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Chromospheric & Coronal Jets:
triggering and driving processes

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Thanks to the members of the ISSI International Team
"Understanding Solar Jets
and their
Role in Atmospheric Structure and Dynamics"

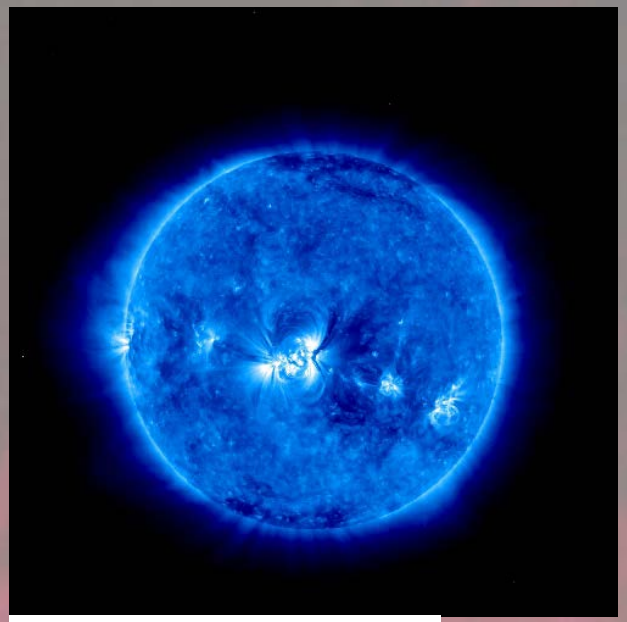
Outlook

- **Introduction**
- Coronal standard jets
- Coronal blowout jets
- Chromospheric jets
- Conclusion

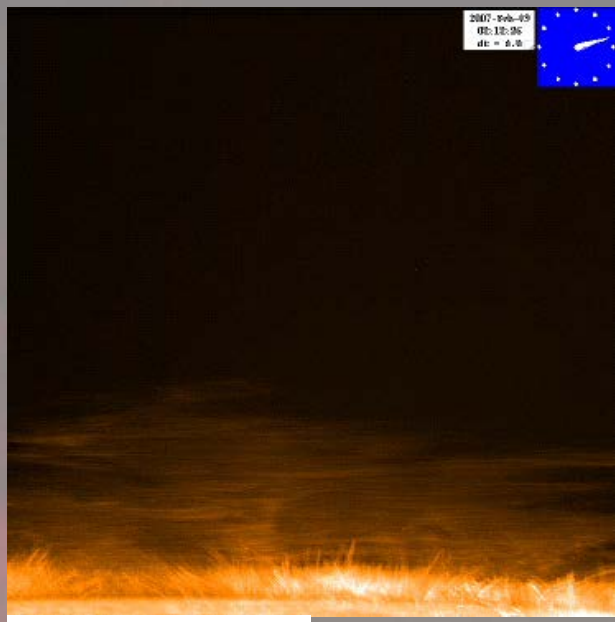
Jets: ubiquitous phenomena

- Jets are sharp edged, collimated & impulsive 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

    Cf. Talk M. Cheung
  - Photospheric jets / spicules :
    - Length < 10^3 km

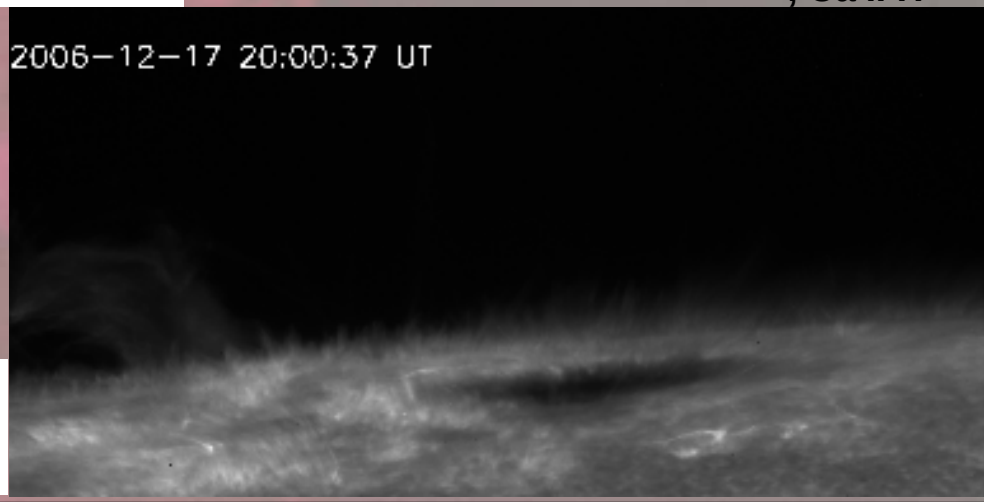


UV+White Light (STEREO) **(Patsourakos et al. 08)**



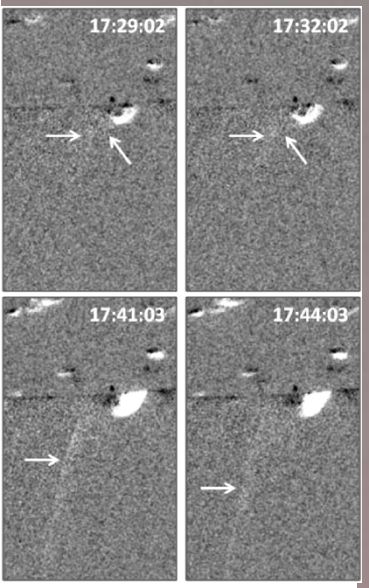
(Liu et al. 09)

SOT/Hinode , Ca II H

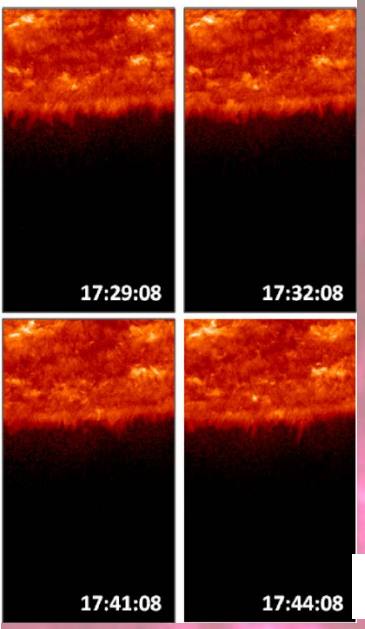


(Shibata et al 07 ; Nishizuka et al. 11)

Standard & Blowout jets

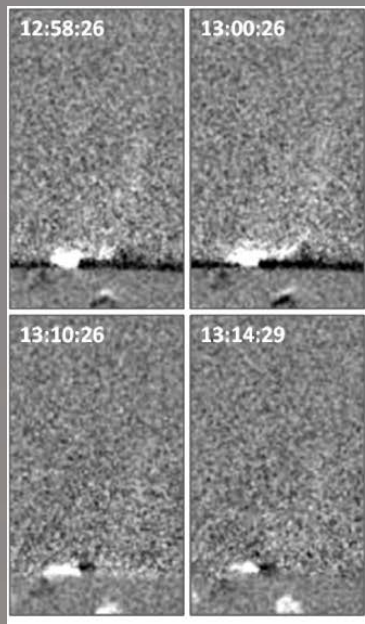


Standard

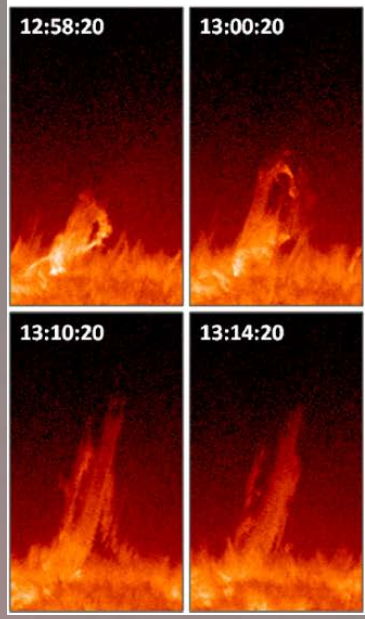


(Moore et al. 13)

- Possibly 2 types of jets: **Moore et al. 10,13**
- **Standard jets:**
  - Simple (“single”) spire
  - X-ray bright point brightening at base
  - Emission in hot lines
  - Little emission in cooler lines.
- **Blowout jets:** **(Moore 10, 13, Sterling et al. 11, Liu et al. 11, Shen et al. 12,Morton et al. 12, Hong et al. 11,13)**
  - Complex, broad spire
  - Strong X-ray base brightening at base
  - Substantial emission in cold lines
  - Rotation strongly marked

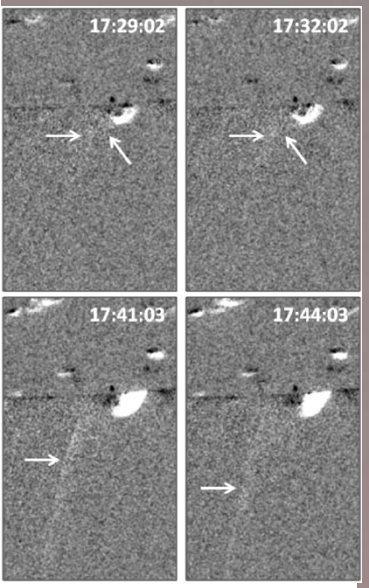


Blowout

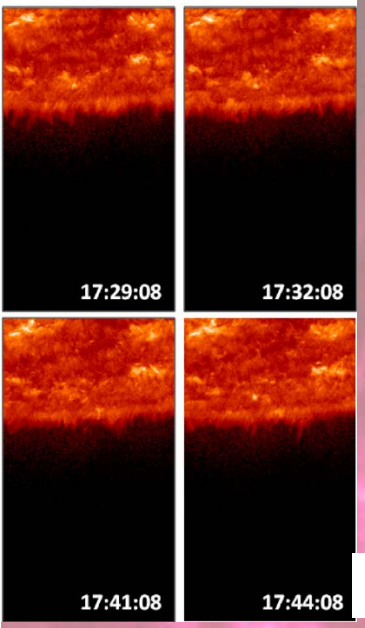


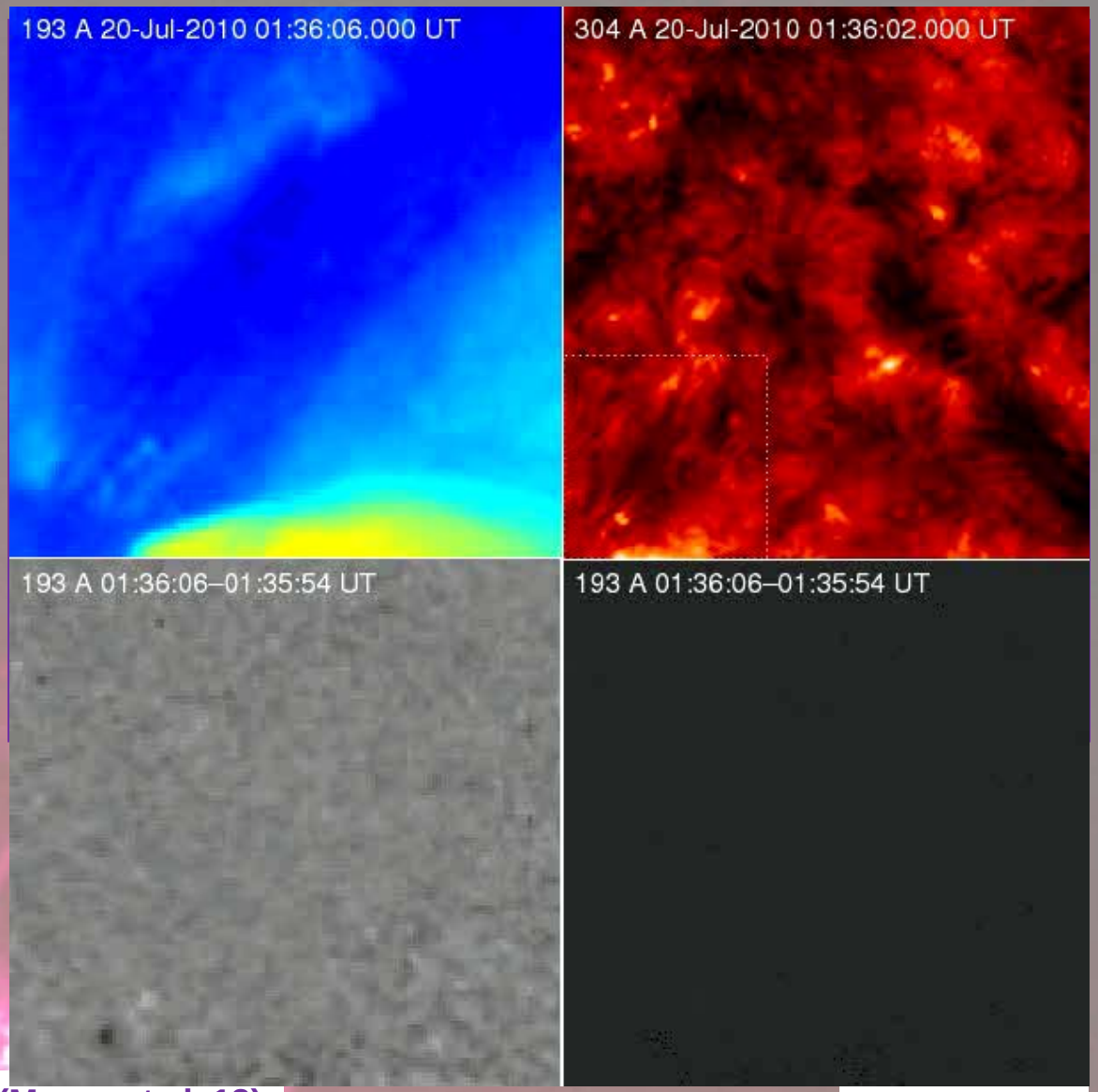
(Liu et al. 11)

