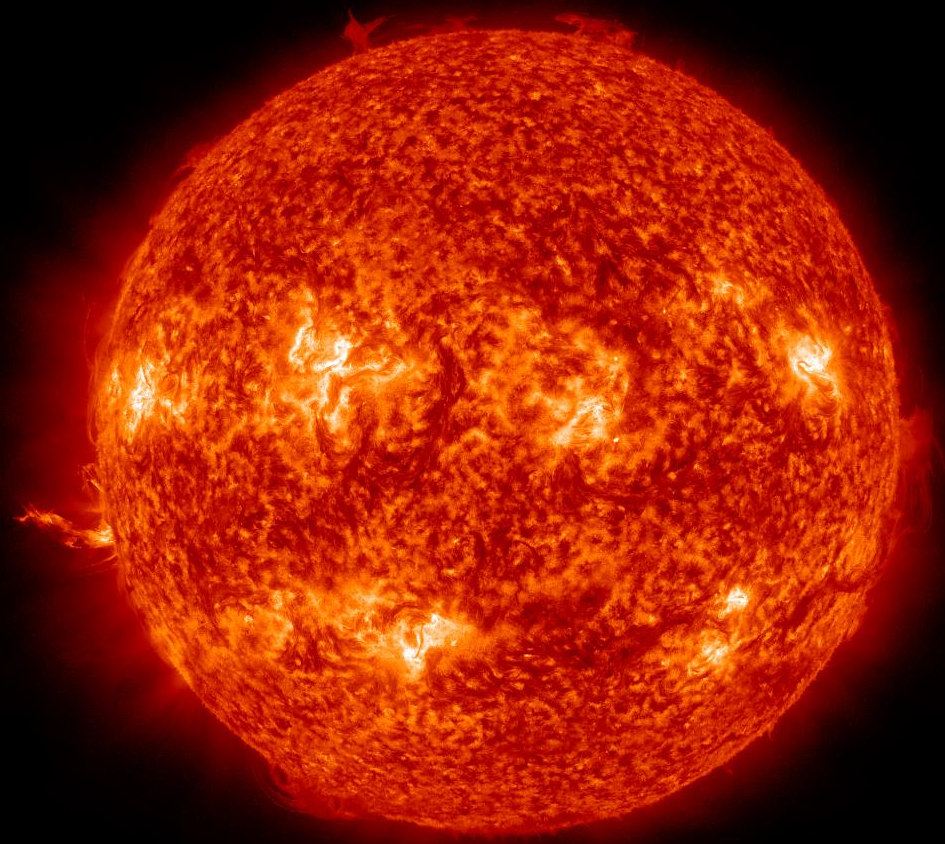
Energetic electrons and coronal jets

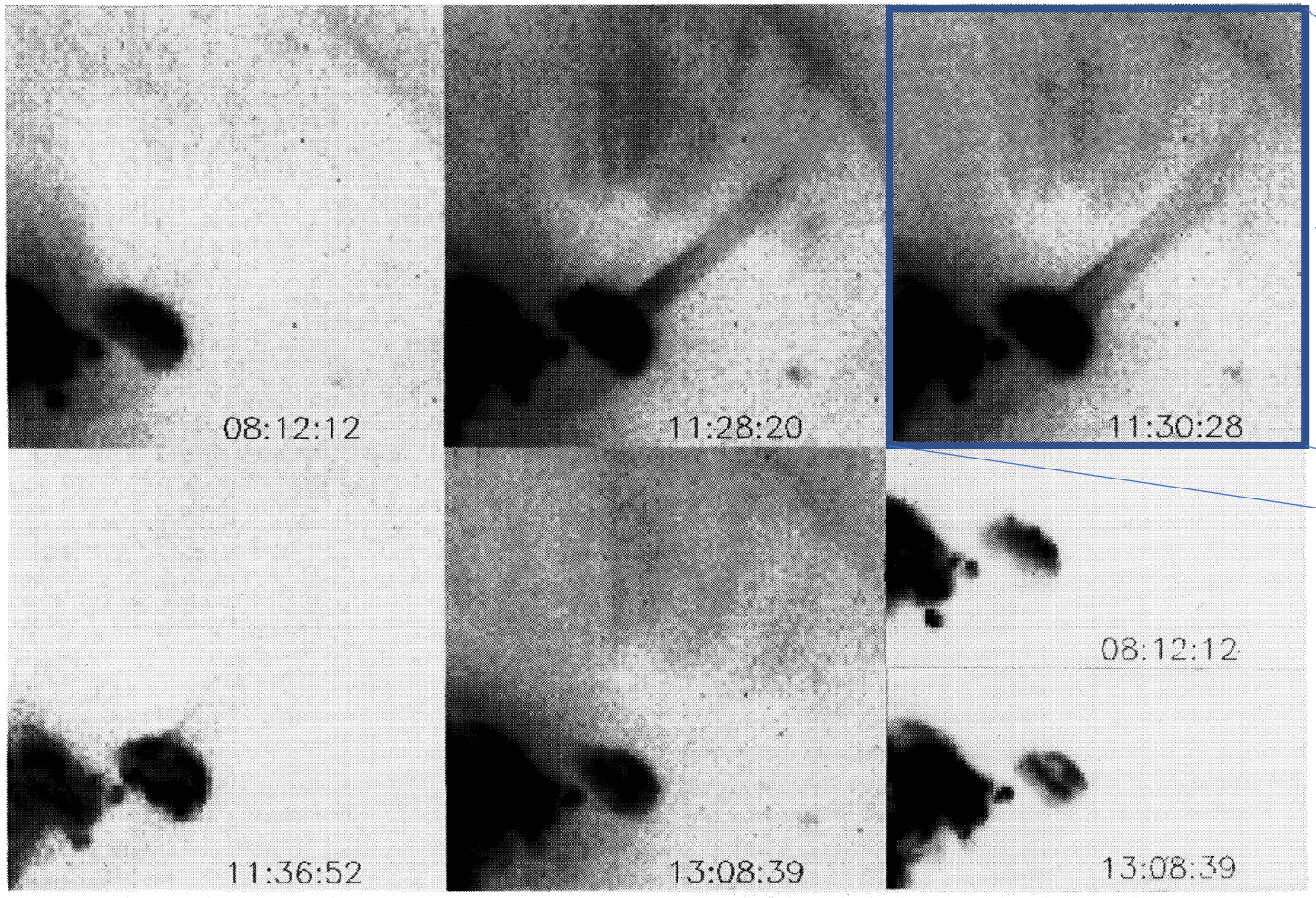
Sophie Musset
University of Glasgow



SolFER Colloquium
Solar Physics Webinar of Global Reach # 36
December 18. 2020

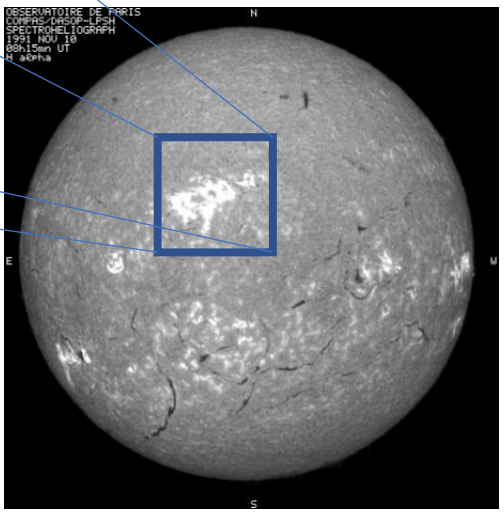
Coronal jets: early observation

Early observation of coronal jet in soft X-ray (<10 keV)



Shibata et al. (1992)

"Typical observation" of coronal jet by Yohkoh SXT (about 0.3 to 5 keV) 1991 Nov 12



The Sun in Hα, Spectroheliograph in Meudon (France), 1991 Nov 10

Coronal jets

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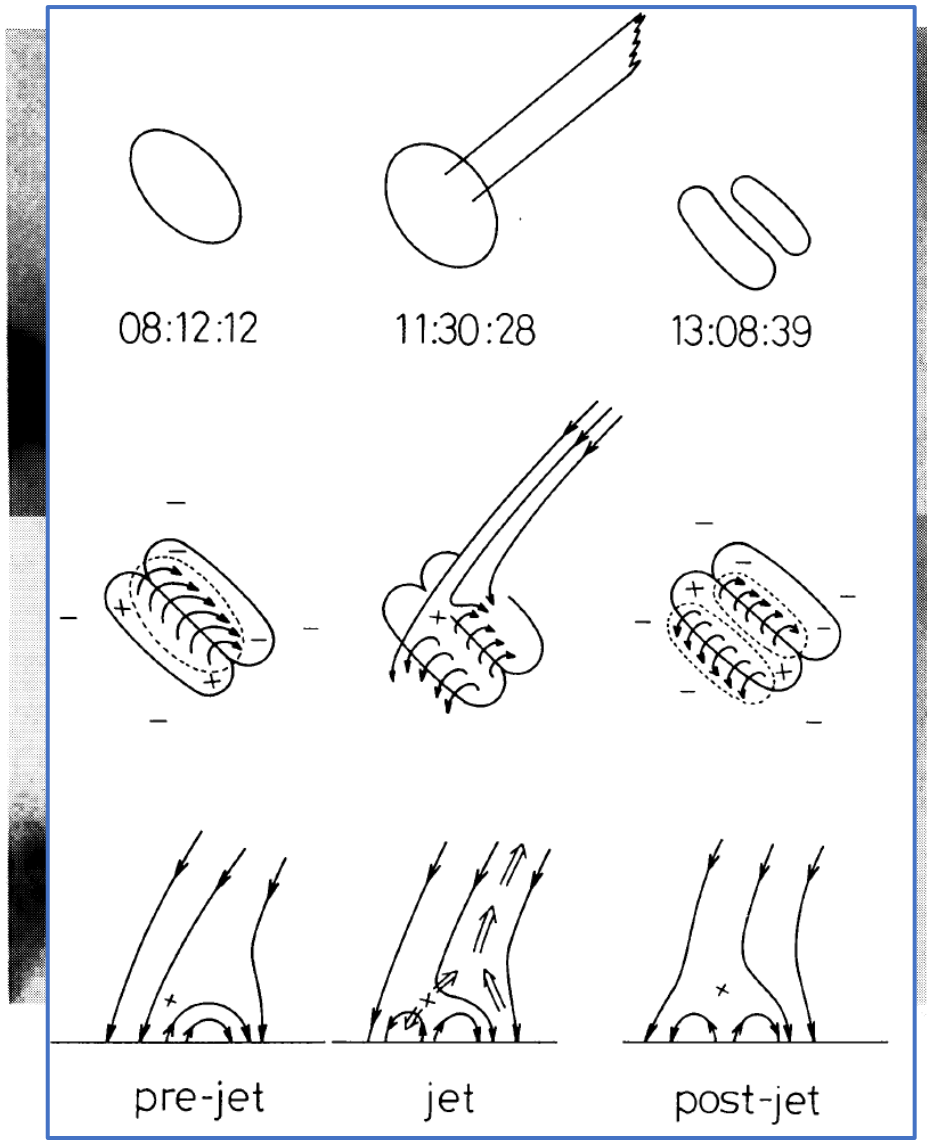

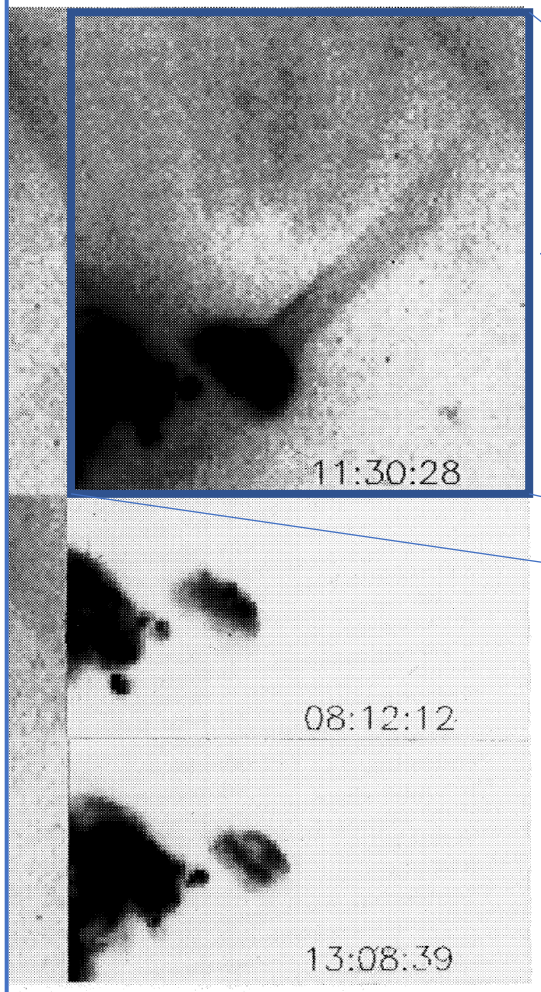

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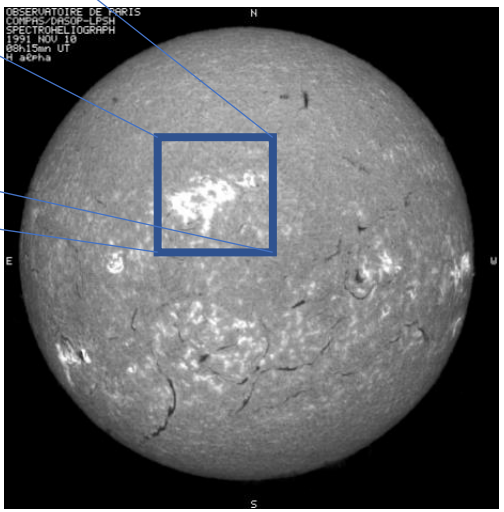

