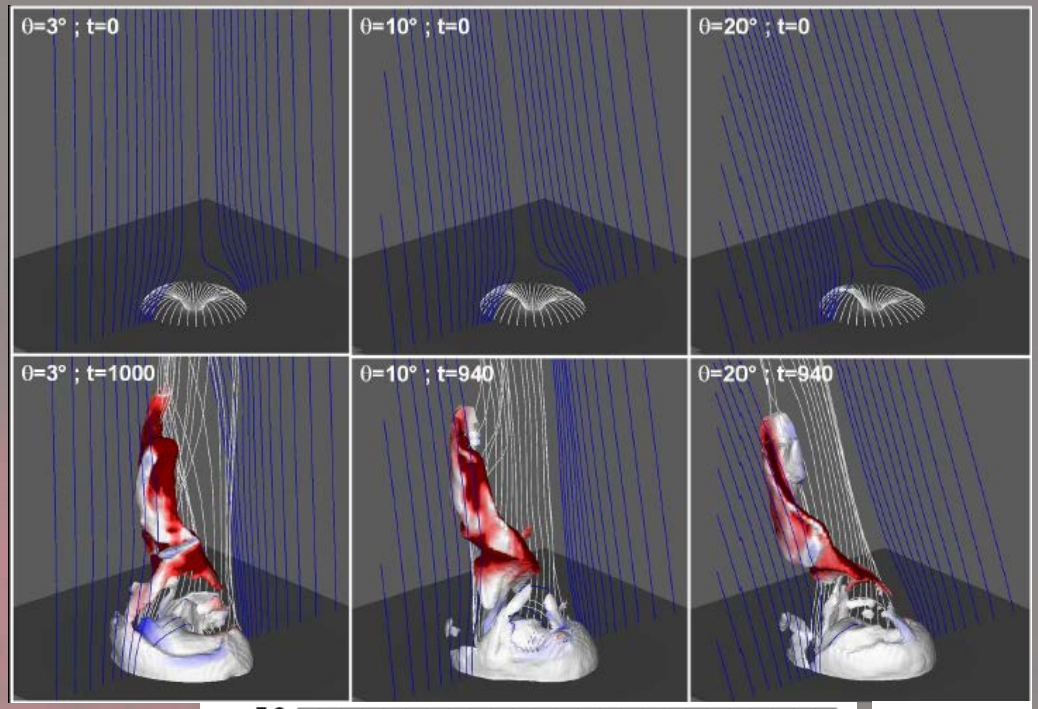
(Pariat et al. 10)



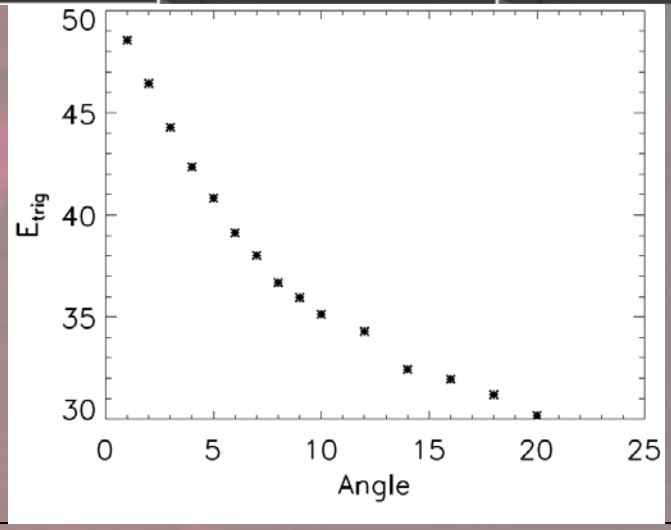


Influence of inclination

- Parametric study of the influence of the inclination, θ, of the coronal field
  - 1°< θ <20°
- **Helical jet always generated in that range of angle**
  - Direction of the blowout jet is given by the inclination θ as for observations
  - Morphology of blowout jet is very similar, i.e. indep. of θ
- **Trigger energy strongly decreases with increasing θ**
  - $E_{trig}(20°)=60\%\ E_{trig}(1°)$
  - Axisymetric system able to store more energy
  - ➔ shall generate more energetic jets

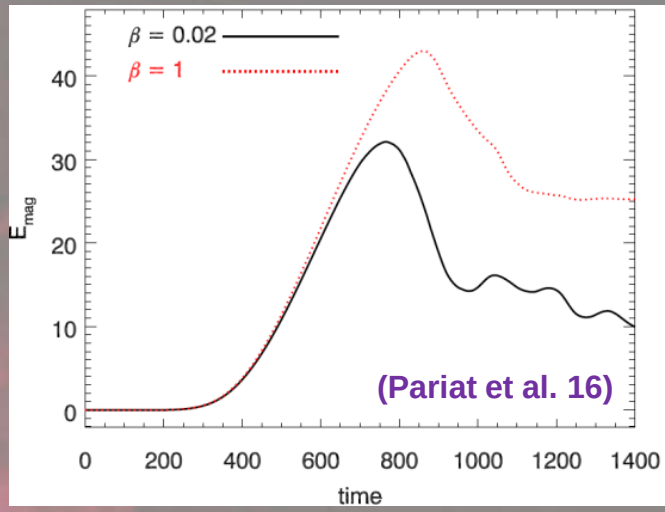


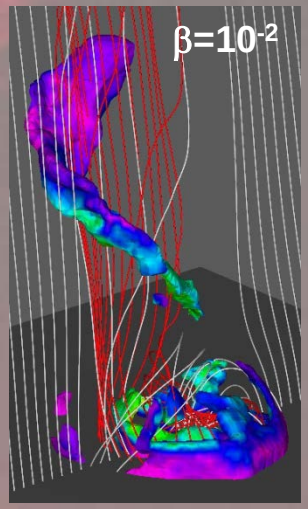
(Pariat et al.15)

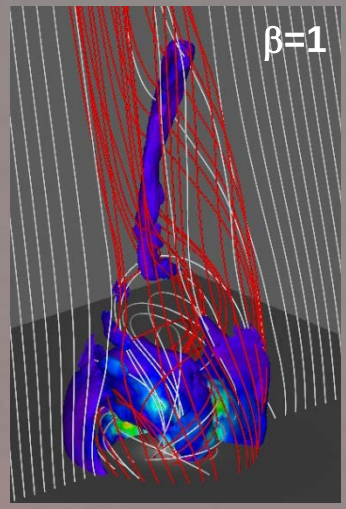


Conclusion

- Recent observations/models allow to strongly focused our understanding of coronal jets:
- **2 main reconnection-induced mechanisms: evaporation & untwisting flows**
  - Occurring concomitantly
  - Responsible for the ≠ obs. properties
  - **Relative importance/interplay of each mechanism to be understood:**
    - Relative energy distribution/transfer
    - Dependence on environmental conditions
  - No simulation is yet able to include processes
- More evidences that jets and eruptions share same type of initial condition / trigger mechanisms
    - **(Helical) jets = reconnection-destroyed erupting structures/CMEs**
    - Same problematic than flare/eruption init.
- Coronal jet study: helps to understanding of chromospheric jet/spicules?







Thanks for your attention