Standard & Blowout jets



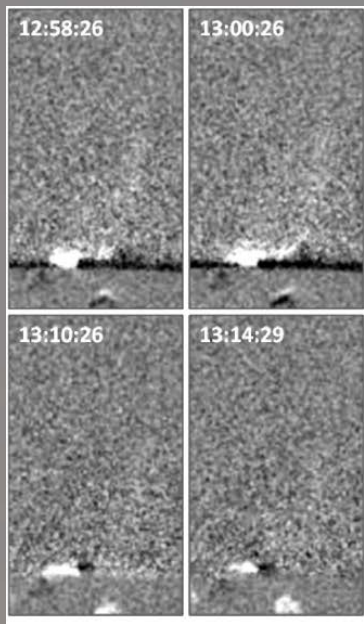
Standard



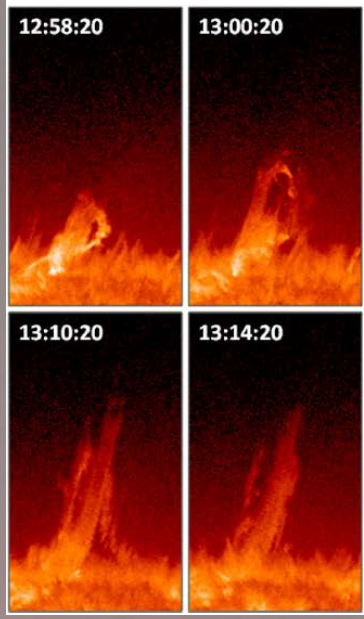


(Moore et al. 13)

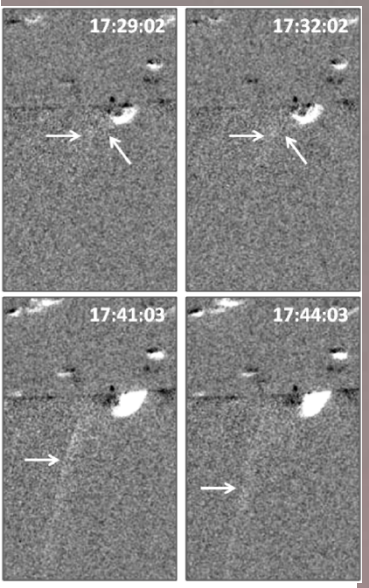
(Liu et al. 11)



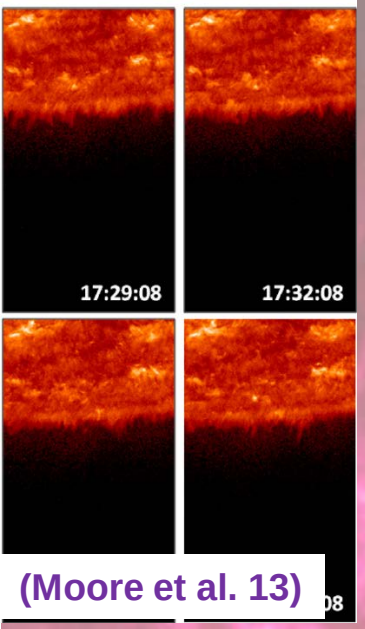
Blowout



Standard & Blowout jets



Standard



(Moore et al. 13)

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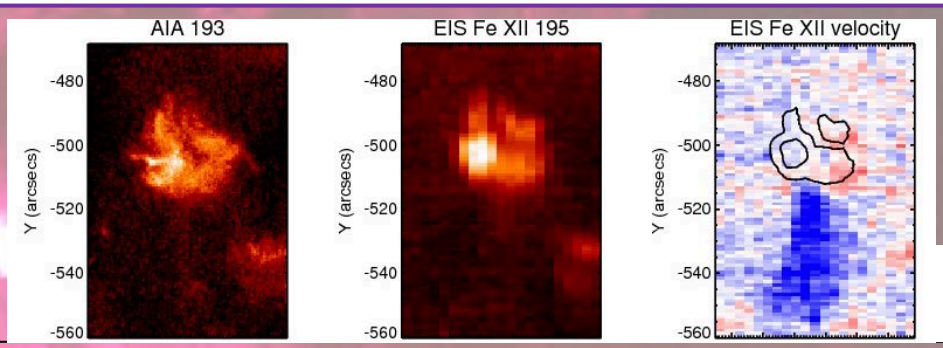
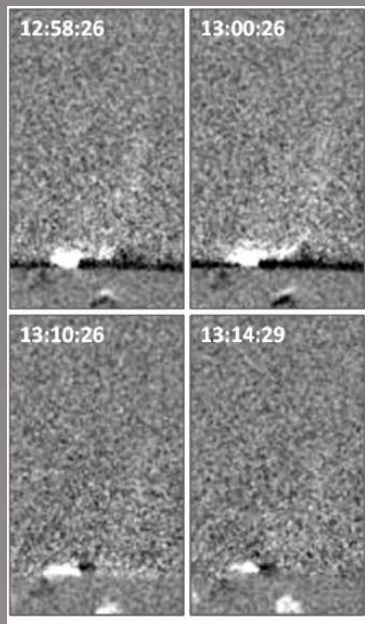
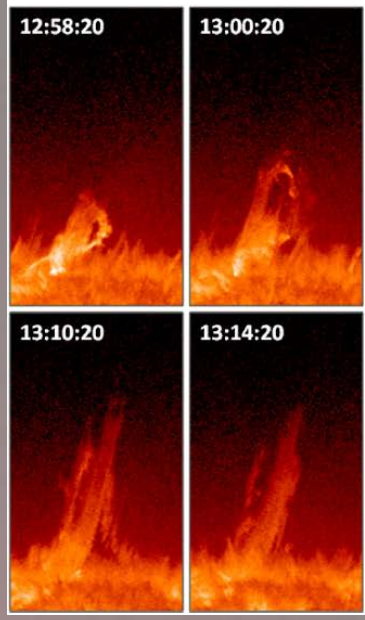
  - Complex, broad spire
  - Strong X-ray base brightening at base
  - Substantial emission in cold lines
  - Rotation strongly marked
- **“Dark” jets: c.f. Peter Young Talk**
  - Large blue-shifted features in EIS spectrograph
  - Very weak intensity signal in EUV AIA images



(Young et al. 13)

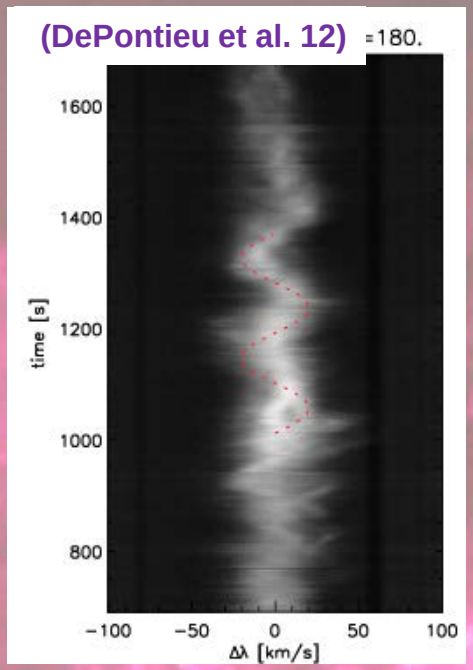


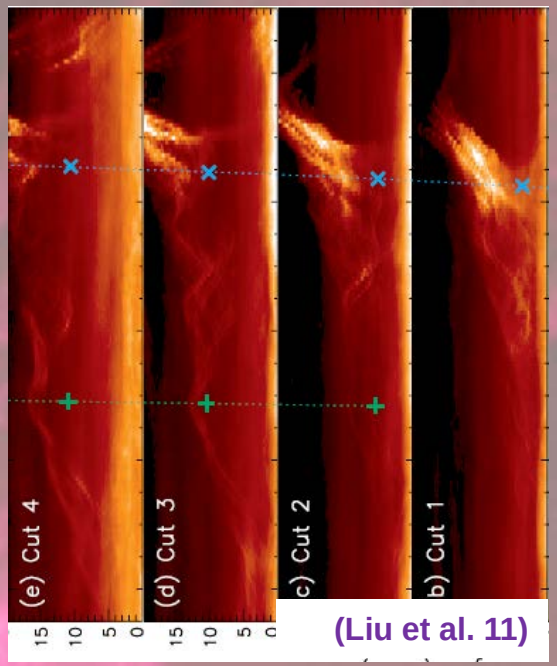
Blowout

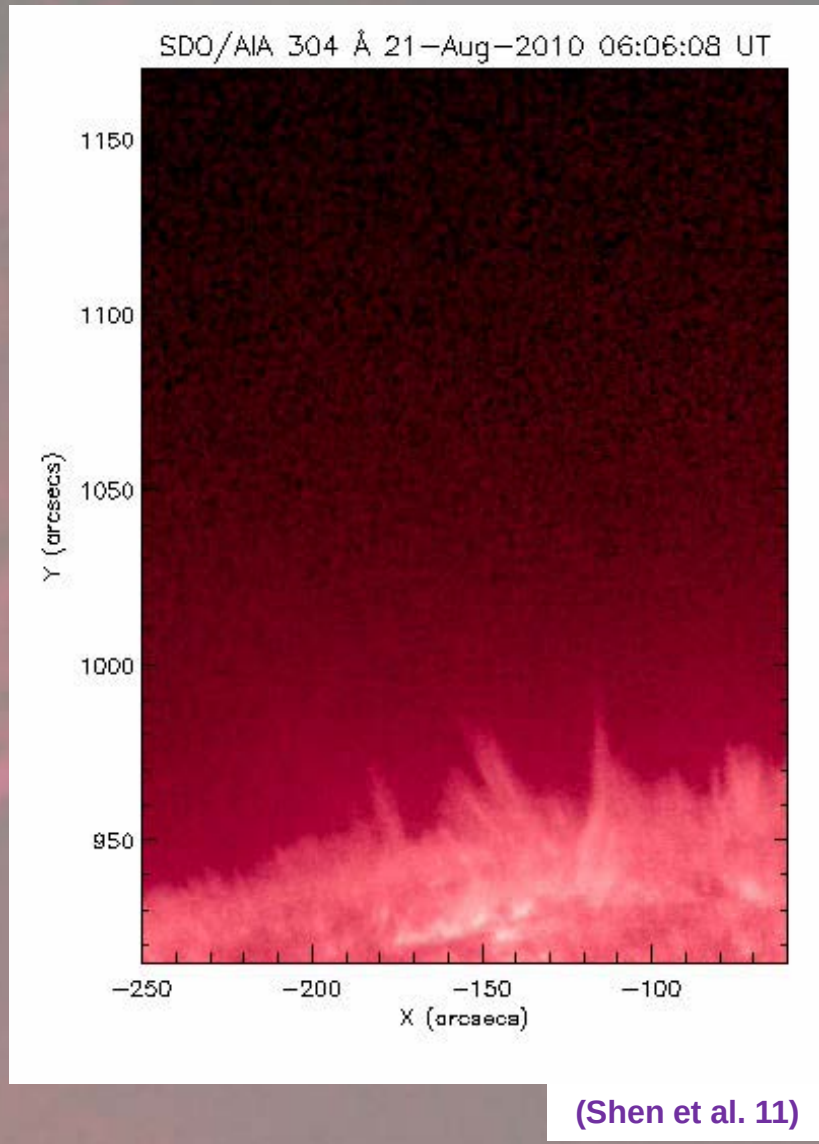


Helical properties of jets

- **Helical structure commonly observed**
  - Morphology **(e.g. Shibata et al. 92, Canfield et al. 96, Jibben et al. 04, Jiang et al. 07, Liu et al. 09,11,Shen et al 11,12, Chen et al. 12, Hong et al. 13)**
  - Doppler imaging **(Harrison et al. 01, Jibben et al. 04)**
  - 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)