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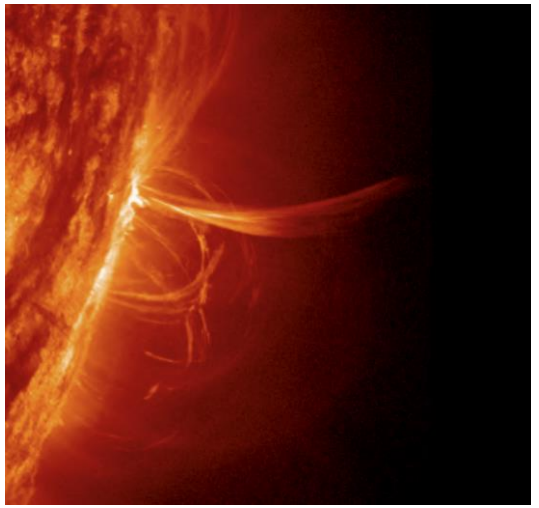
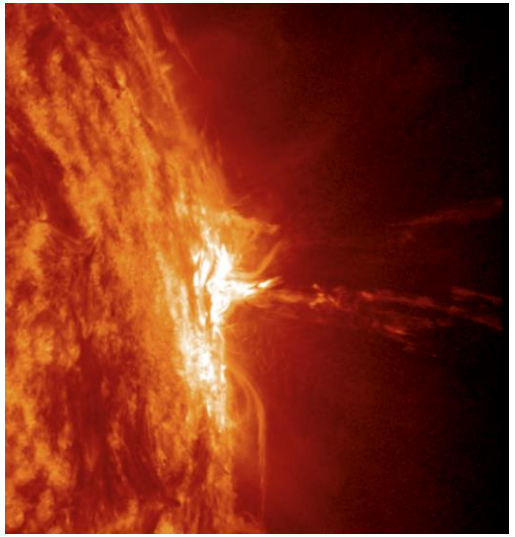
Coronal jets

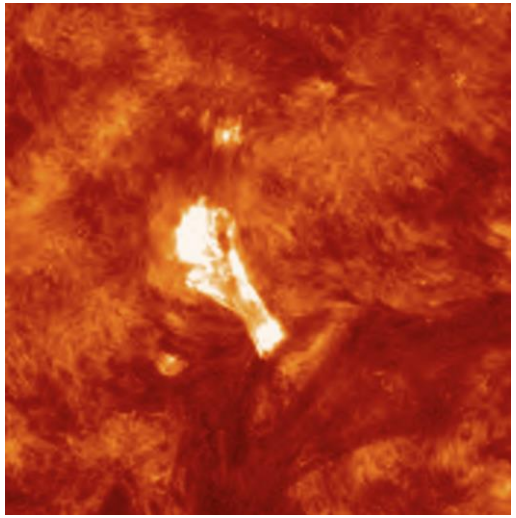
Coronal jets = collimated ejections of plasma, generally seen in soft X-rays (SXR) and extreme ultraviolet (EUV)

Here in SDO/AIA 304 Å

Seen at coronal hole boundaries, in quiet sun, in active regions, in connection with solar flares…







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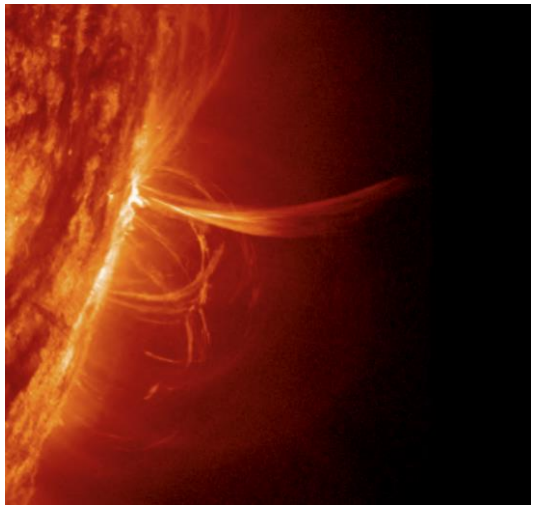
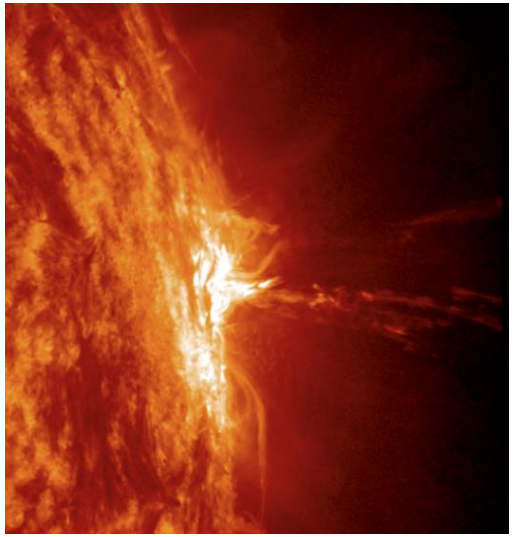
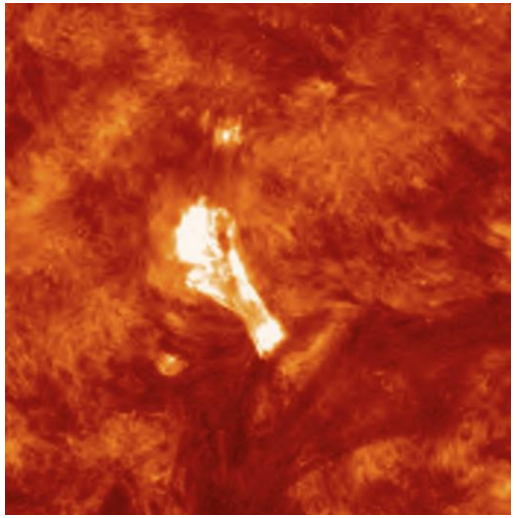




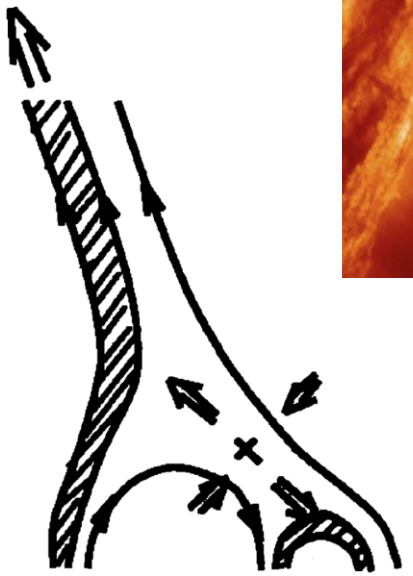


Seen at coronal hole boundaries, in quiet sun, in active regions, in connection with solar flares…

Seem to follow open magnetic field lines

→ May offer a path for particles to escape the solar atmosphere

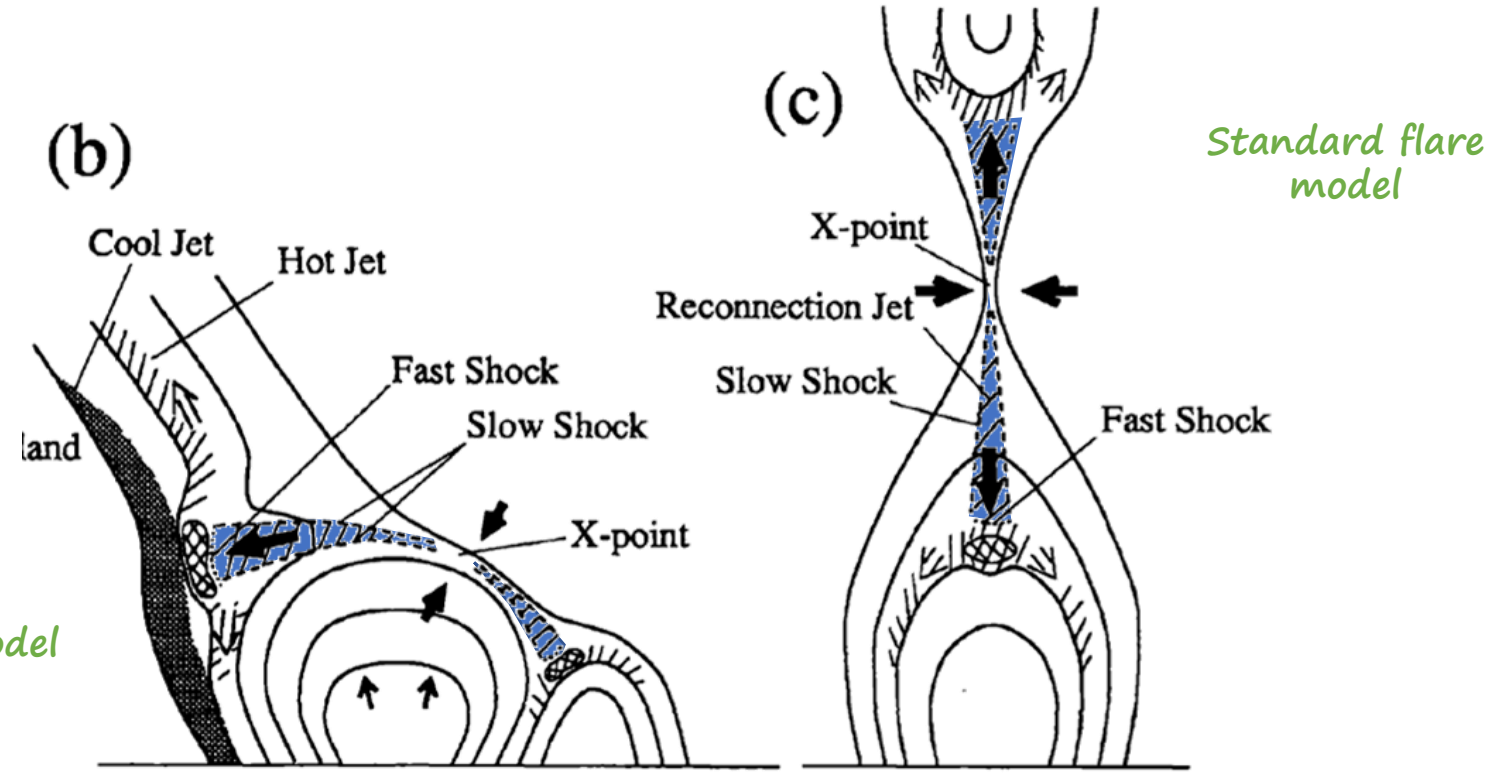
Standard model: interchange reconnection



Yokoyama & Shibata (1996)

Early jet models

Magnetic reconnection → reconnection jets at Alfven velocity



Jet model

Standard flare model

Yokoyama & Shibata (1996)

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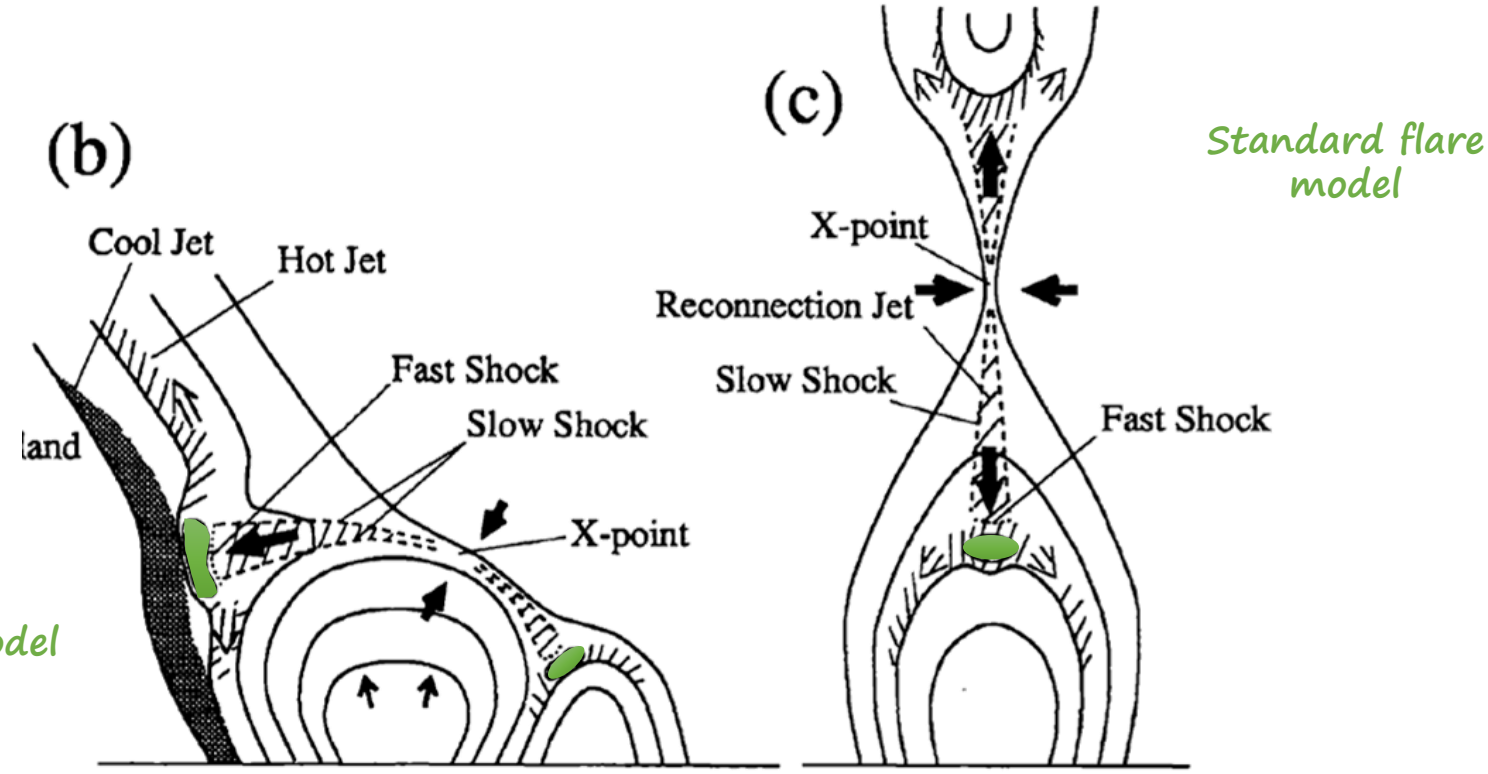
Fast mode MHD shocks form at the termination of the reconnection jets