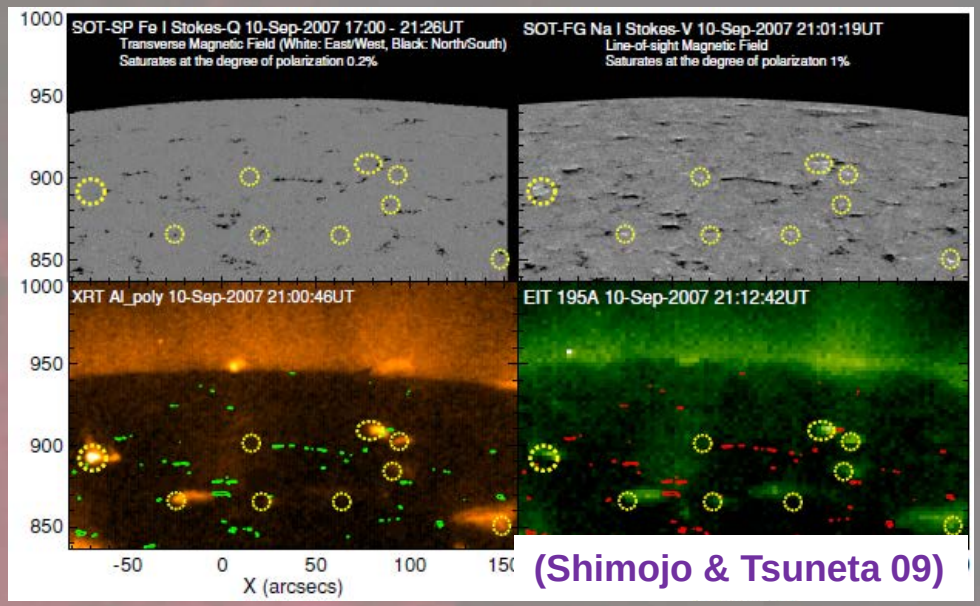




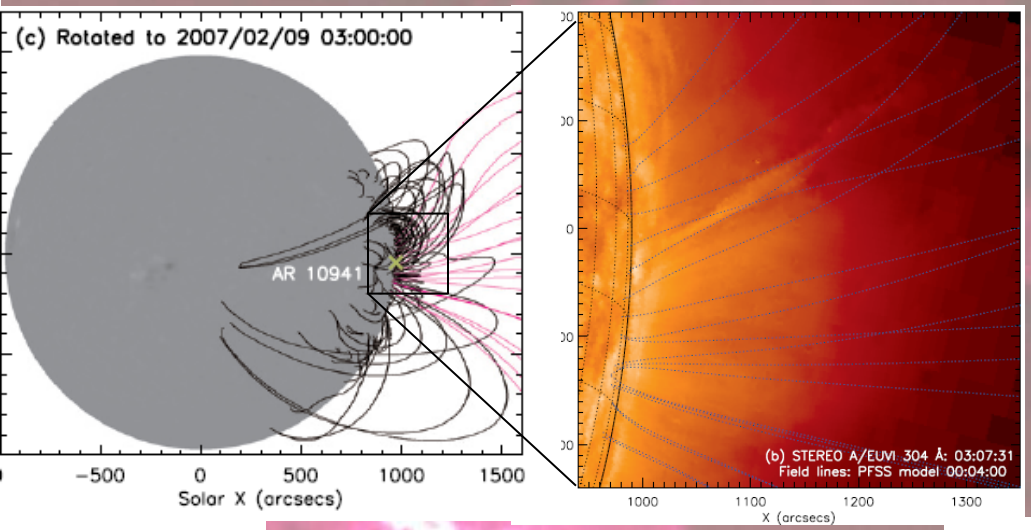


Magnetic field properties

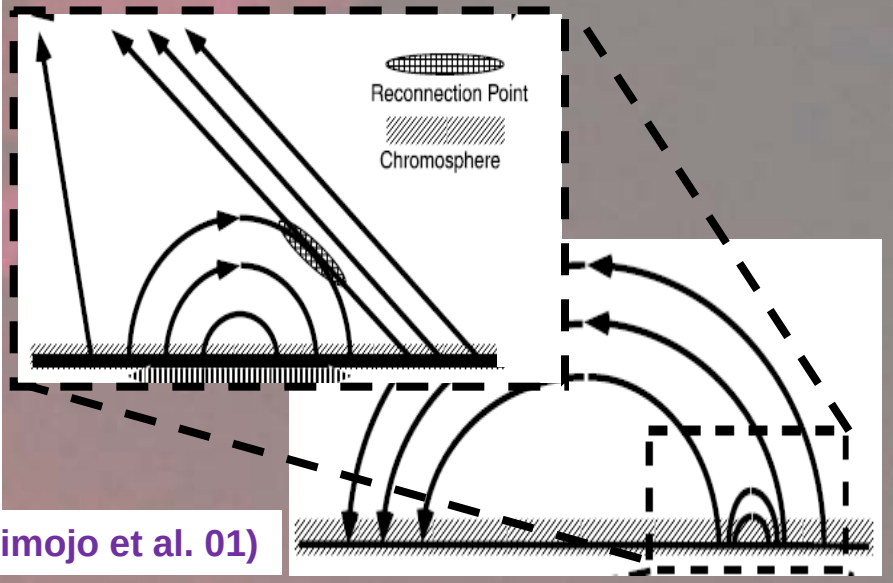
- Jets generally (~90%) associated with multipolar fields. **(Shimojo et al, 98,09)**
- Jet collimated along “open” **B** lines:
- **Jets occur at the interface of two connectivity domains:**
- close & “open” = two different characteristic length of **B** gradients
  - **Necessary ingredients for jets**



(Shimojo & Tsuneta 09)



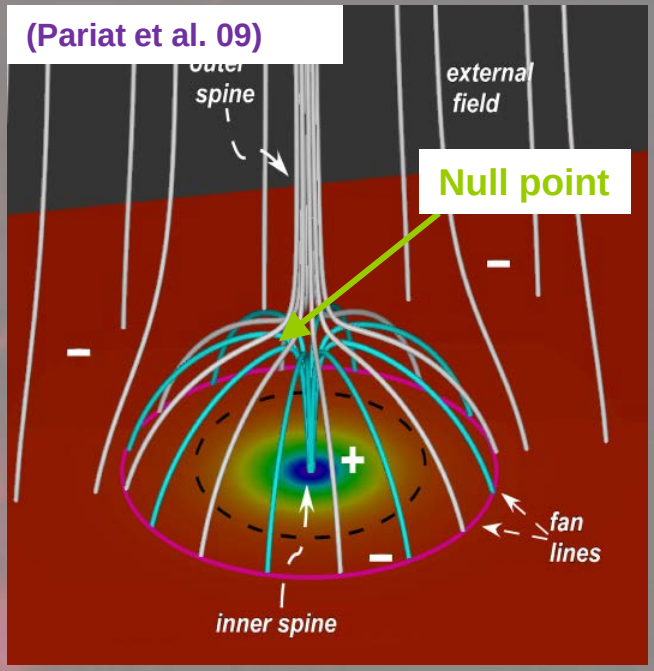
(Liu et al. 11)

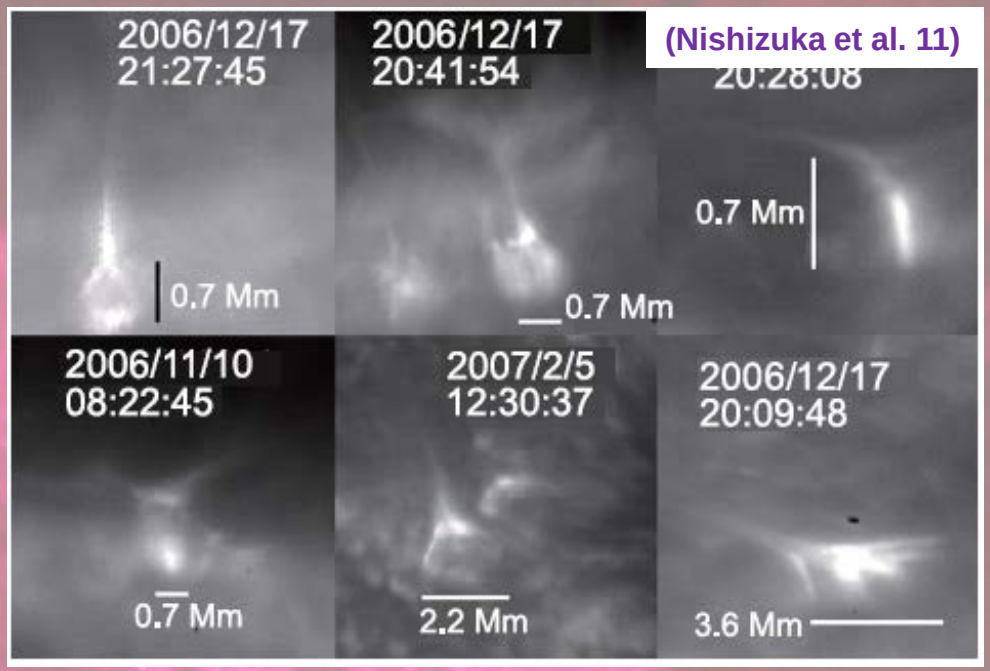


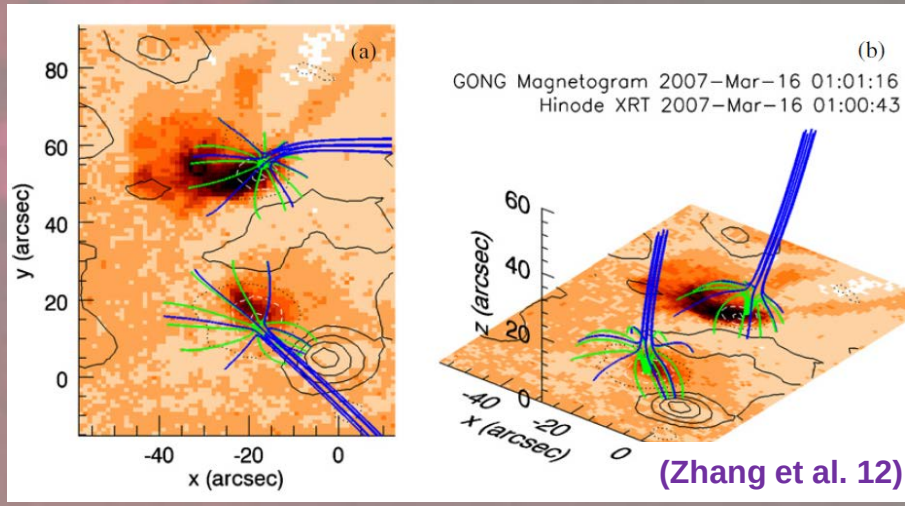
(Shimojo et al. 01)

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**





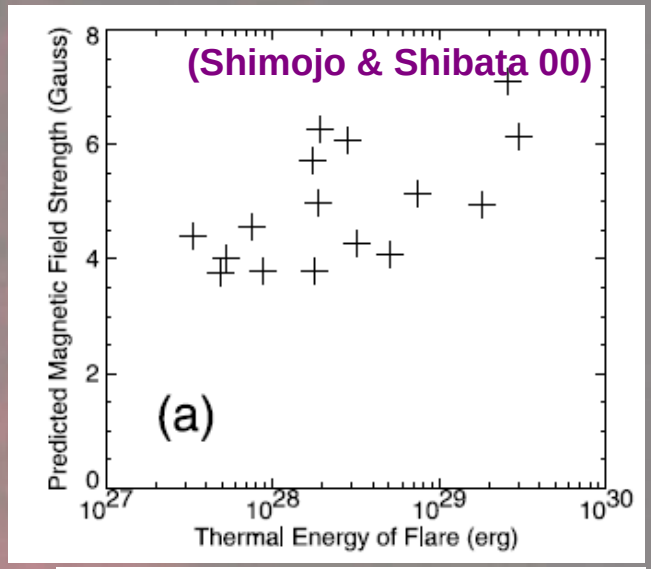


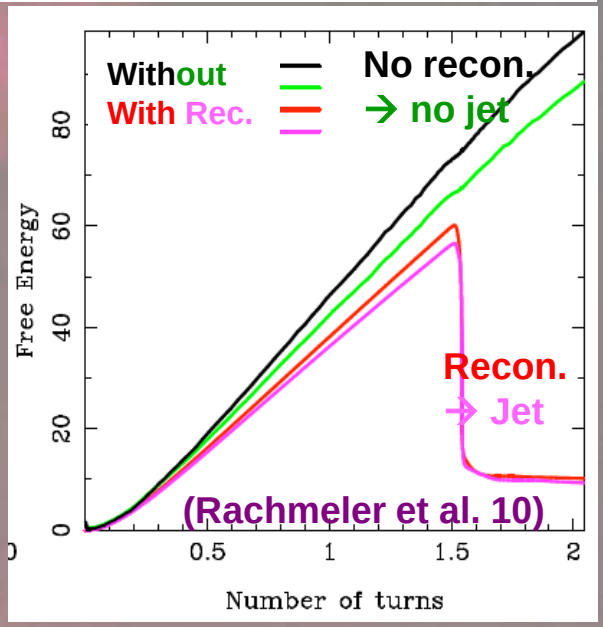
Outlook

- Introduction
- **Coronal standard jets**
- Coronal blowout jets
- Chromospheric jets
- Conclusion

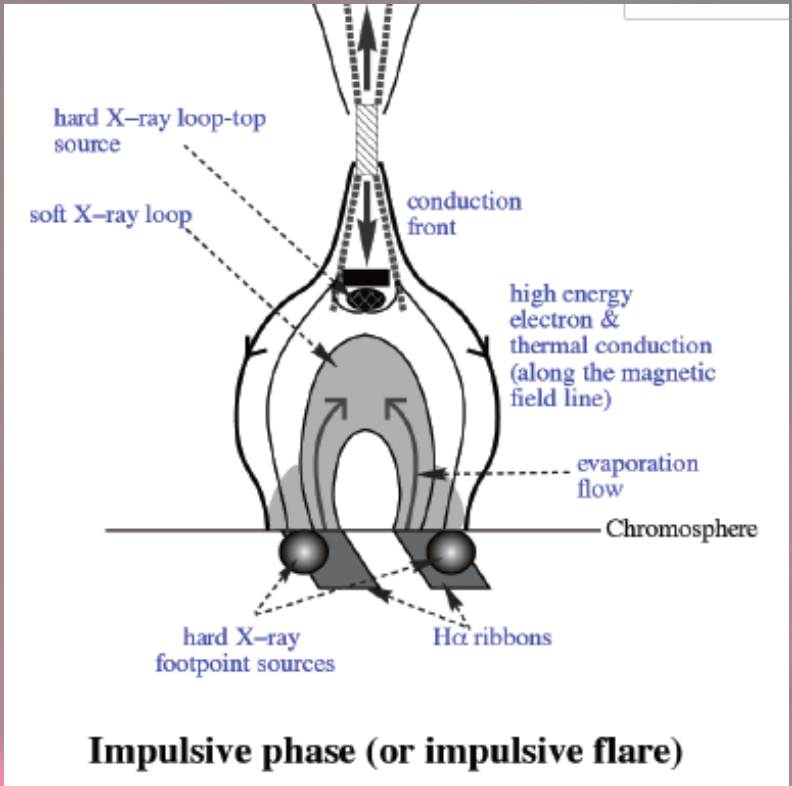
Evidence for magnetic reconnection

- 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**

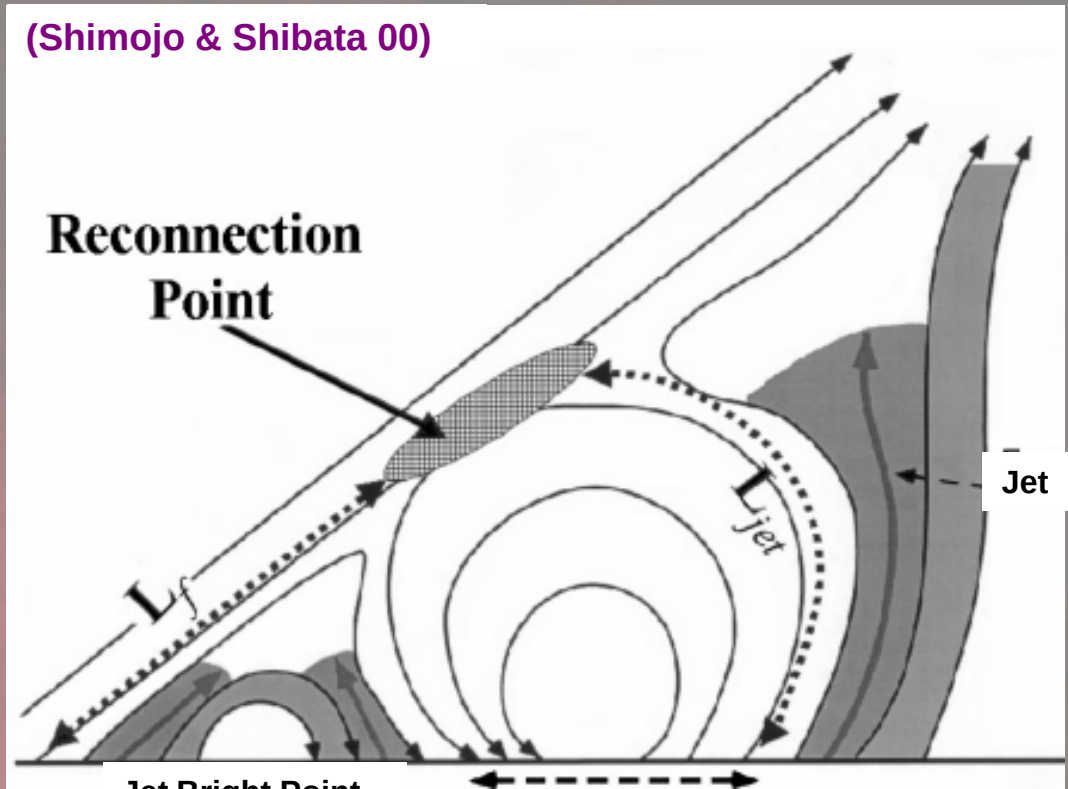




Mechanism for jets (2D)



(Shimojo & Shibata 00)

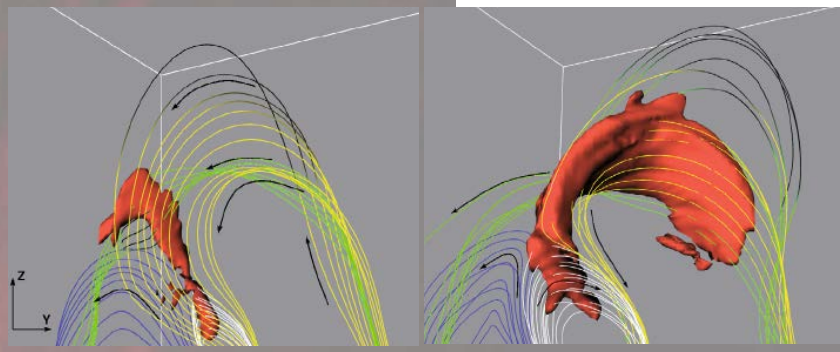


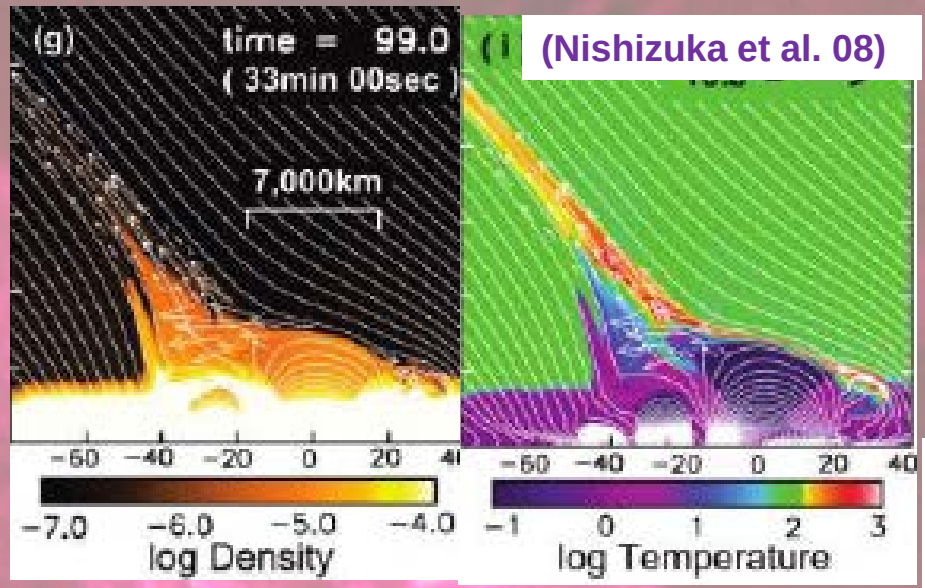
- **Jet bright point: standard post flare loop**
- **Jet: non-standard post flare loop**
  - Energy deposit close to base of a extended loop
  - Transfer of energy along the extended loop
    - Kinetic (Bulk flow, waves) ? Internal (Thermal Conduction) ? Magnetic (waves) ?

Reconnection jet

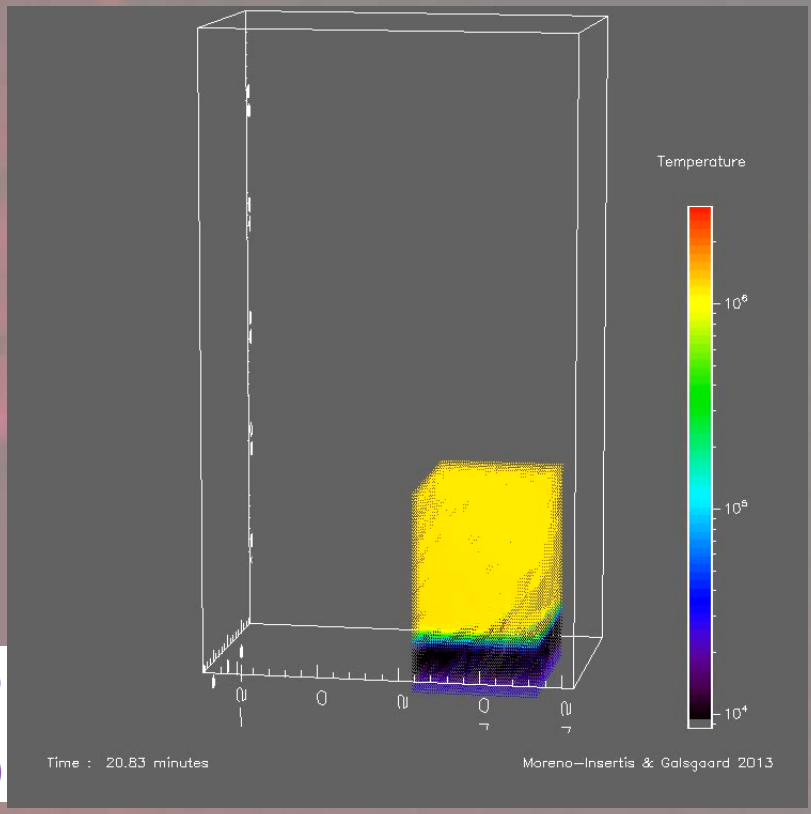
- **Plasma accelerated along B by magnetic tension (slingshot)** : $V_{jet} \sim V_{alfvén}$
  (e.g. Shibata et al. 92, Yokoyama et al. 95, 96, Shimojo et al. 98,00; Galsgaard et al. 05, Moreno-Insertis et al . 08, 13, Nishizuka et al. 08, Rachmeler et al. 10, Archontis et al. 13)
- Intense heating ➔ hot, low density jets
- Advected plasma: cool & dense jet/surge on the side.
  - "Jet" shape in 3D ? **(Moreno-Insertis et al. 13)**

Gontikakis et al. 09





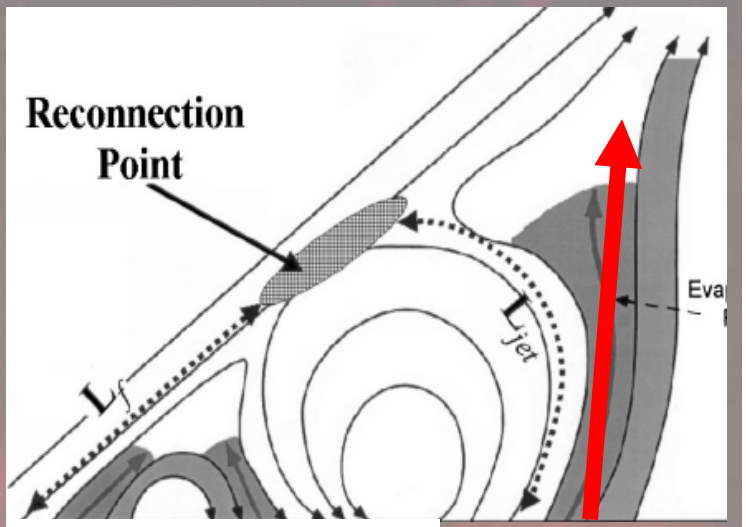
(Nishizuka et al. 08)