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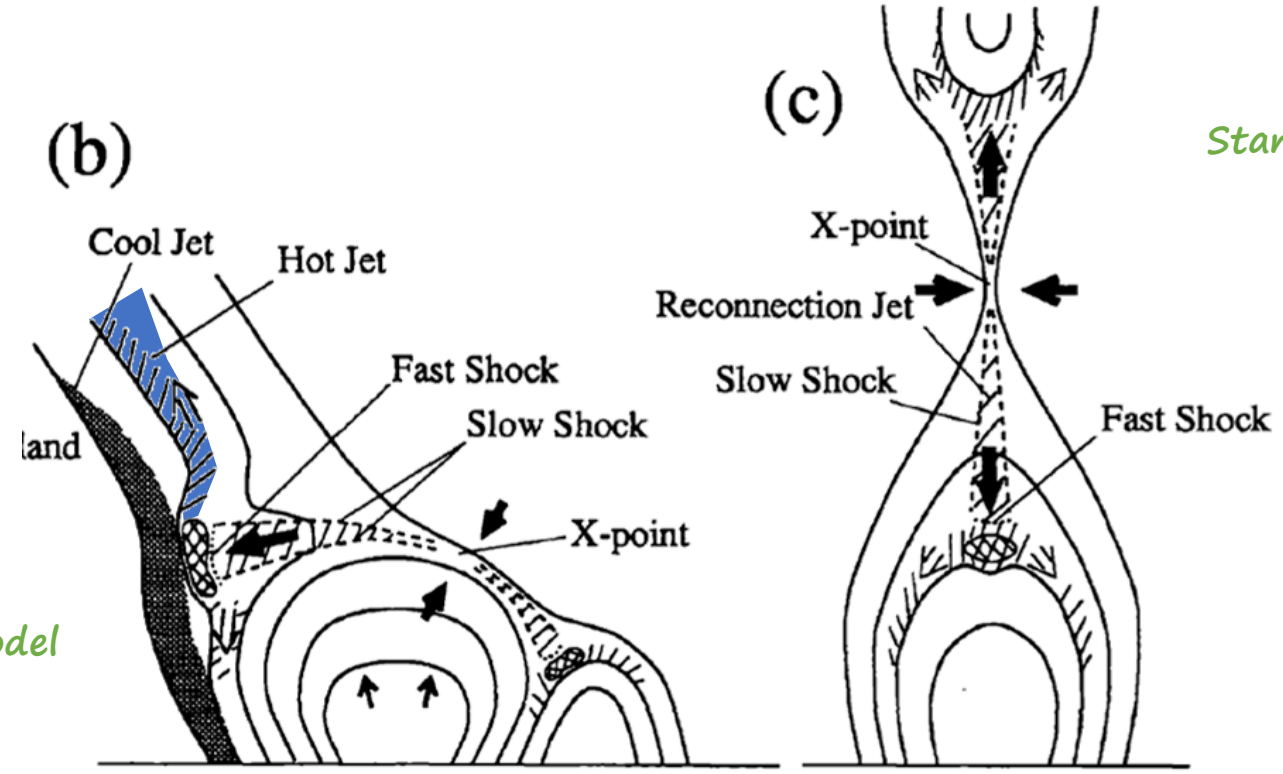
Speed of hot jets is comparable to the **sound speed** of the jet plasma



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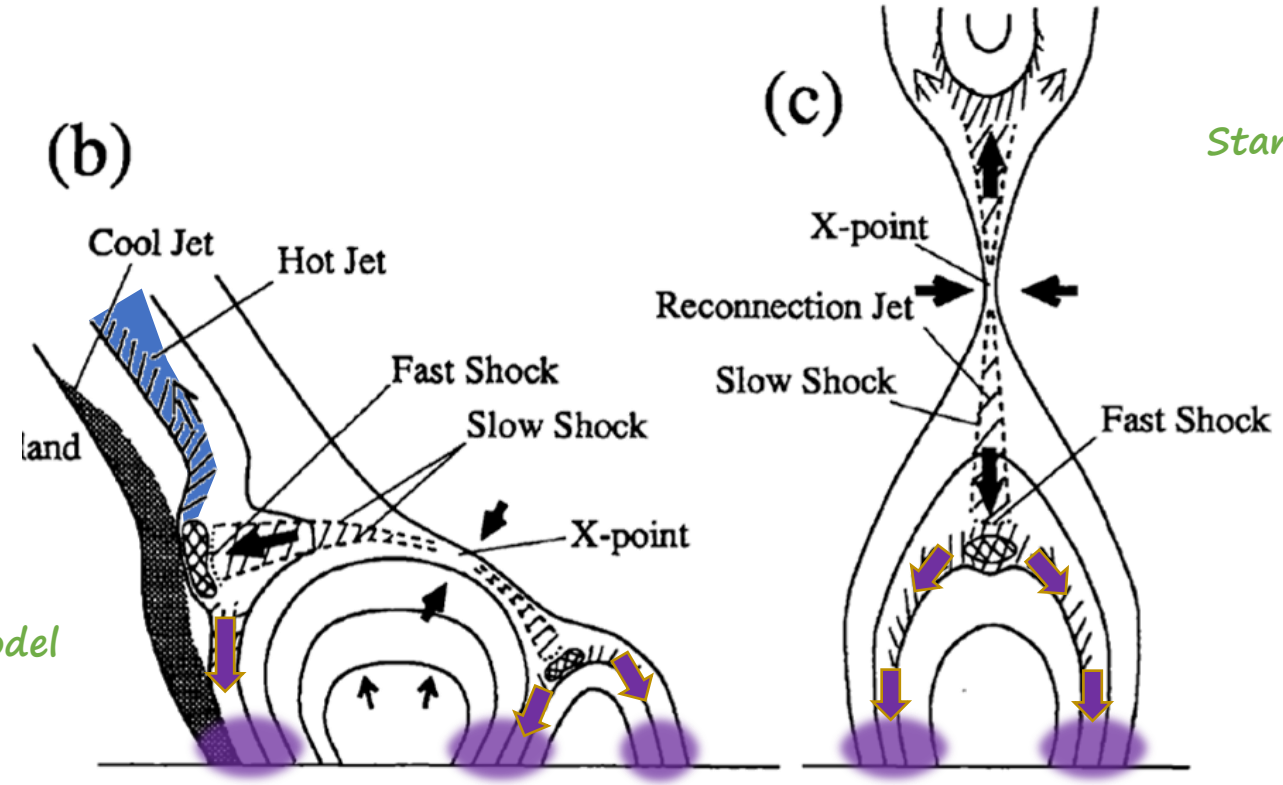


Jet model

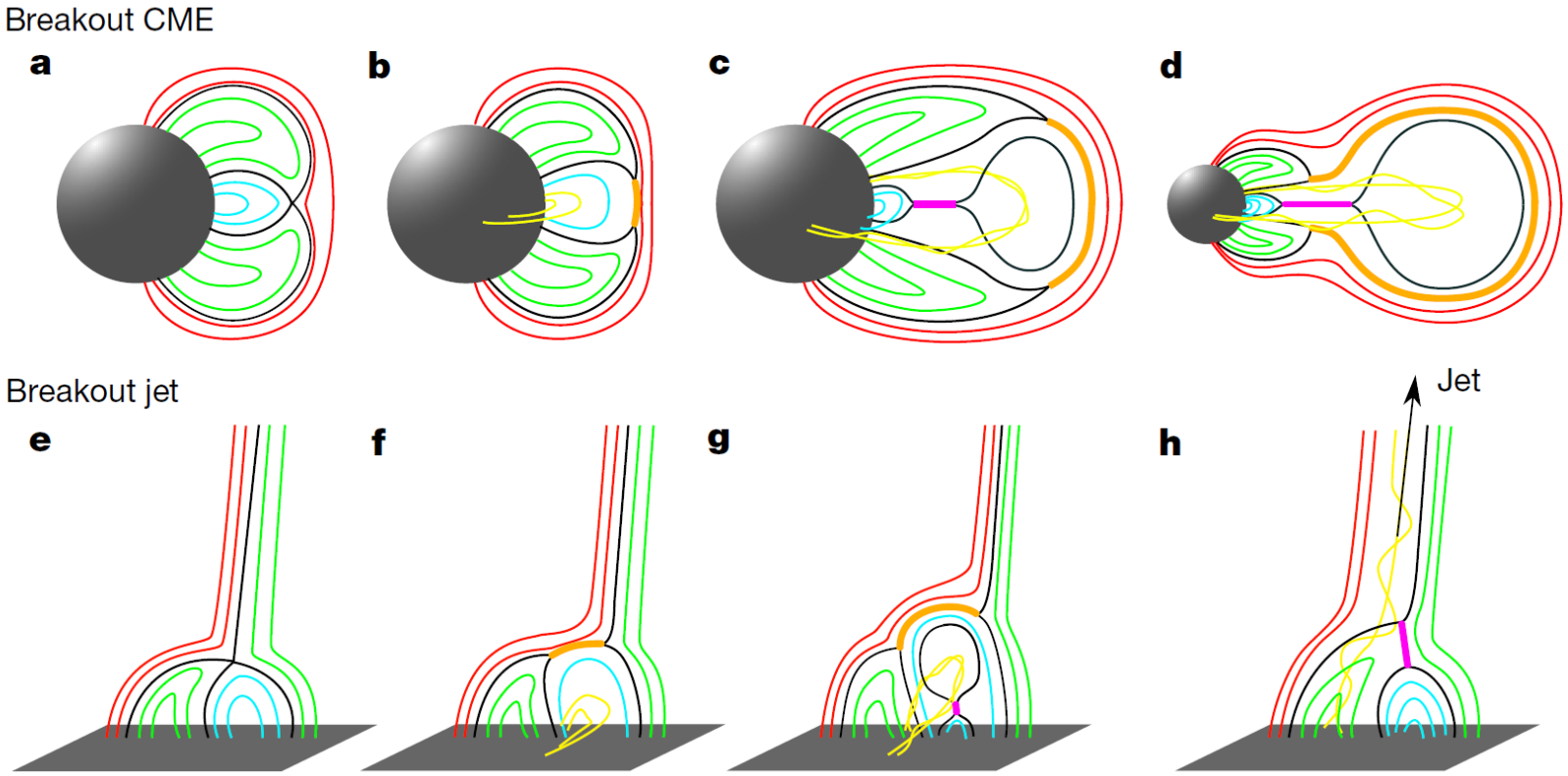
Standard flare model

Energetic electrons propagating towards the Sun surface
→ X-ray (bremsstrahlung)

Yokoyama & Shibata (1996)

Recent model: jets as mini-CMEs

Formation of a filament ➔ Eruption of the filament via magnetic reconnection (Breakout model)



Wyper et al. (2017)

Are jets mini-filament eruptions?

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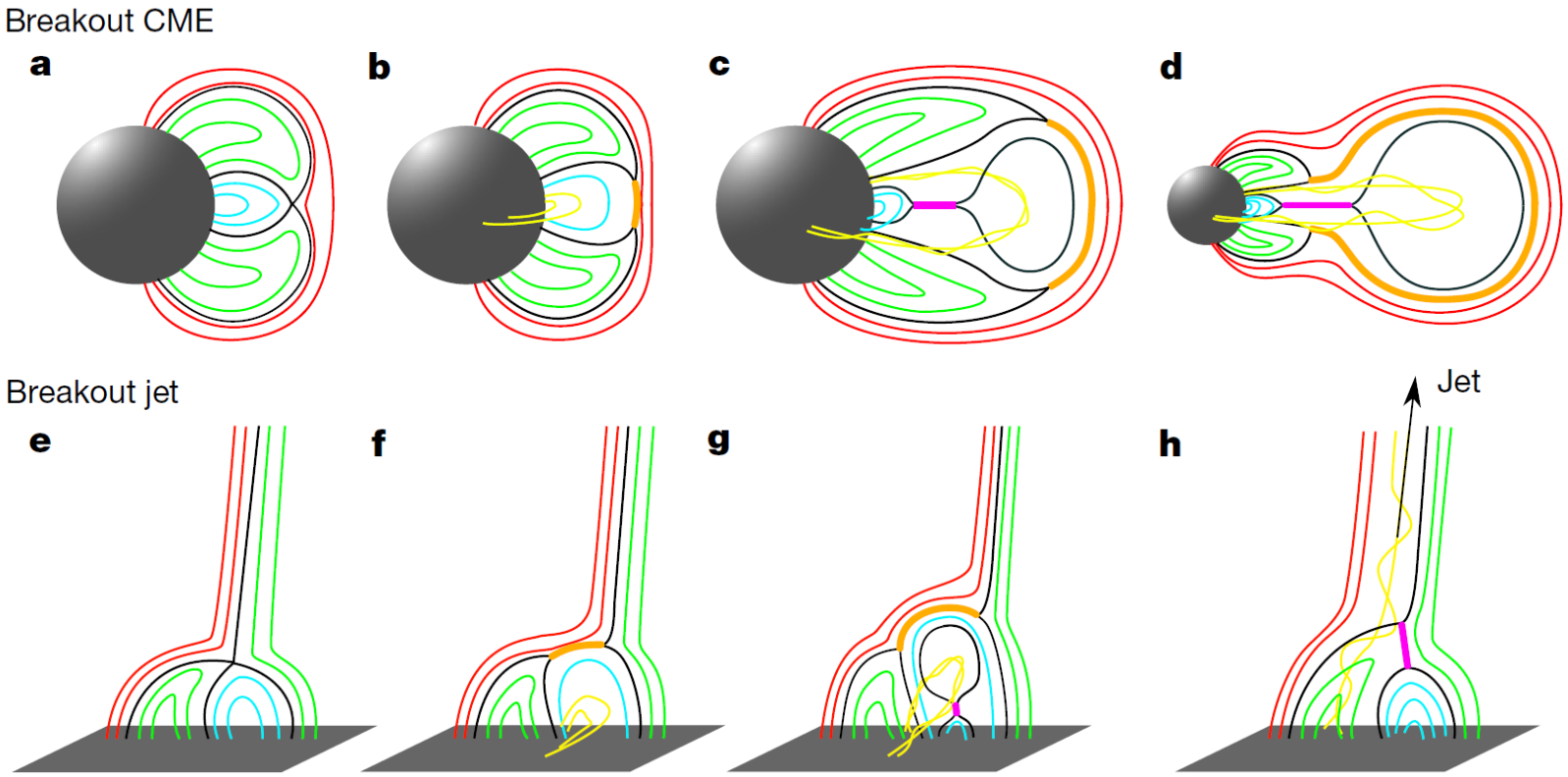