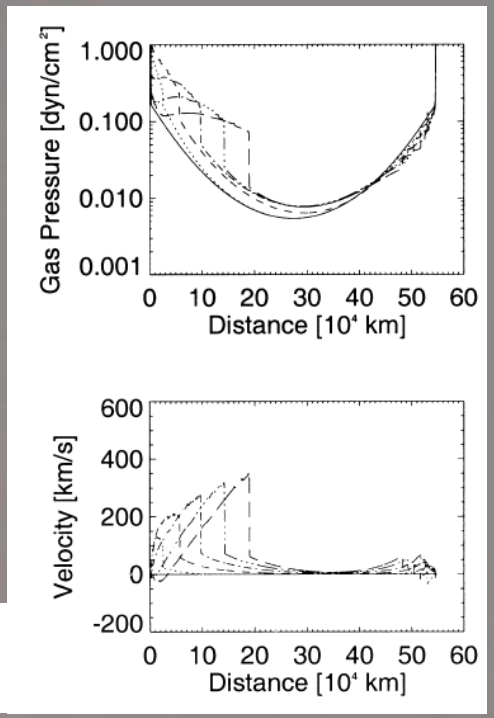
(Moreno-Insertis et al. 13)

Evaporation-flow jet

- **Evaporation-flow jet:**
  - Effect of heat conduction
  - Energy deposit in the lower denser layer by reconnection
  - ➔ Upflow of material: $V_{Jet} \propto Cs$
  - **Driver: gas pressure gradient force**

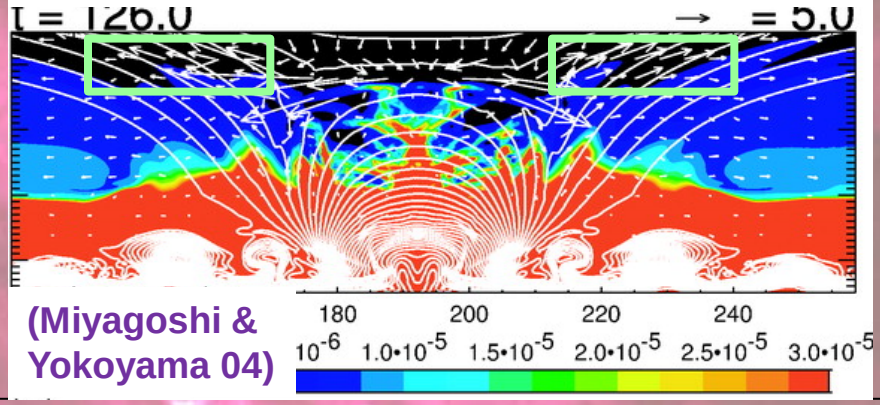


Shimojo & Shibata, 00



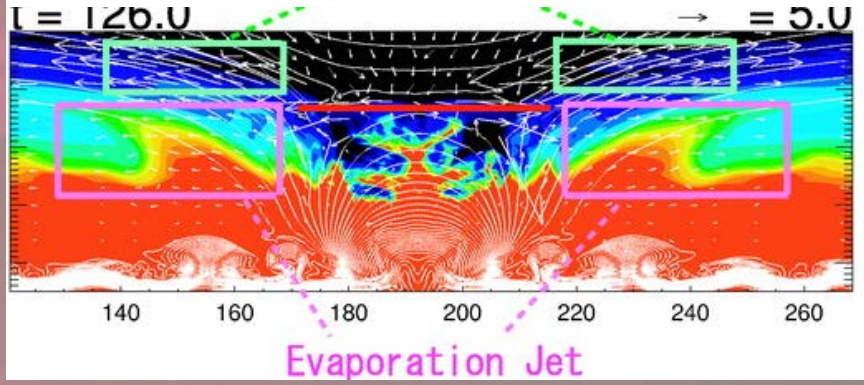
Shimojo et al. 01

No heat conduction



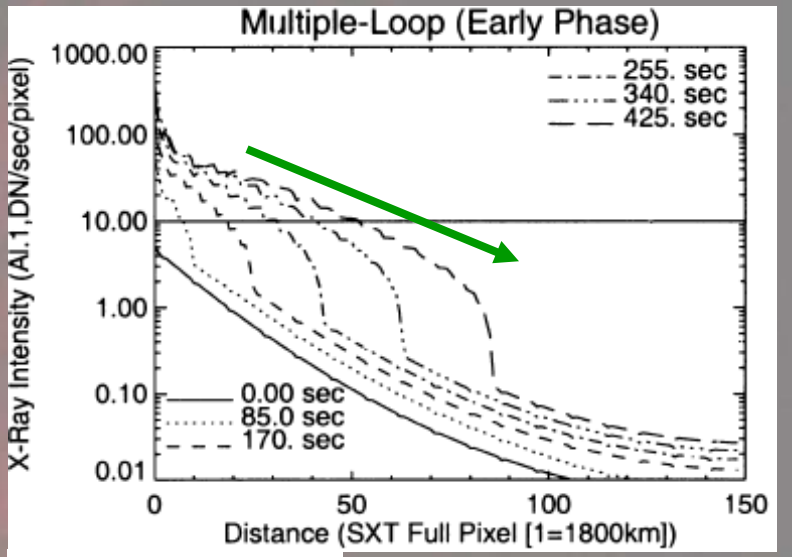
(Miyagoshi & Yokoyama 04)

Reconnection Jet



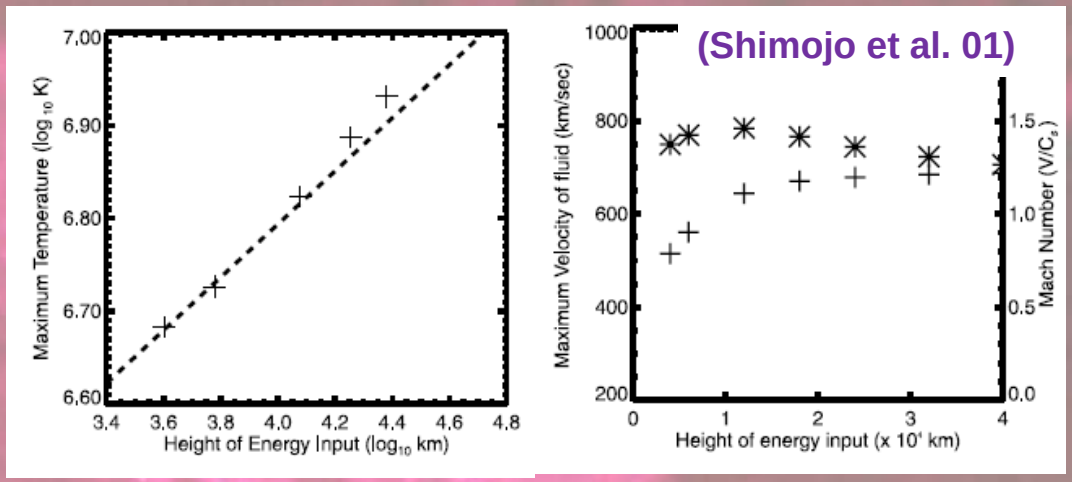
Evaporation-flow jet

- **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 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

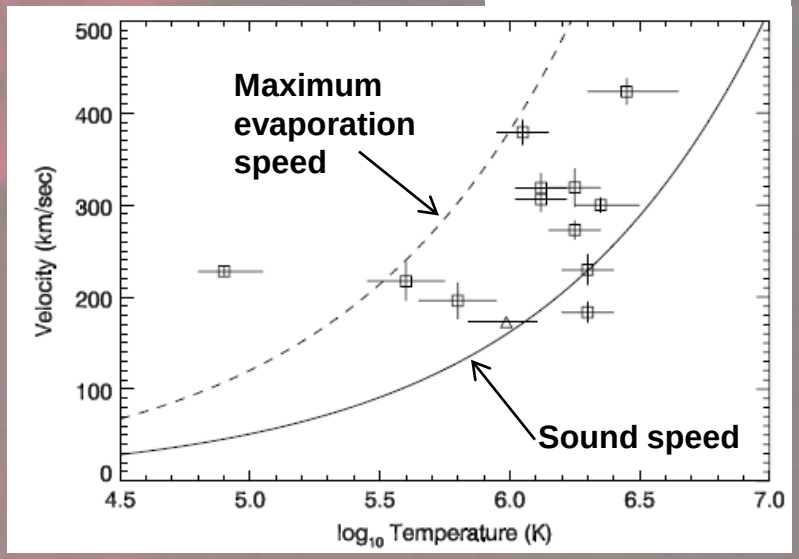


Shimojo et al. 01

Matsui et al. 12



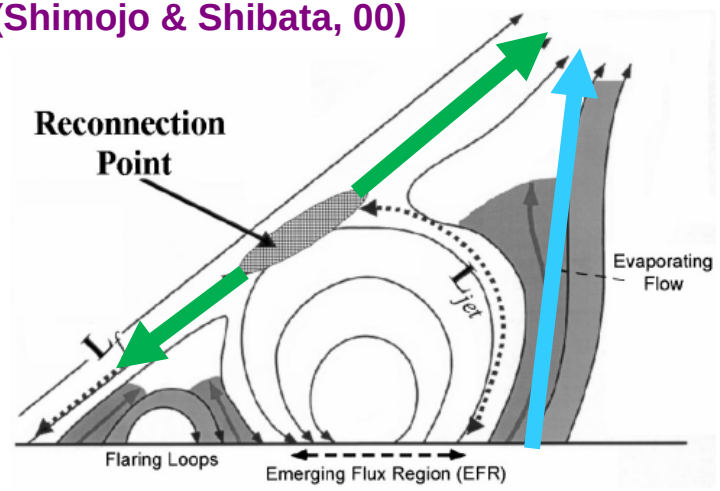
(Shimojo et al. 01)

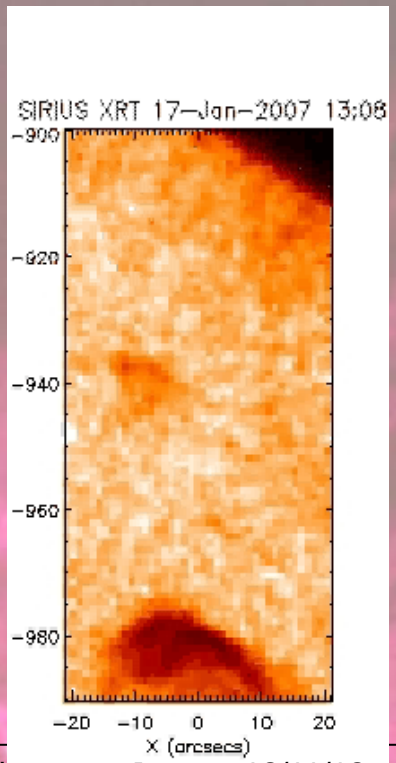


Mechanism for Jets

1) **Reconnection jet: (e.g., Shibata et al. 1992)**
   Plasma accelerated by the magnetic tension (slingshot) : $V_{jet} \sim V_{alfvén}$
2) **Evaporation flow: (e.g., Shimojo et al. 2001)** Plasma accelerated by gas pressure gradient induced by heating at the foot of reconnected loops : $V_{jet} \sim C_{Sound}$

(Shimojo & Shibata, 00)





(Cirtain et al. 07)

- **Trigger of standard jets = trigger of impulsive reconnection**
  - Dynamical forcing on the current sheet (e.g. flux emergence)
  - Instability (e.g. secondary tearing) at the current sheet
- **These mechanism cannot however explain the 3D helical structure of "blowout jets"**