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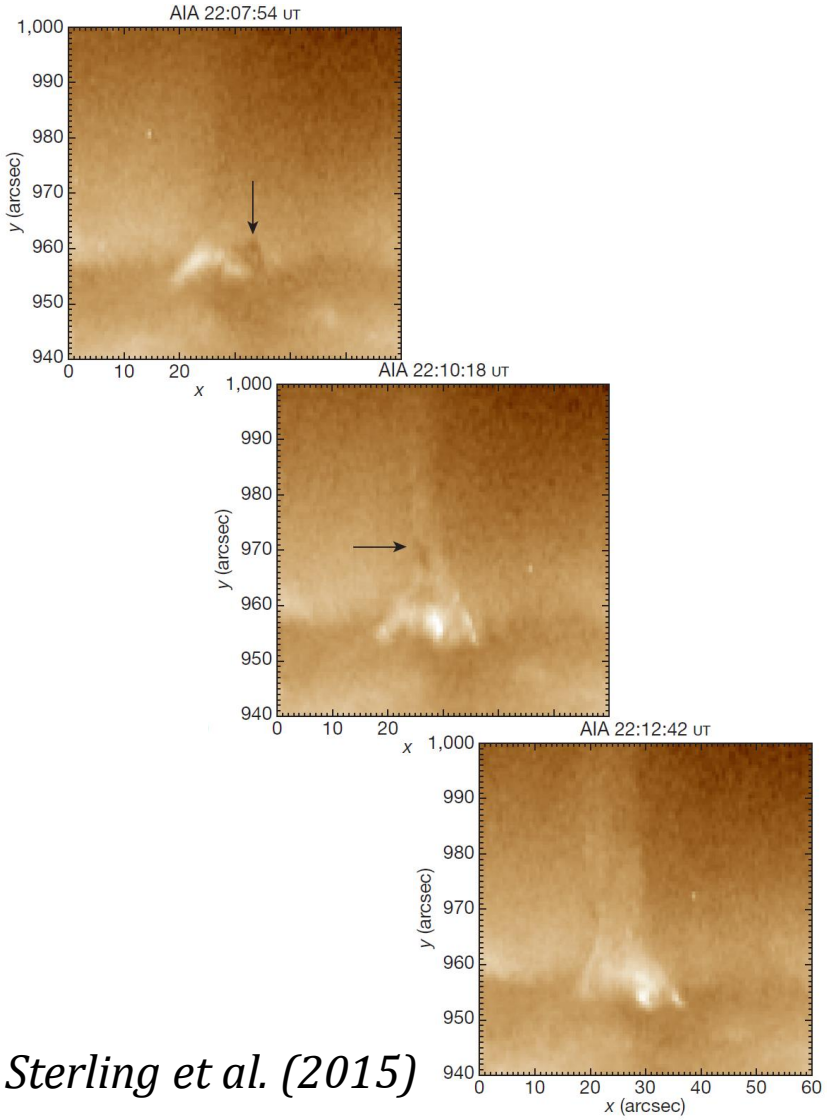


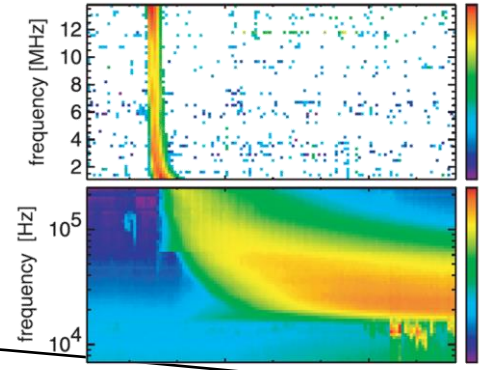
Sterling et al. (2015)

Are jets mini-filament eruptions?

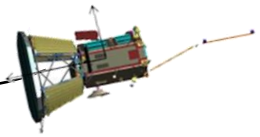
Coronal jets: a path for particles to escape?

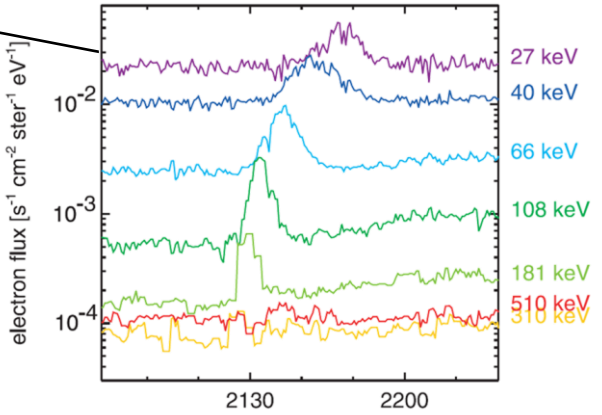
Not to scale

Escape to high corona and interplanetary medium = radio bursts



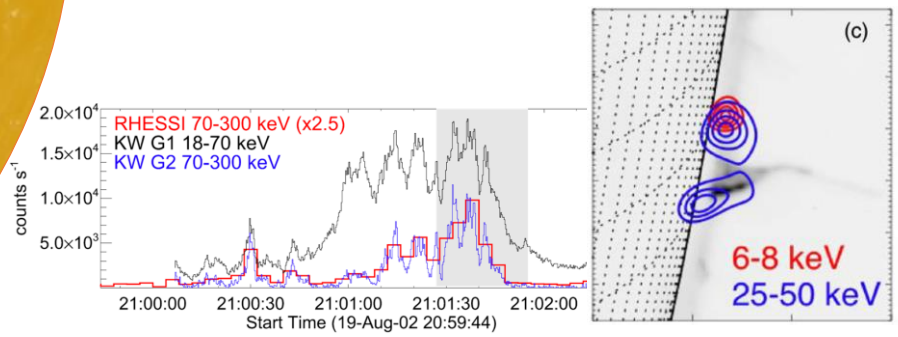
Detection in-situ

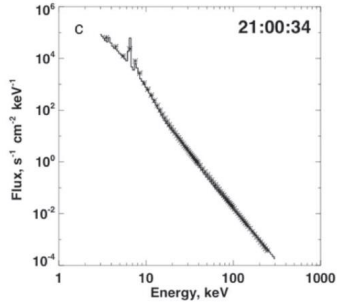




Magnetic reconnection = acceleration site

Interaction in low corona = X-ray emission

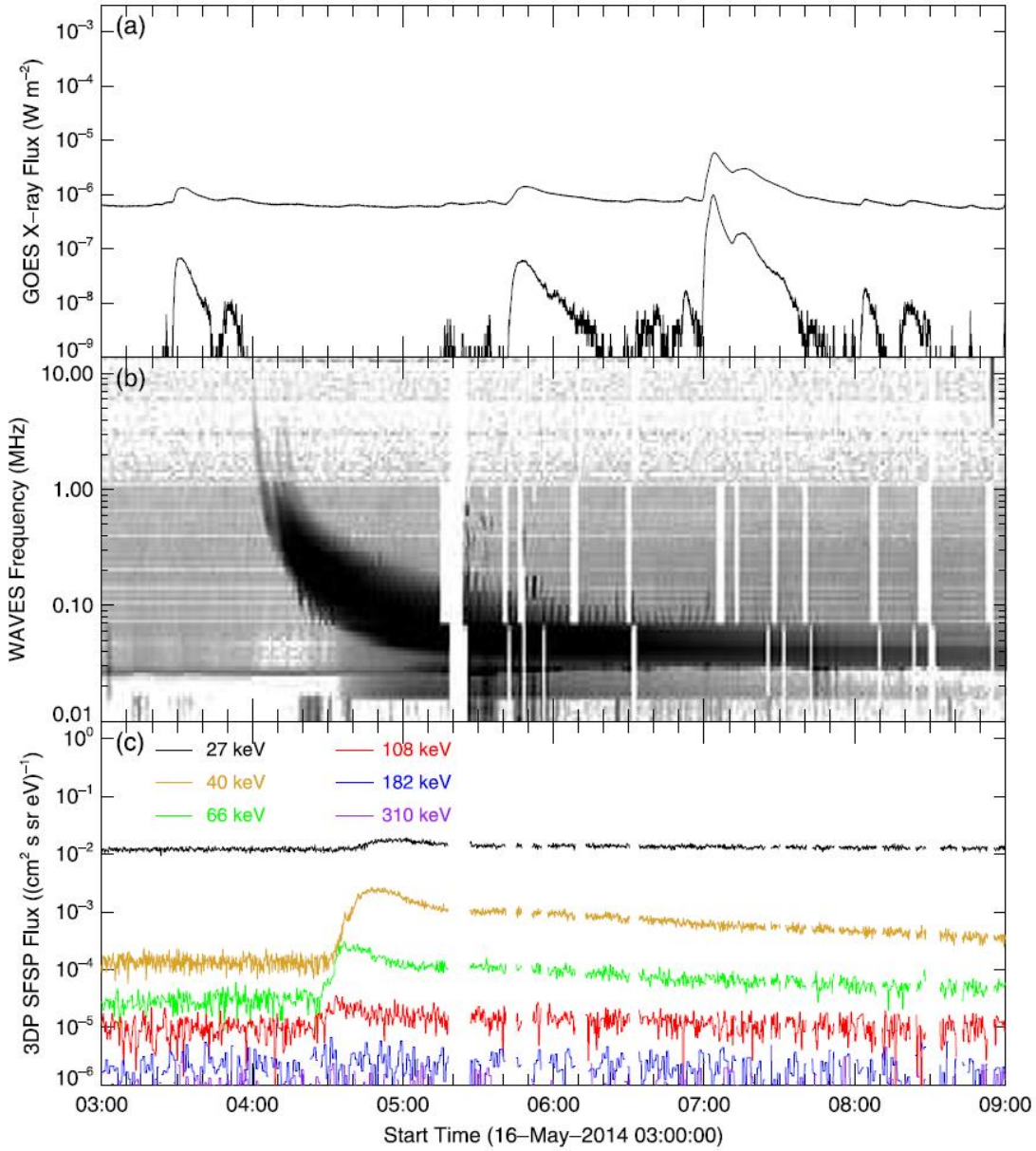




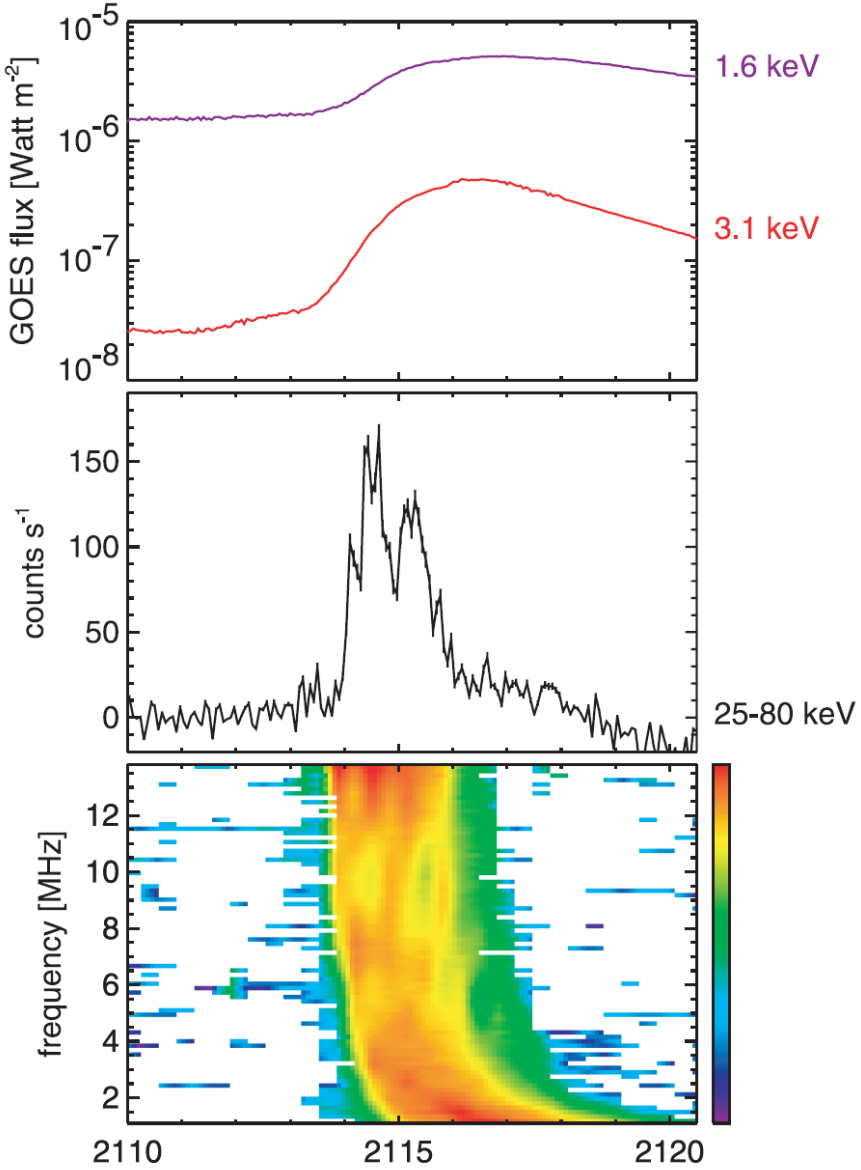
Coronal jets and particle events at 1 a.u.

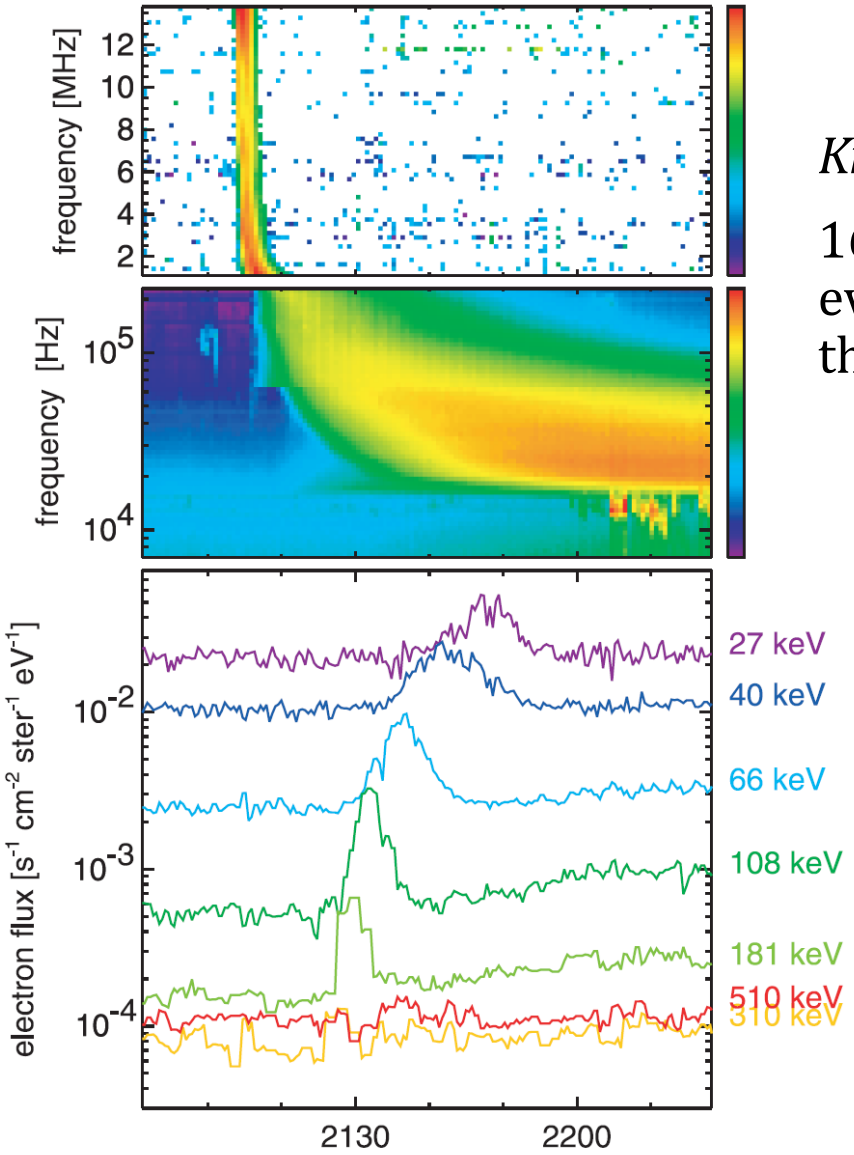
Nitta et al. 2015: 26 ^{3}He-rich Solar Energetic Particle (SEP) events (cycle 24)

- Associated with **type III** radio bursts and **electron events**
- **Weak solar activity** at source location (SXR), small eruptions (12), jets (13) and EUV waves (4)
- **Weak or no correlation between the properties of the solar sources and the energetic ions** (spectral form, 3He/4He ratio…)



Impulsive energetic electron events

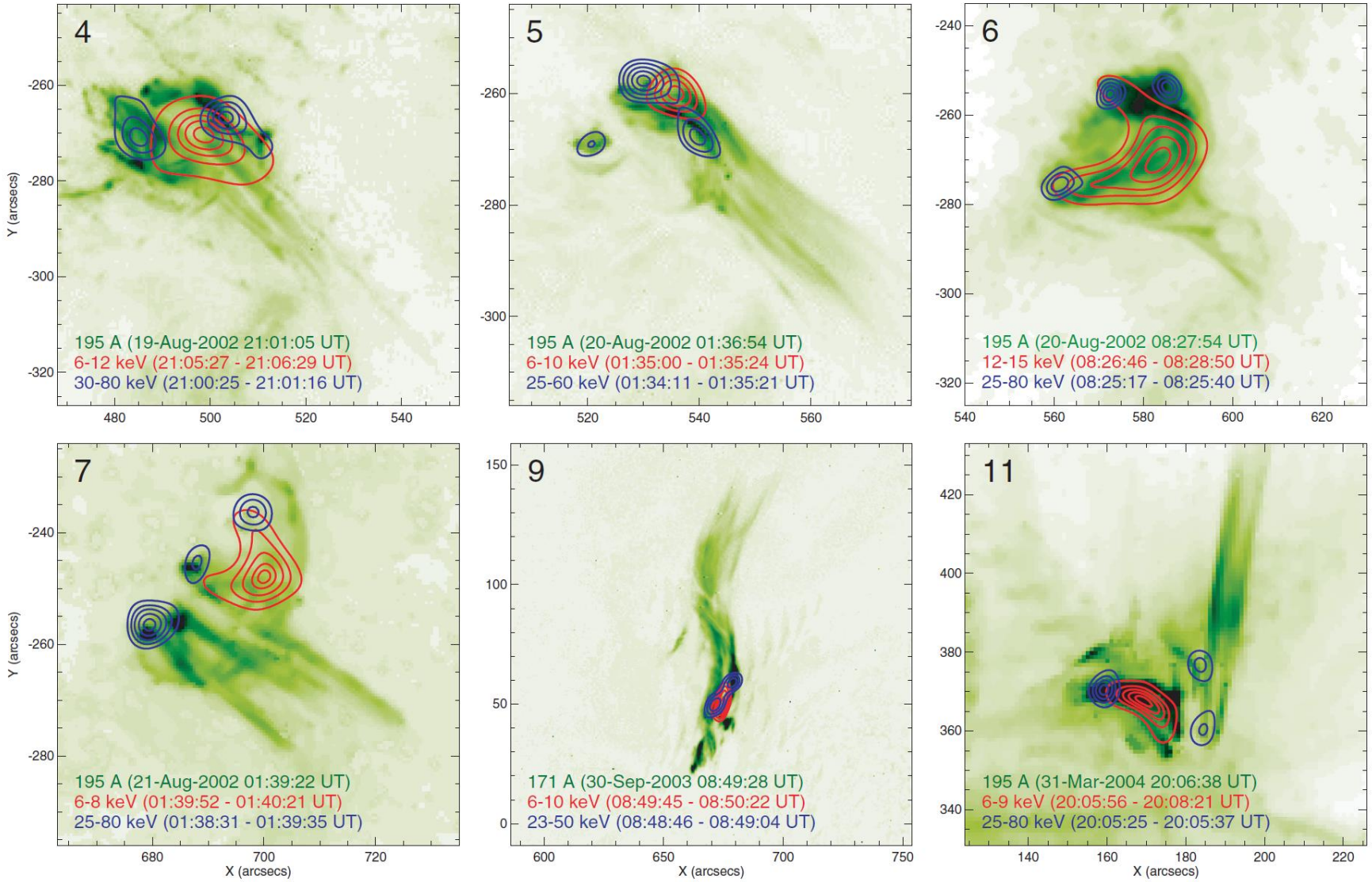




Krucker et al. (2007):

16 “prompt” energetic electron events associated with non-thermal X-ray emission.

Are jets « always » linked to escaping particles?

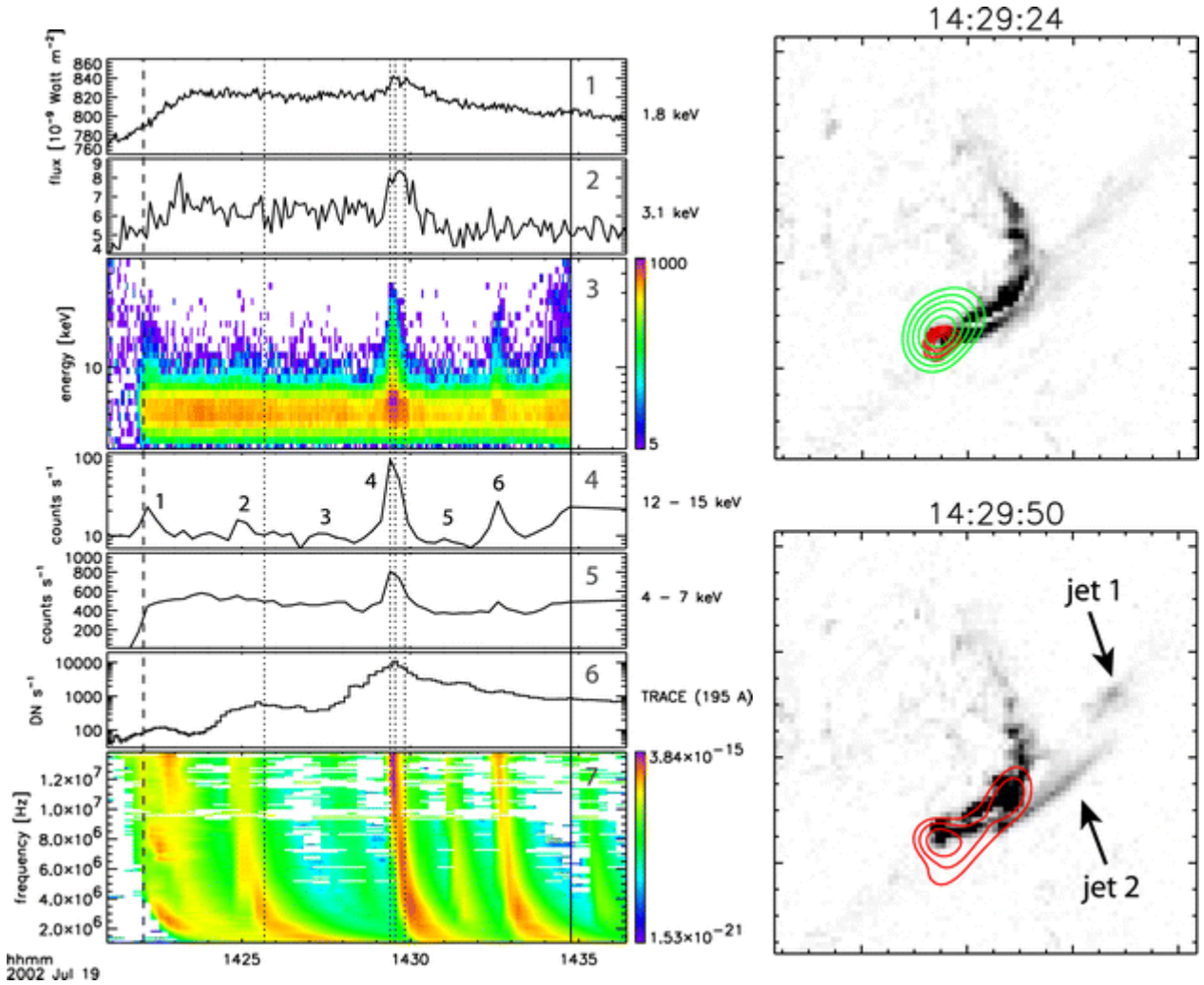


EUV observations of the sources of these prompt event were available for only 6 events:

Each of them is associated with a coronal jet (*Krucker et al, 1999*)