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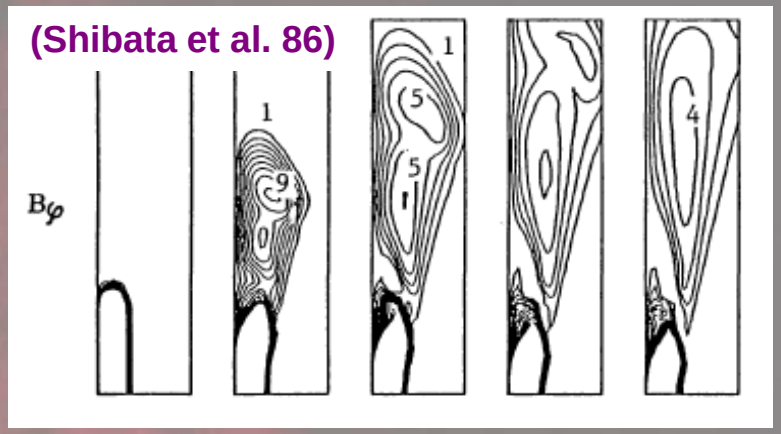
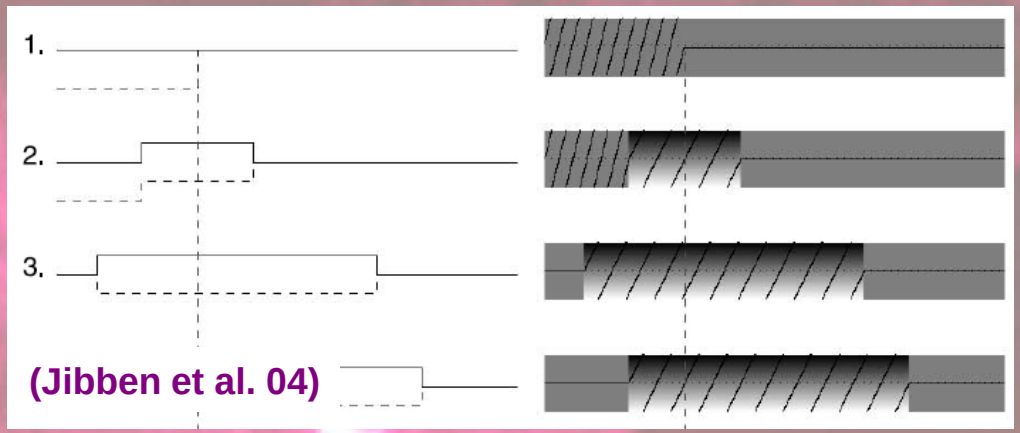
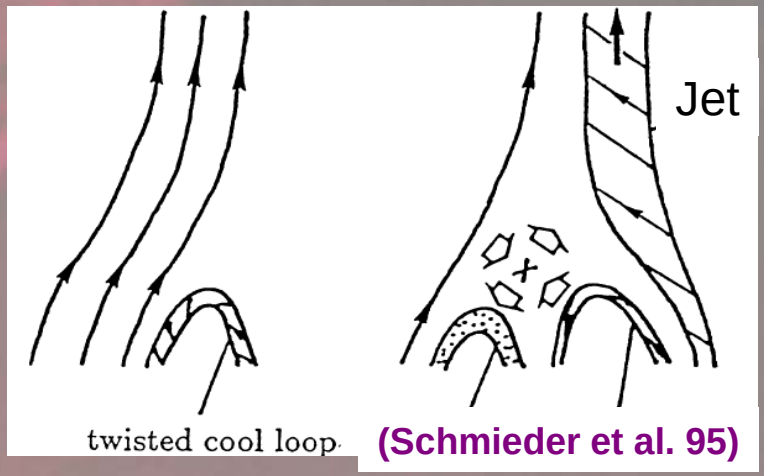
Magnetic untwisting jet

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

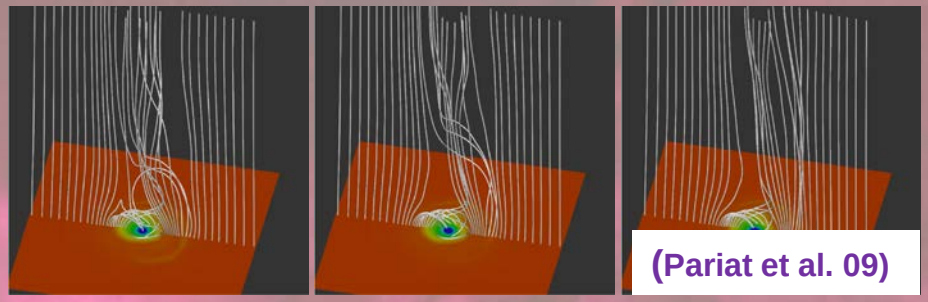




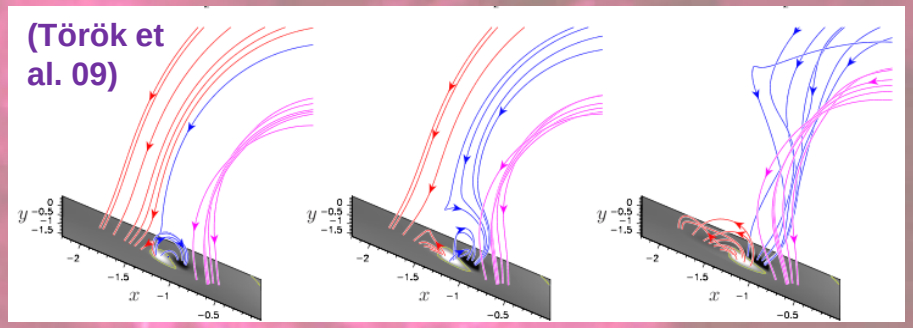


3D model of magnetic untwisting jet

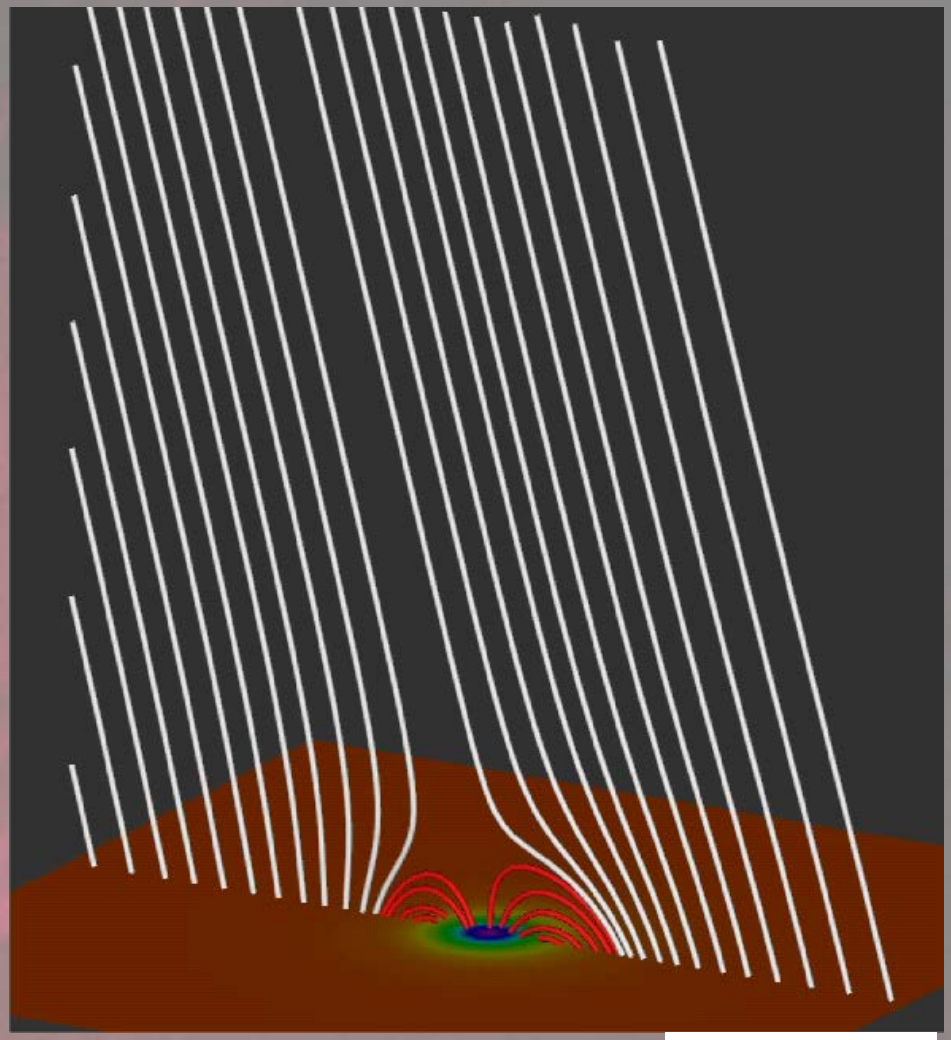
- **Blowout jet formed by the sequential reconnection of field lines (Pariat et al.09,10; Török et al. 09; Dalmasse et al.12)**
  - **➔ 3D helical structure**
  - Pref. obs. at lower temp. (e.g. 304)
- 2 types of concomitant flows
  - Embedded reconnection-jet
  - Non-linear Alfvénic wave



(Pariat et al. 09)



(Török et al. 09)



(Pariat et al.10)

Blowout jet = disrupted erupting flux rope

- Erupting flux ropes interact with the coronal environment
  - Magnetic reconnection between the erupting flux rope and surrounding field

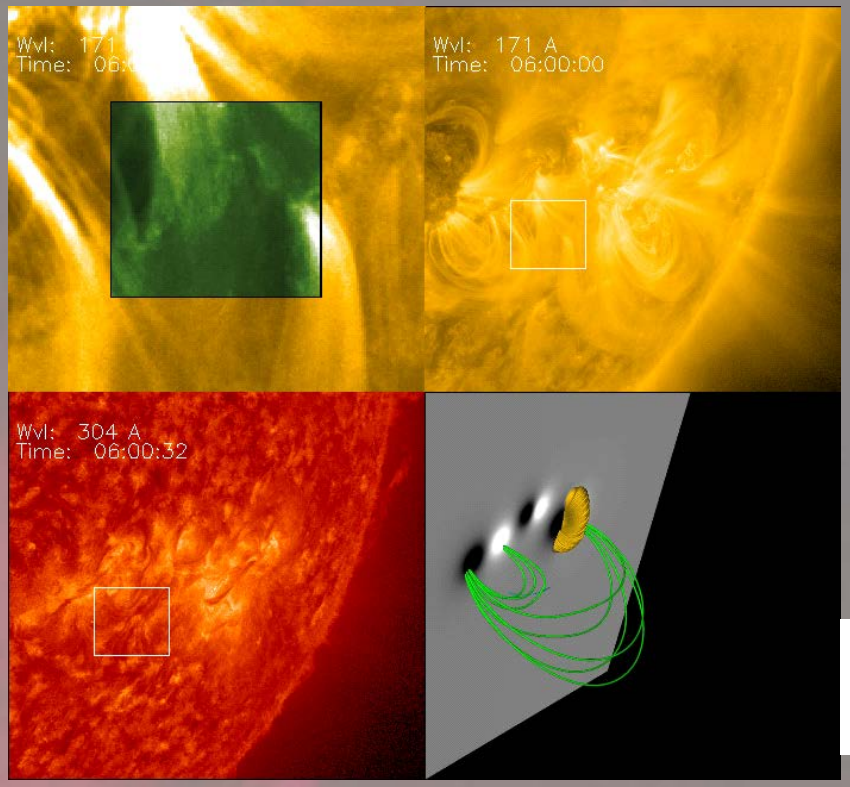
    (Hudson et al. 96, Pick et al. 98, Maia et al. 99, Attrill et al. 06, 07, Wen et al. 06, Mandrini et al. 07 Roussev et al. 07, van Driel-Gesztelyi et al. 08, 14, Cohen et al. 09, 10, Lugaz et al.11)

- If $\Phi_{\text{erupting flux rope}} >> \Phi_{\text{environement}}$
  ➔ erupting flux rope "survives"
  ➔ CME

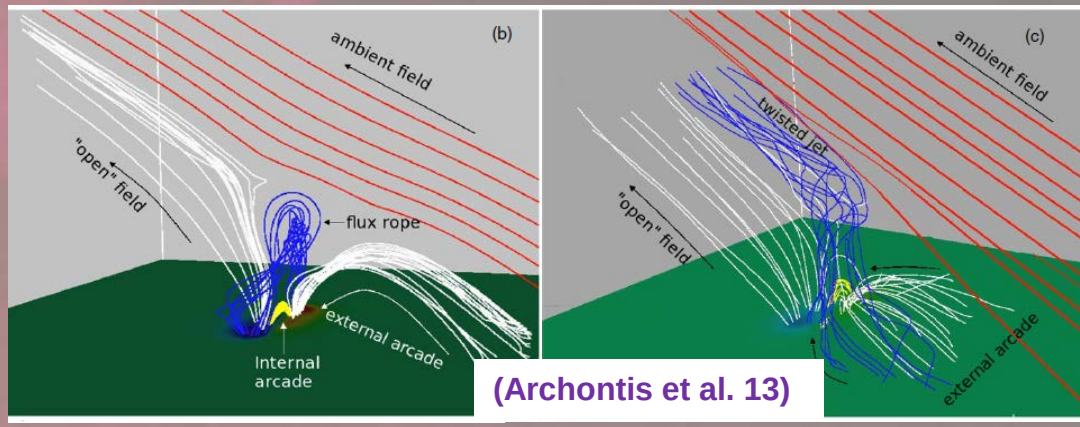
- If $\Phi_{\text{erupting flux rope}} < \Phi_{\text{environement}}$
  ➔ erupting flux rope is disrupted, i.e. reconnects fully with surrounding fields