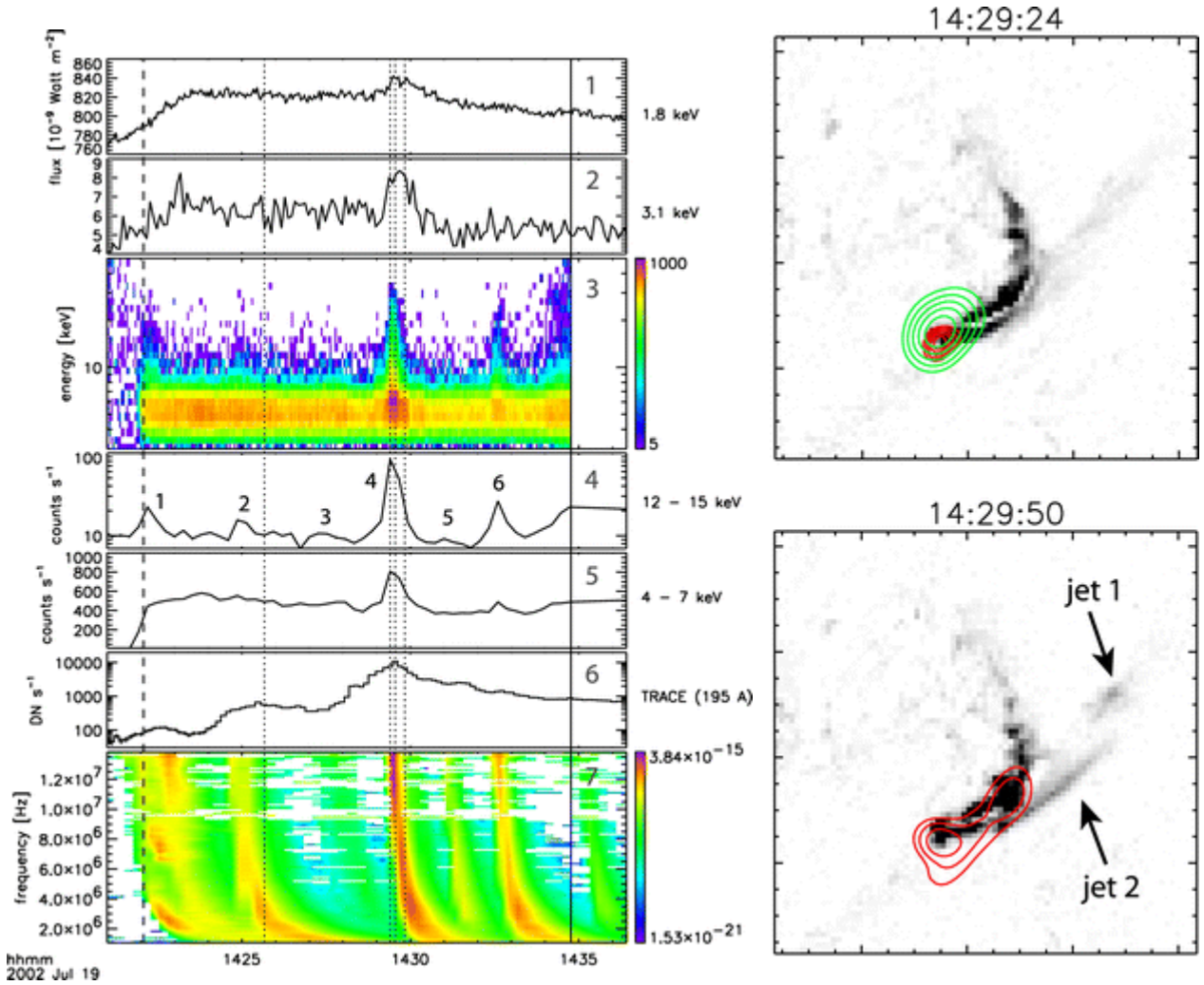
➔Are jets always associated with energetic electrons events detected in situ?

Coronal jets and type III radio bursts



SXR and EUV jets are “often” associated with type III radio bursts (example from *Christe et al. 2008*)

Coronal jets and type III radio bursts



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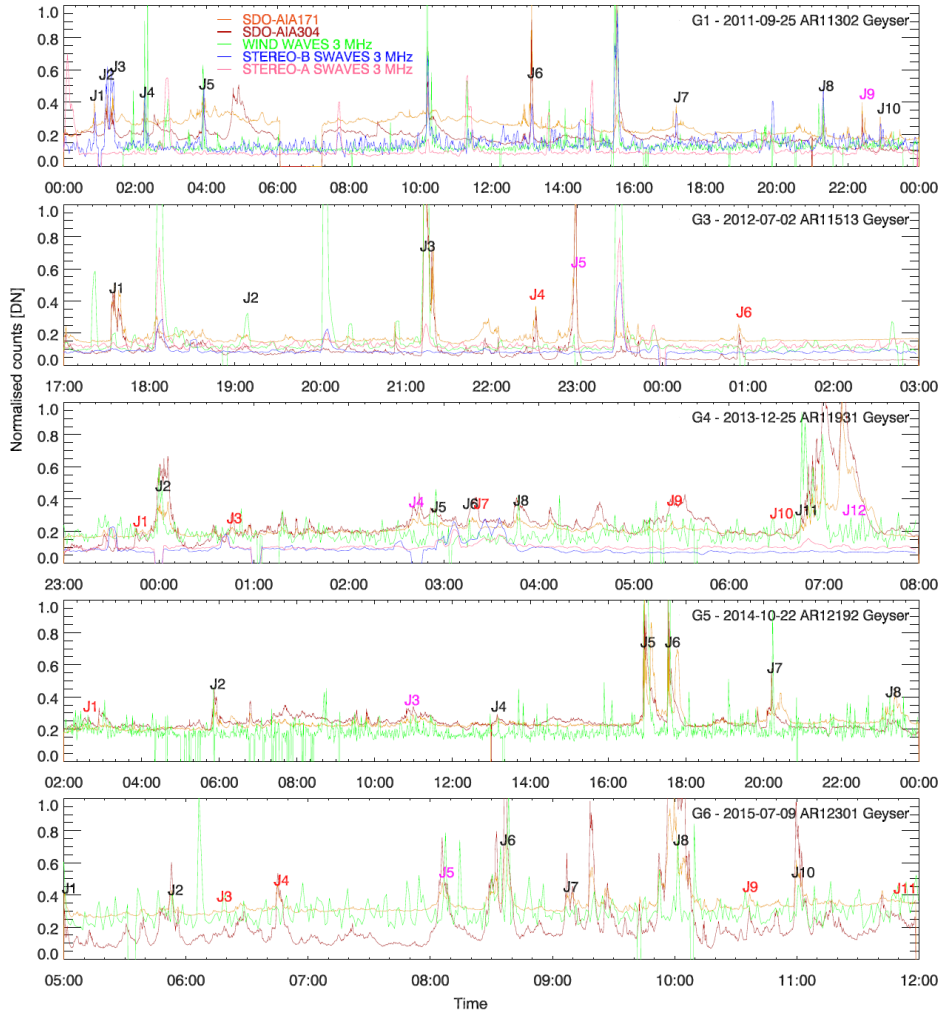
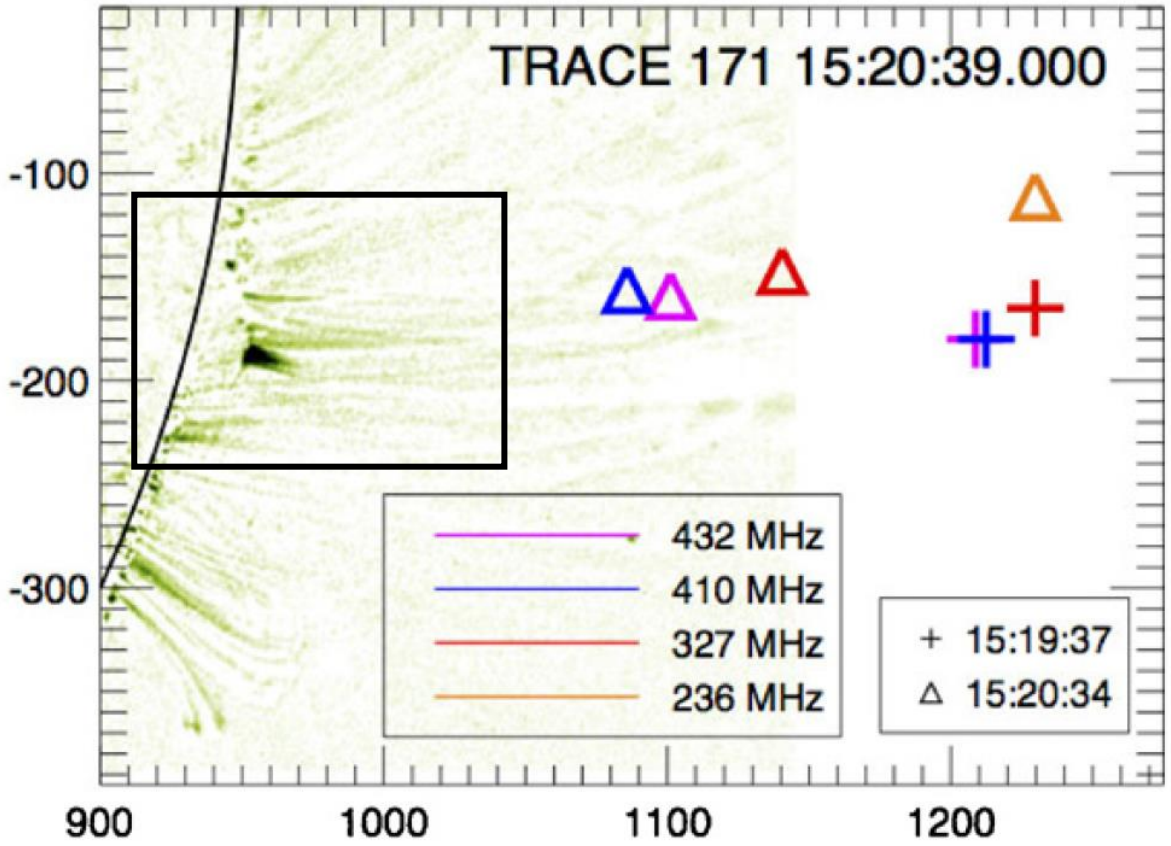
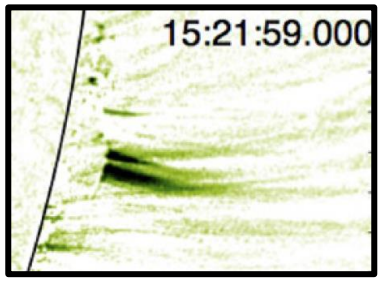


Recurring jets associated with type III radio bursts (*Paraschiv et al. 2019*)

Coronal jets and type III radio bursts

Imaging of coronal type III radio burst sources



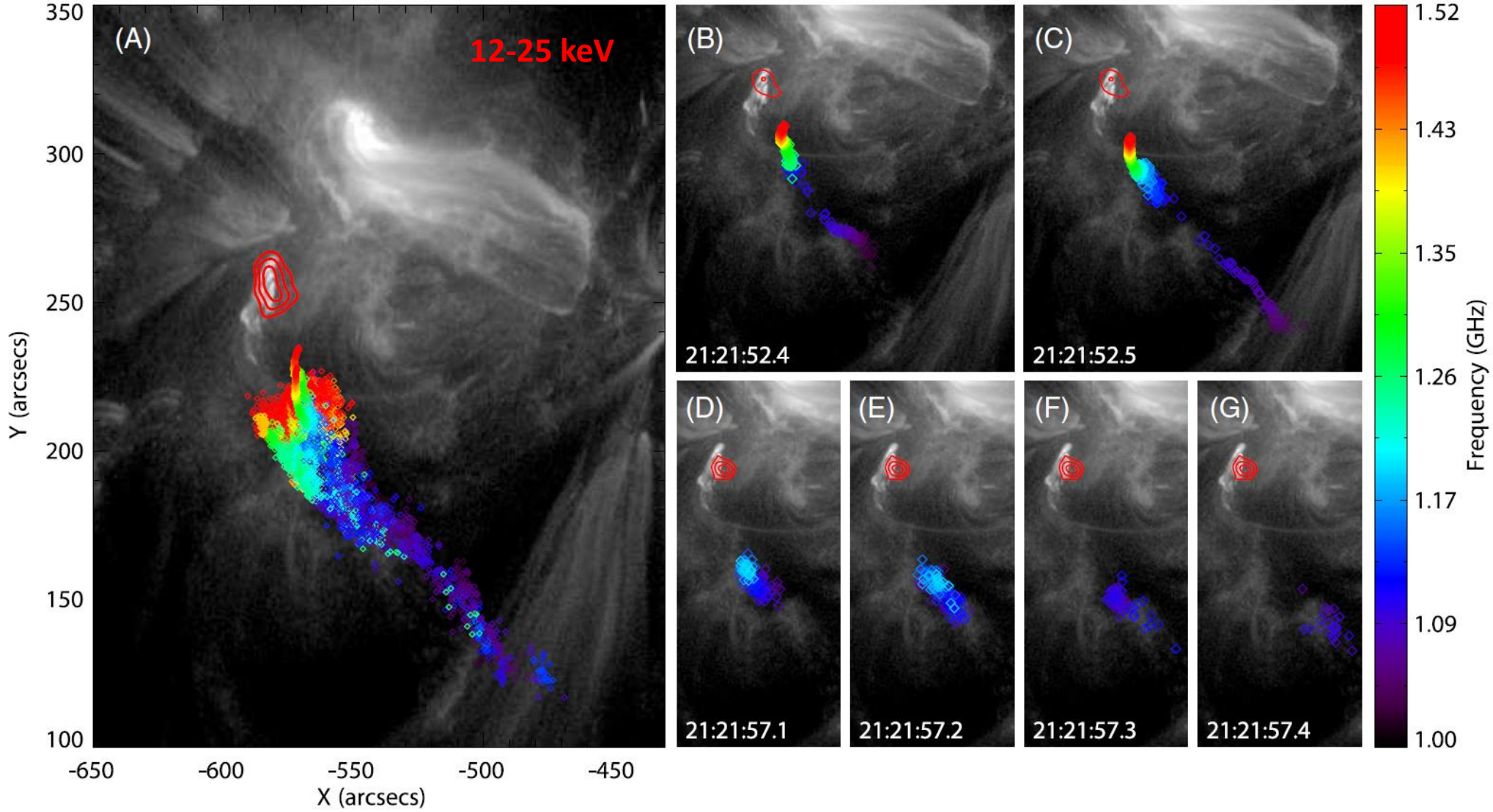


Jet and type III burst follow the same open magnetic field line

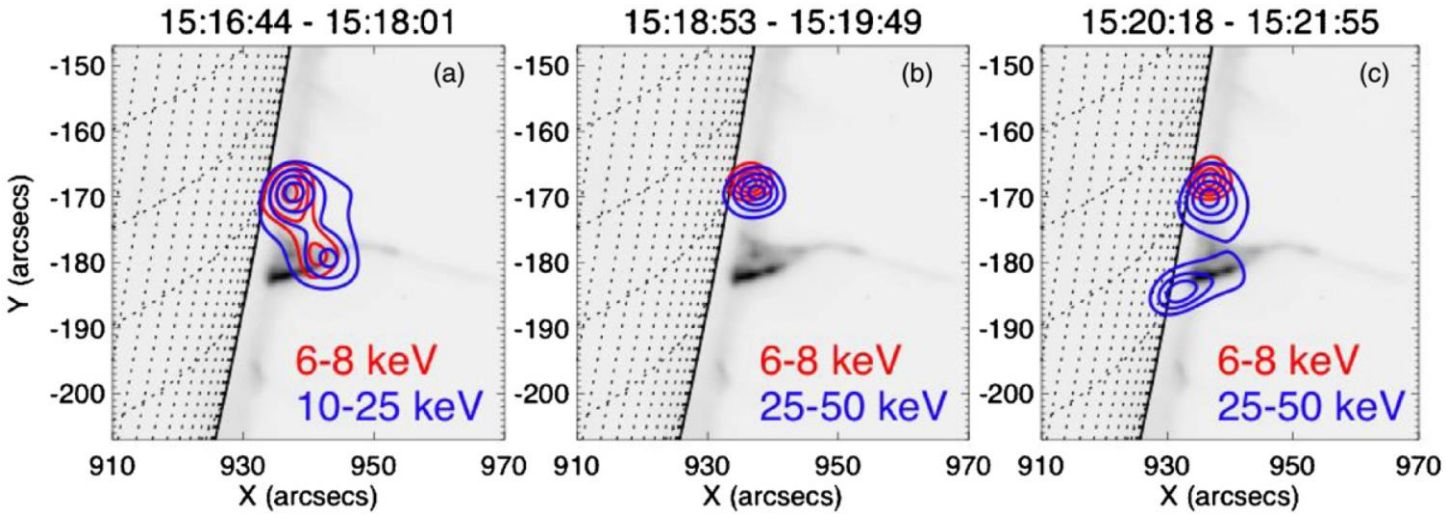
Glesener et al. (2012)

Coronal jets and type III radio bursts

Jet and associated type III decametric bursts observed with the VLA (*Chen et al, 2013*)



Hard X-rays signatures in coronal jets



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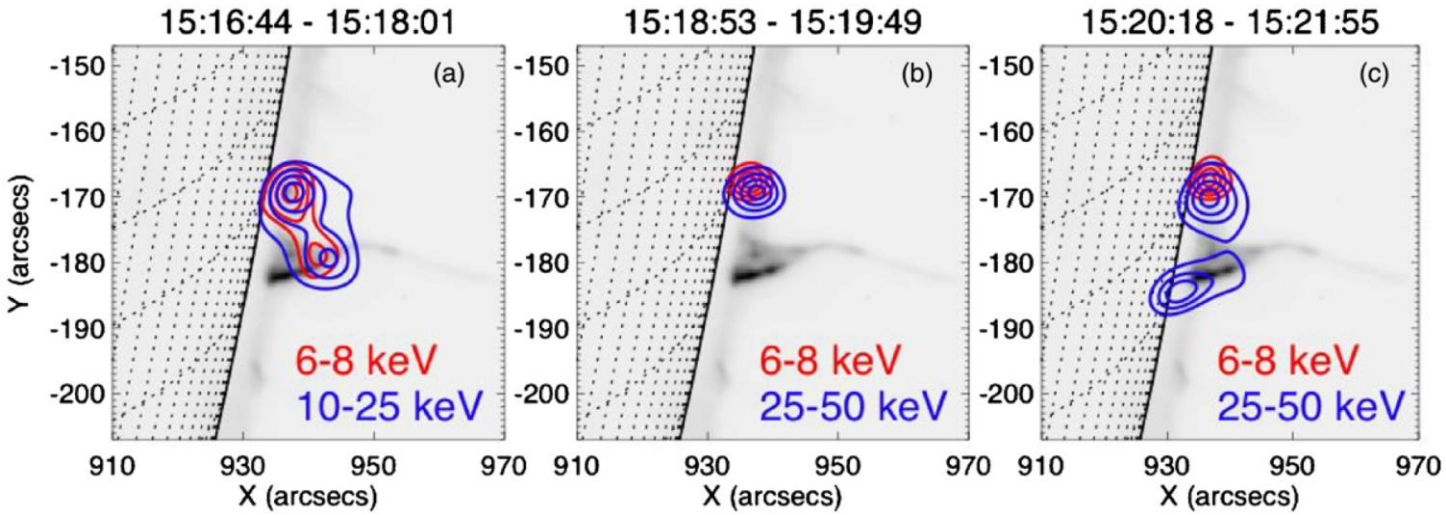
Non-thermal HXR emission from the jet

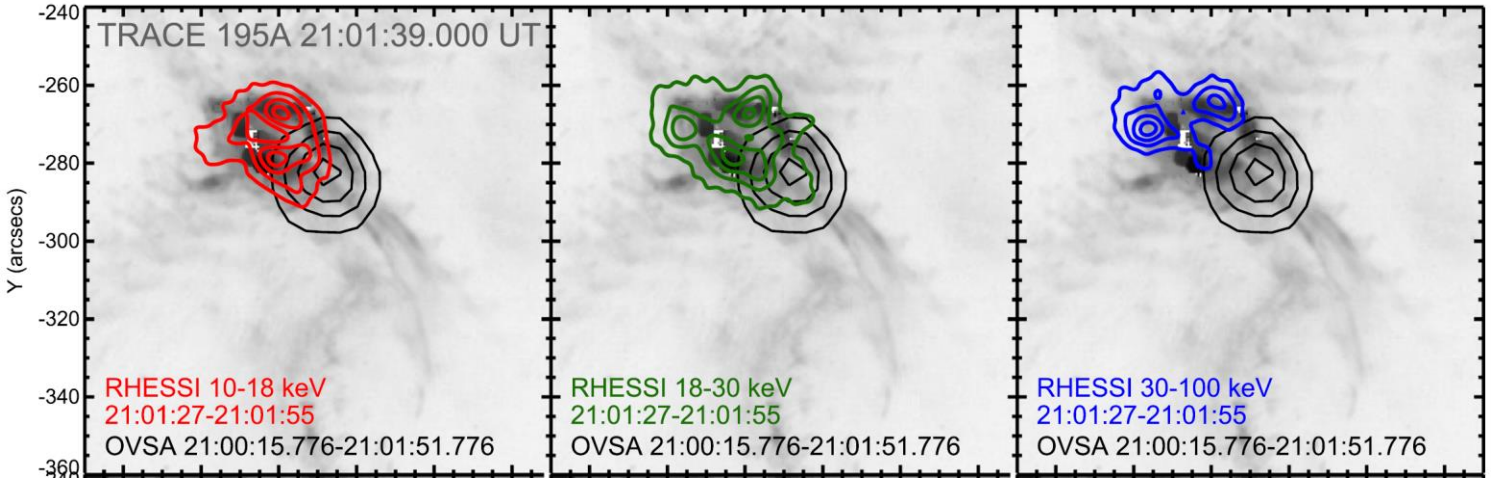
Hard X-rays signatures in coronal jets



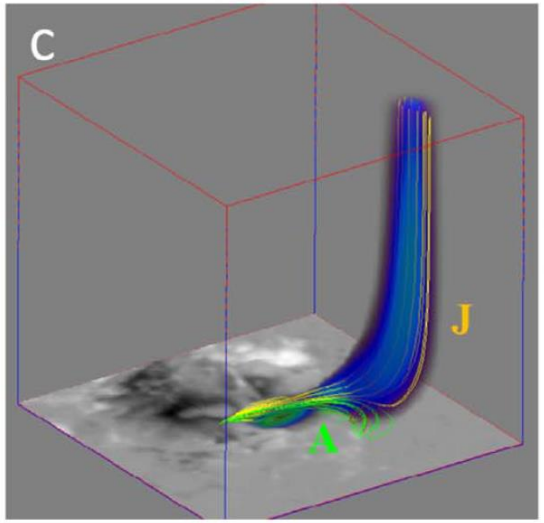
Glesener et al. (2012)

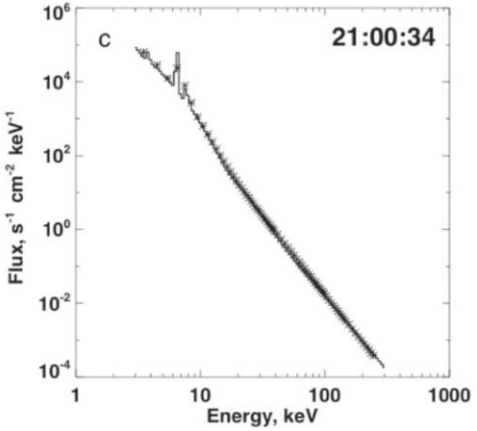
Non-thermal HXR emission from the jet

Non-thermal HXR and gyrosynchrotron emissions from the jet and simulation



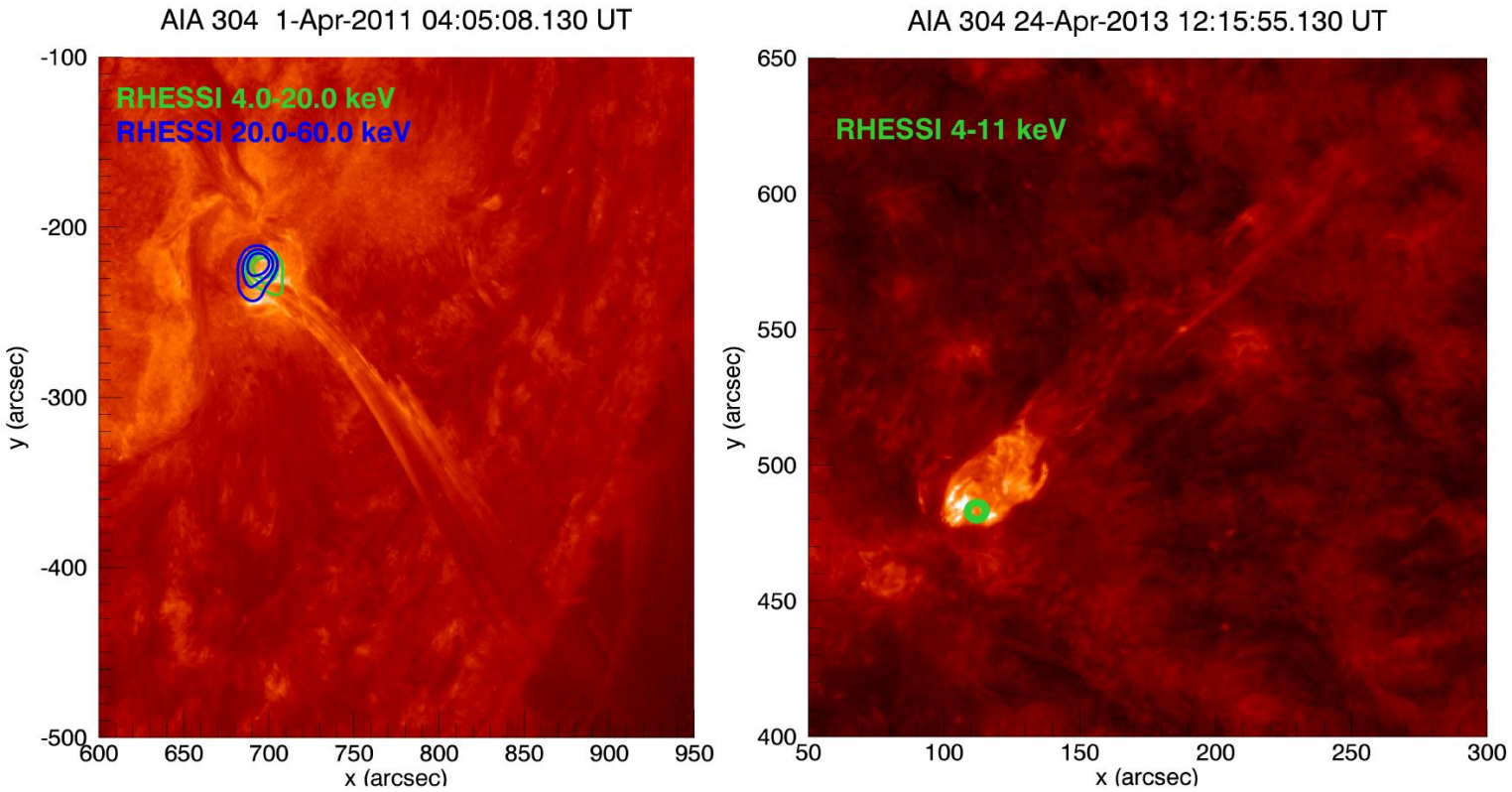
Glesener & Fleishman (2018)