  ➔ twist transferred to open magnetic field

  ➔ **untwisting jet**



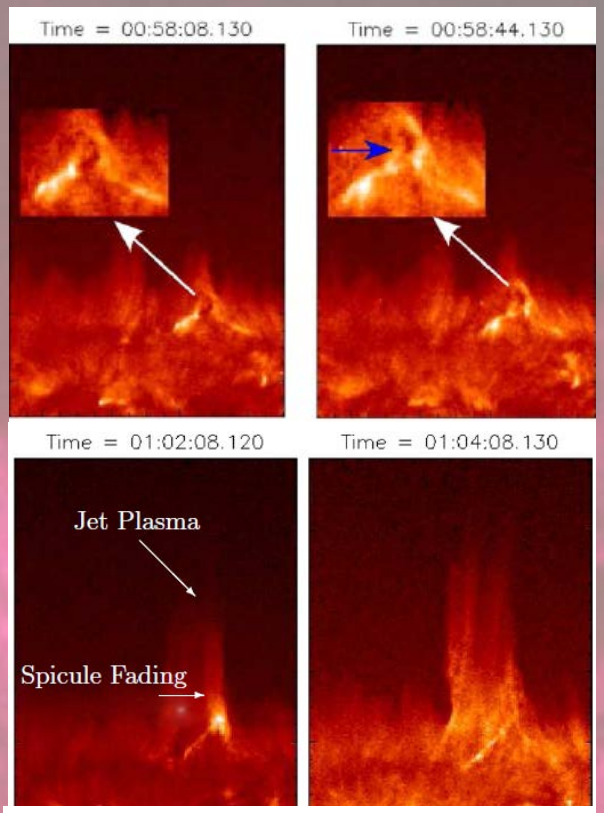
(van Driel-Gesztelyi et al. 13)



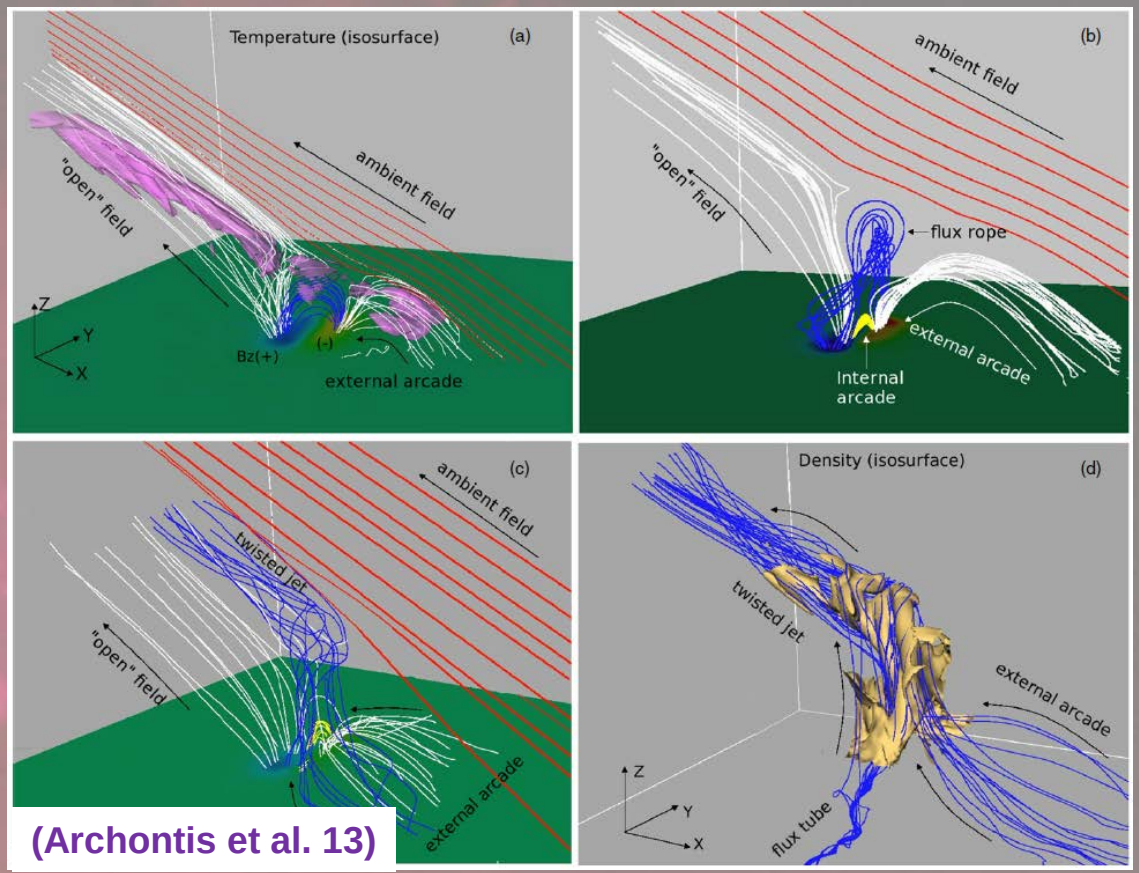
(Archontis et al. 13)

Blowout jet = disrupted erupting flux rope

- **Blowout jets are disrupted erupting flux rope** (Moore et al. 10, Raouafi et al. 12, Moreno-Insertis et al. 13, Archontis et al. 13, Kayshap et al. 13)
- Jet driver: untwisting of the reconnected field lines of the disrupted flux rope (Pariat et al. 09,10, Török et al. 09, Moore et al. 10,13)
- **Trigger of blowout jets = trigger of coronal mass ejection**



(Kayshap et al. 13)



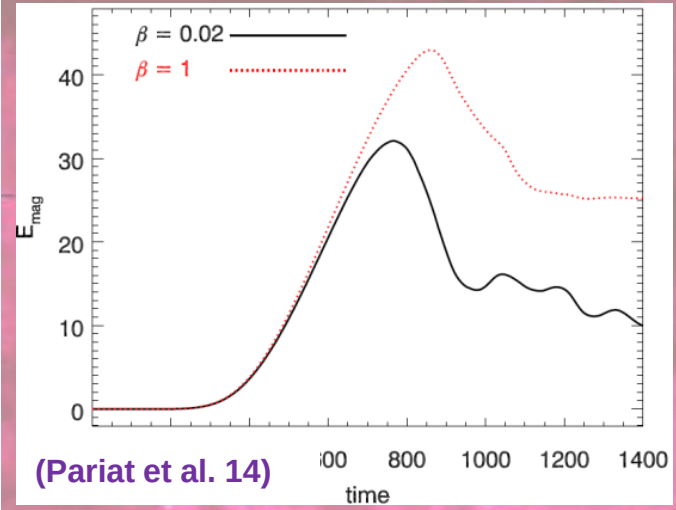
(Archontis et al. 13)

Outlook

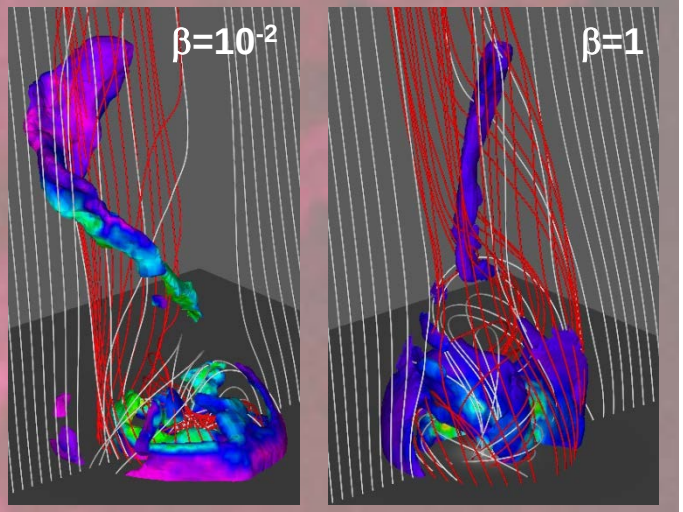
- Introduction
- Coronal standard jets
- Coronal blowout jets
- **Chromospheric jets**
- Conclusion

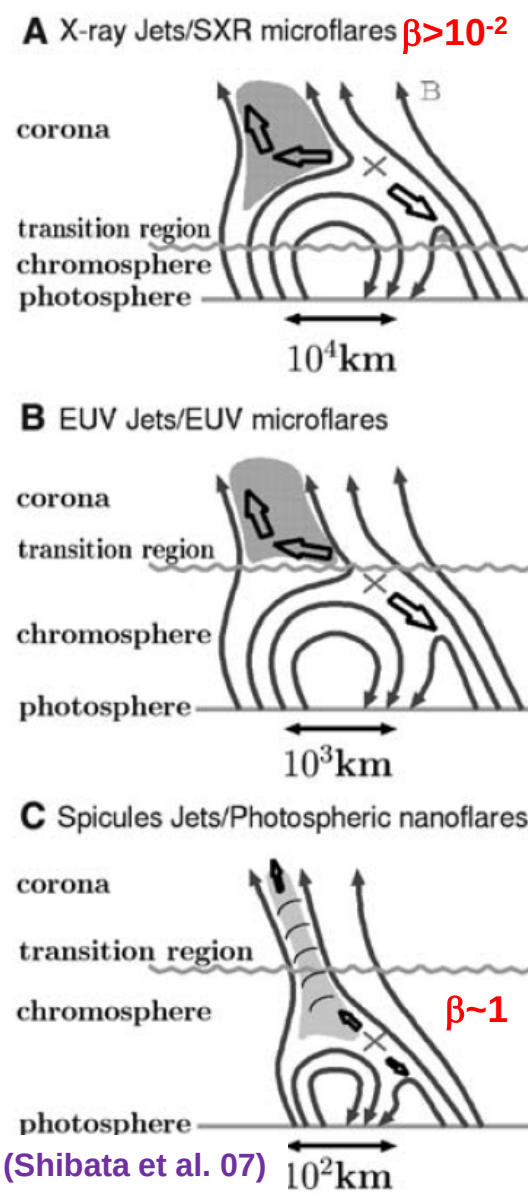
From coronal to chromospheric jets

- Within MHD, same mechanisms that drive coronal jet in play for TR & chromospheric jets
- **However, ≠ MHD regime: Corona: β << 1; Chrom.: β~1**
  - Modification of the energy transfer mechanism
  - Modification of the geometrical property
- **Chromosphere has a very different dynamics**
  - Low-ionization induces different properties for reconnection
    (e.g. Cheung et al. 12, Leake et al. 12, Martinez-Sykora et al. 12)
- **Magnetic field not the unique possible energy source**
  - wider variety of possible mechanisms in the chromosphere



(Pariat et al. 14)

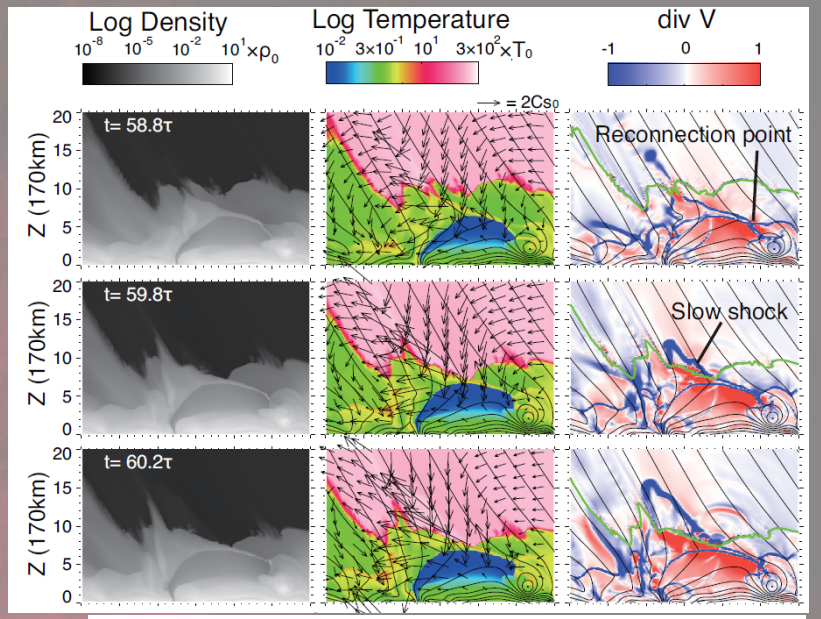


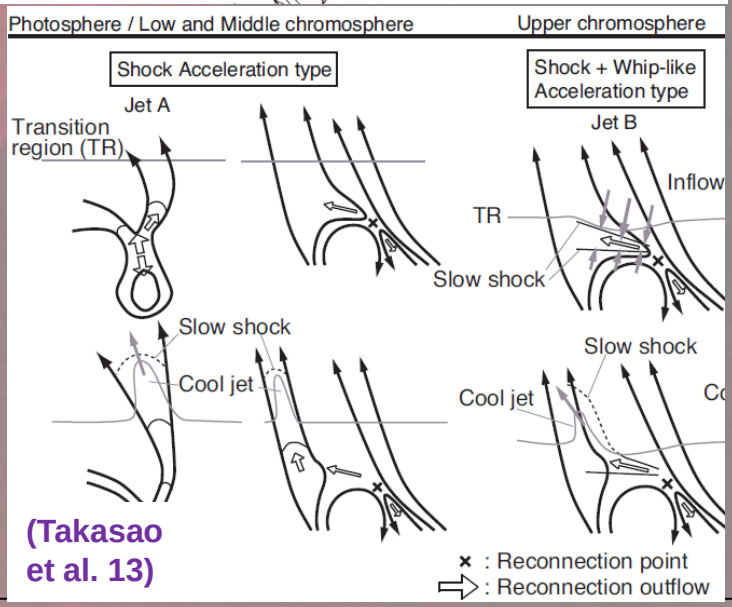


(Shibata et al. 07)

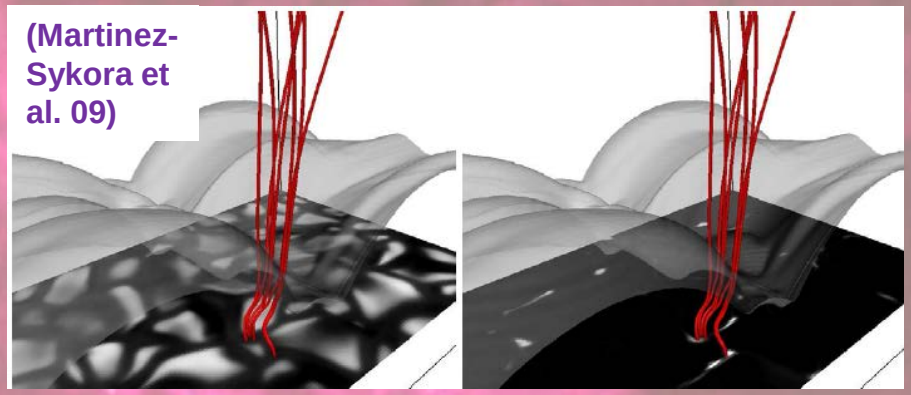
Slow shock acceleration

- **Slow mode wave inducing a shock because of strong density stratification in low atmo. ➔ plasma acceleration**
  - Slow mode wave generated without recon. (e.g. p –modes, granule collapse): Type I spicules **(e.g. Martinez-Sykora et al. 09)**
  - Reconnection induced slow mode
    cf. Talk of Takasao
- Density increase possibly too mild for large chromospheric jets
- Slow mode waves possibly only secondary effect modulating the flow of reconnection jet **(Yang et al. 13)**





(Takasao et al. 13)

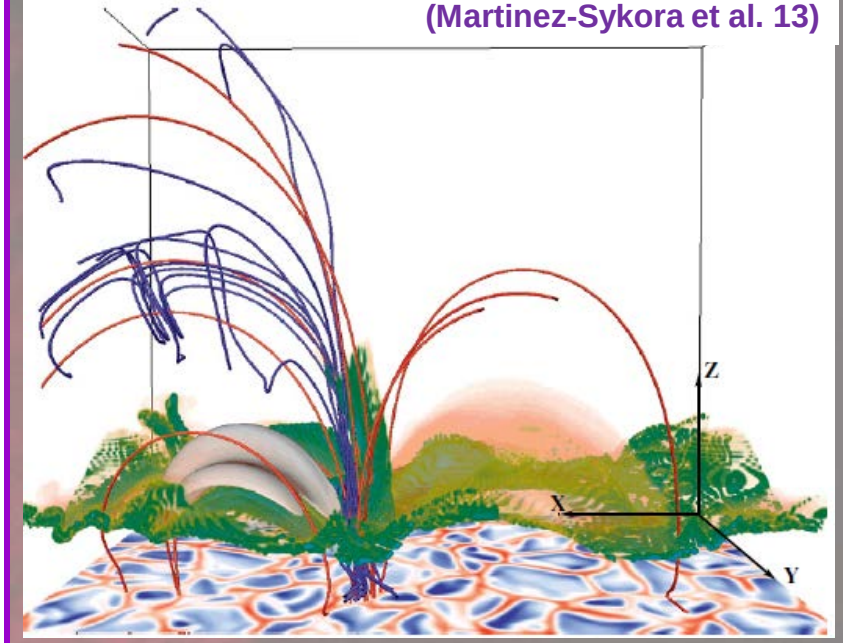


(Martinez-Sykora et al. 09)

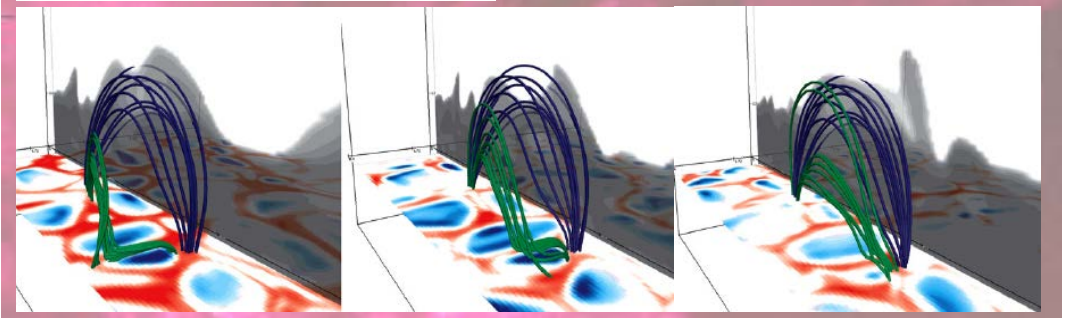
Pressure outflows

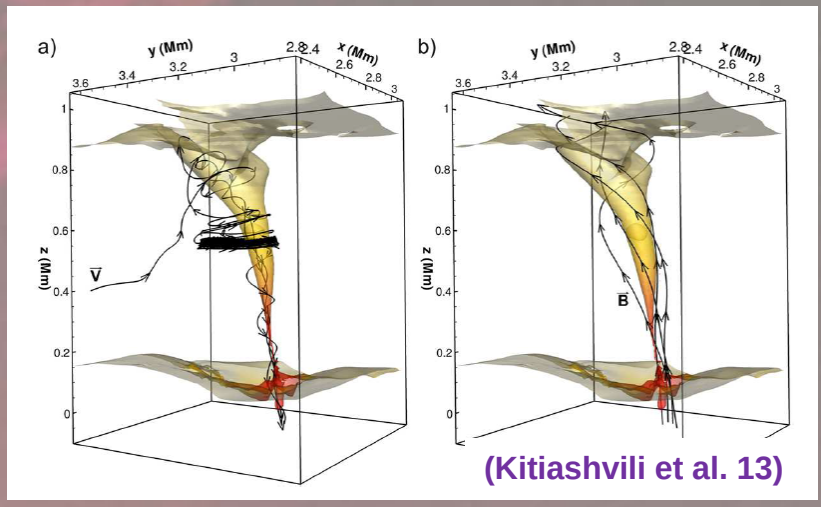
- **Outflows induced by dynamic pressure increase in the low atmo.**
  - Dynamical emergence of magnetic vortex tubes: **cf. Talk of I. Kitiashvili**
  - Lorentz force induced plasma pressure incease at the base of “vertical” field lines **(Martinez-Sykora et al. 11,13)**
- **May not be “violent” enough (Martinez-Sykora et al. 11,13)**
  - Axial and twisting velocities low range
  - May not be impulsive & frequent enough
- Possible “help” of “reconnection” ?

(Martinez-Sykora et al. 13)



(Martinez-Sykora et al. 11)





(Kitiashvili et al. 13)

Outlook

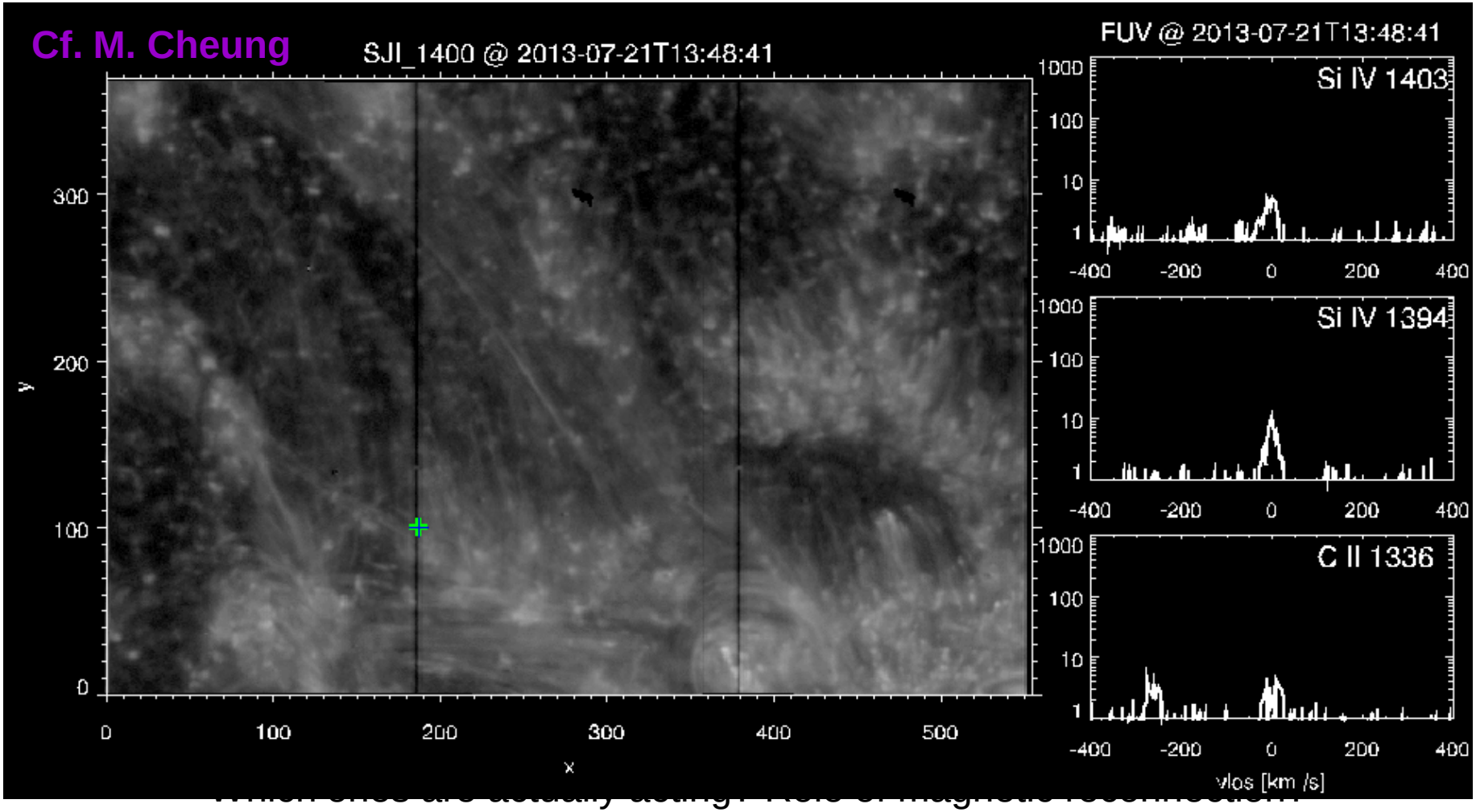
- Introduction
- Coronal standard jets
- Coronal blowout jets
- Chromospheric jets
- **Conclusion**

Conclusion

- **Hinode has allowed to strongly focused our understanding of coronal jets:**
  - Three reconnection-based mechanisms: slingshot, evaporation, untwisting
    - Occurring concomitantly
    - Responsible for the different observational properties of the jets
  - **Relative importance/interplay of each mechanism to be understood:**
    - Relative energy distribution/transfer
    - Dependence on environmental conditions ; e.g. plasma properties, magnetic field configuration
    - **No simulation is yet able to include all three processes**
  - Trigger mechanisms: blowout = disrupted CMEs ; standard = confined flare
    - Similar problematic than flare/eruption initiations

- **Hinode has opened the field of study of chromospheric jets**
  - **Complex environment: wide variety of mechanisms**
    - Which ones are actually acting? Role of magnetic reconnection?
  - Needs for observations of these small, complex to interpret structures
    - **Strong impact of IRIS and Solar-C**

Conclusion



- Needs for observations of these small, complex to interpret structures
  - **Strong impact of IRIS and Solar-C**

Thanks for your attention

ひので七のLOCの皆様に大変ありがとうございました