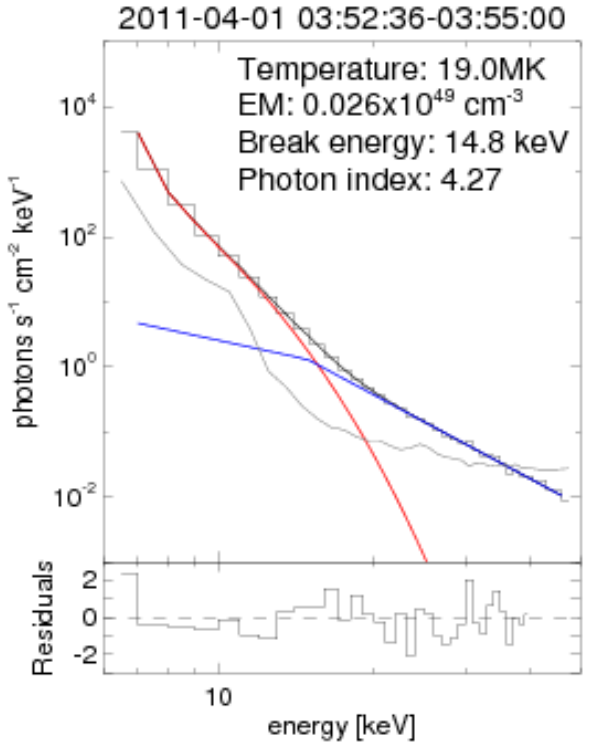


Statistics of coronal jets and particle acceleration

Jets visible in the 304 Å AIA filter
Association with hard X-ray signatures during solar flares

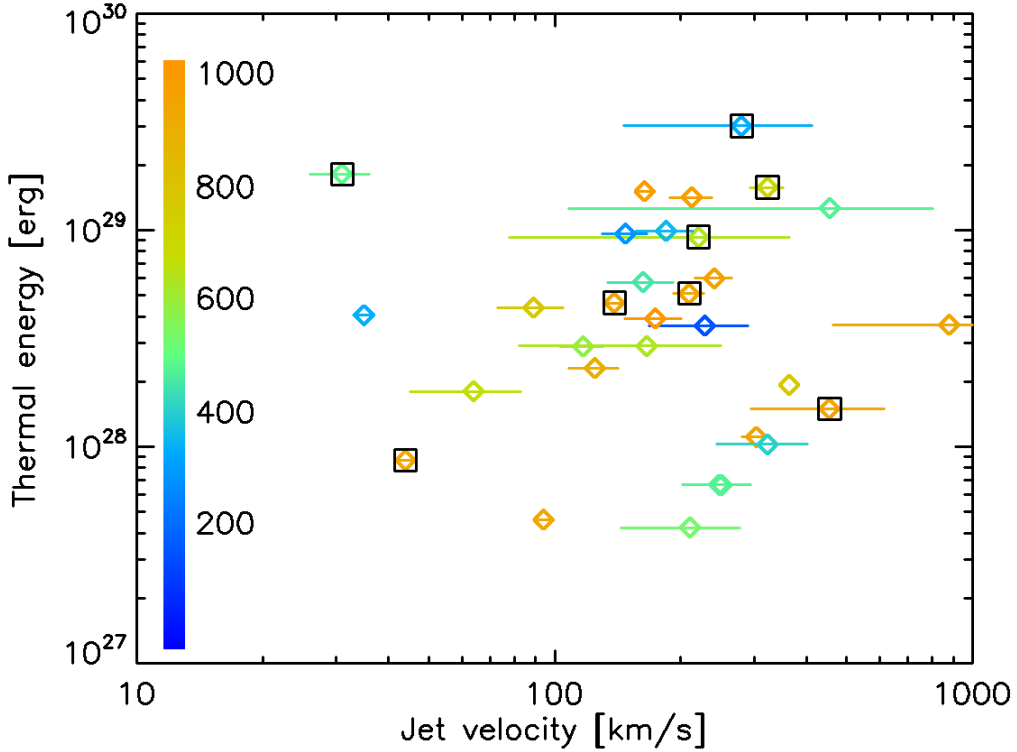


Musset et al. (2020)



X-ray spectroscopy: only 25% of events have a clear non-thermal signature

Statistics of coronal jets and particle acceleration



Musset et al. 2020: 33 flare-related jets associated with hard X-ray signatures

- 6 events have a clear **non-thermal component**
- Most of the flares are B-class
- **No correlation between the properties of the flare** (intensity in X-ray, thermal energy) **and the jet** (duration, velocity)

Energetic particles and coronal jets

Current open questions

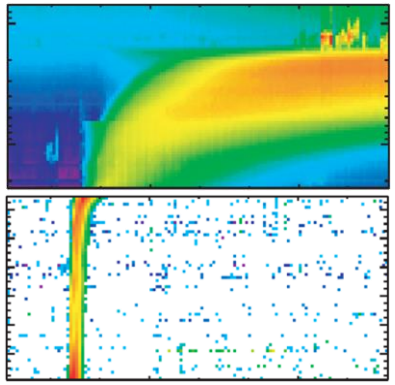
- **Are jets always present in sources of electron events?**
- **How often are jets associated with escaping beams of electrons?**
- **What is the relation between the properties of the jets and the distribution of non-thermal electrons?**
- **Are jets small-scale CMEs? Mini-filament eruptions?**

→ Science case for Solar Orbiter and Parker Solar Probe

"How do solar eruptions produce energetic particle radiation that fills the heliosphere"

Diagnostics in the Solo/PSP era

Not to scale

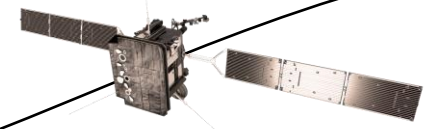


SolO/RPW
PSP/FIELDS

- ✓ Interplanetary radio type III bursts
- ✓ Coronal radio type III bursts

Ground-based radio observatories,
e.g., NRH, ORFEES, VLA, SKA, LOFAR...

Magnetic field lines

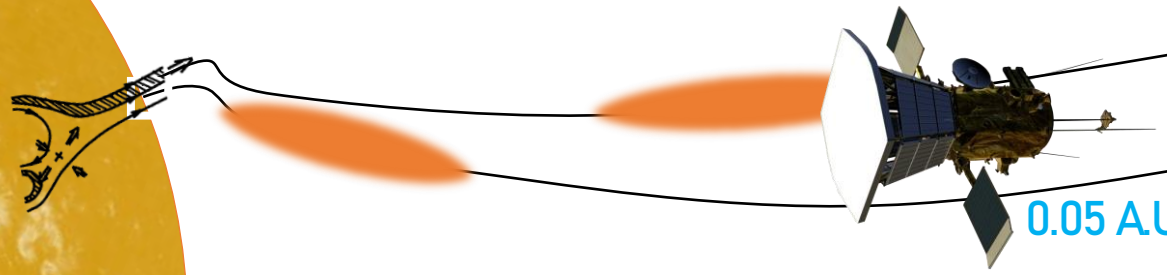


0.3 A.U.

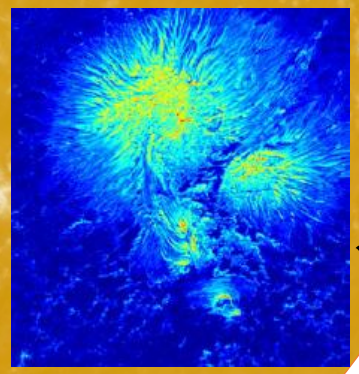
- ✓ SEP events
- ✓ Energetic electron events

- ✓ EUV emission

SolO/EUI

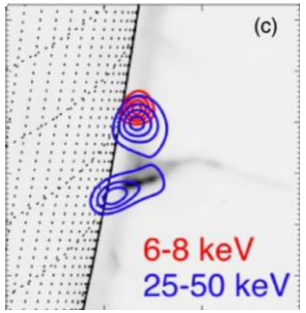


0.05 A.U.



SolO/PHI

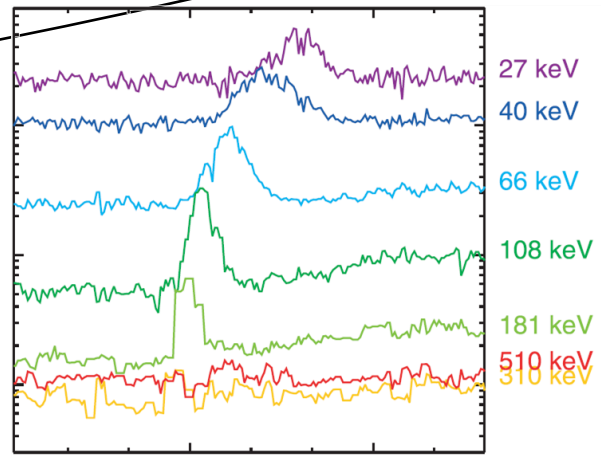
- ✓ Vector magnetic field (photosphere)



SolO/STIX

- ✓ X-ray emission
- ✓ Gyrosynchrotron emission

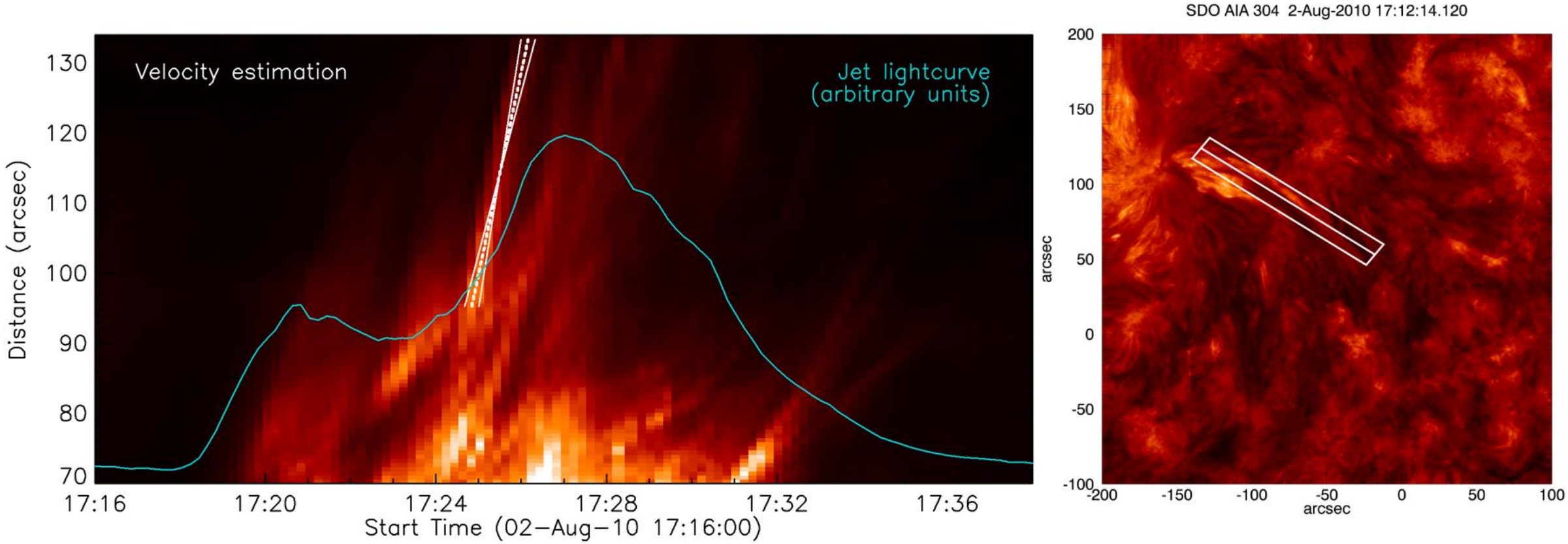
Ground-based radio observatories,
e.g. EOVSA, VLA, SKA...



SolO/EPD
PSP/ISOIS

Coronal jet velocities

Measure of the projected velocities in a time-distance plot



Musset et al. (2020)

Coronal jet velocities

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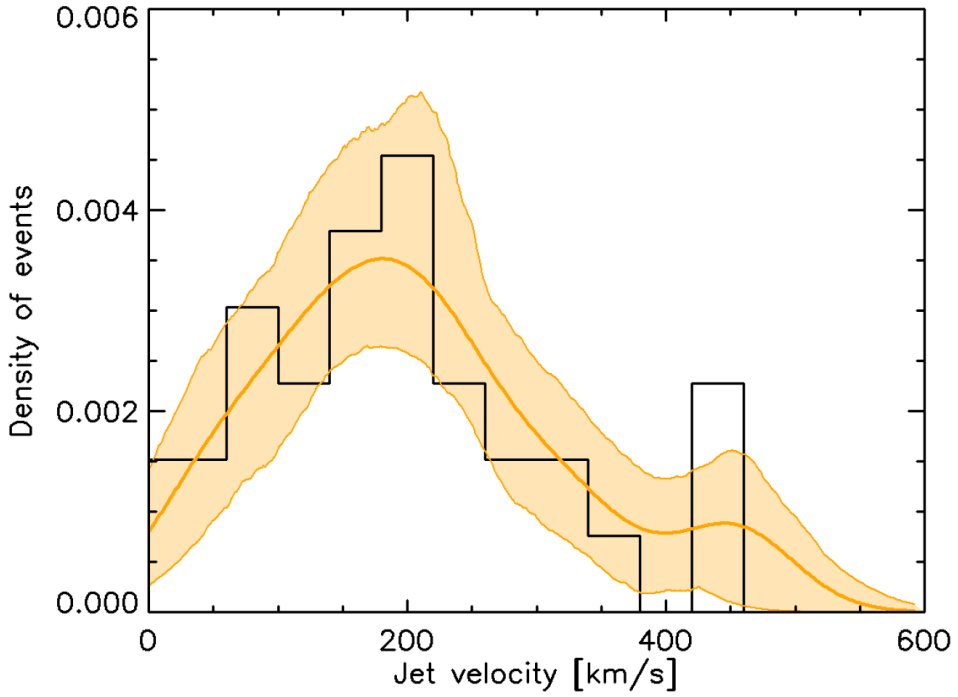

	Mean (km/s)	STDDEV (km/s)	Median (km/s)
304 A	213	158	185

Comparable to the velocity average of 271 km/s for the 20 jets in active regions studied by *Mulay et al. (2016)*

Musset et al. (2020)

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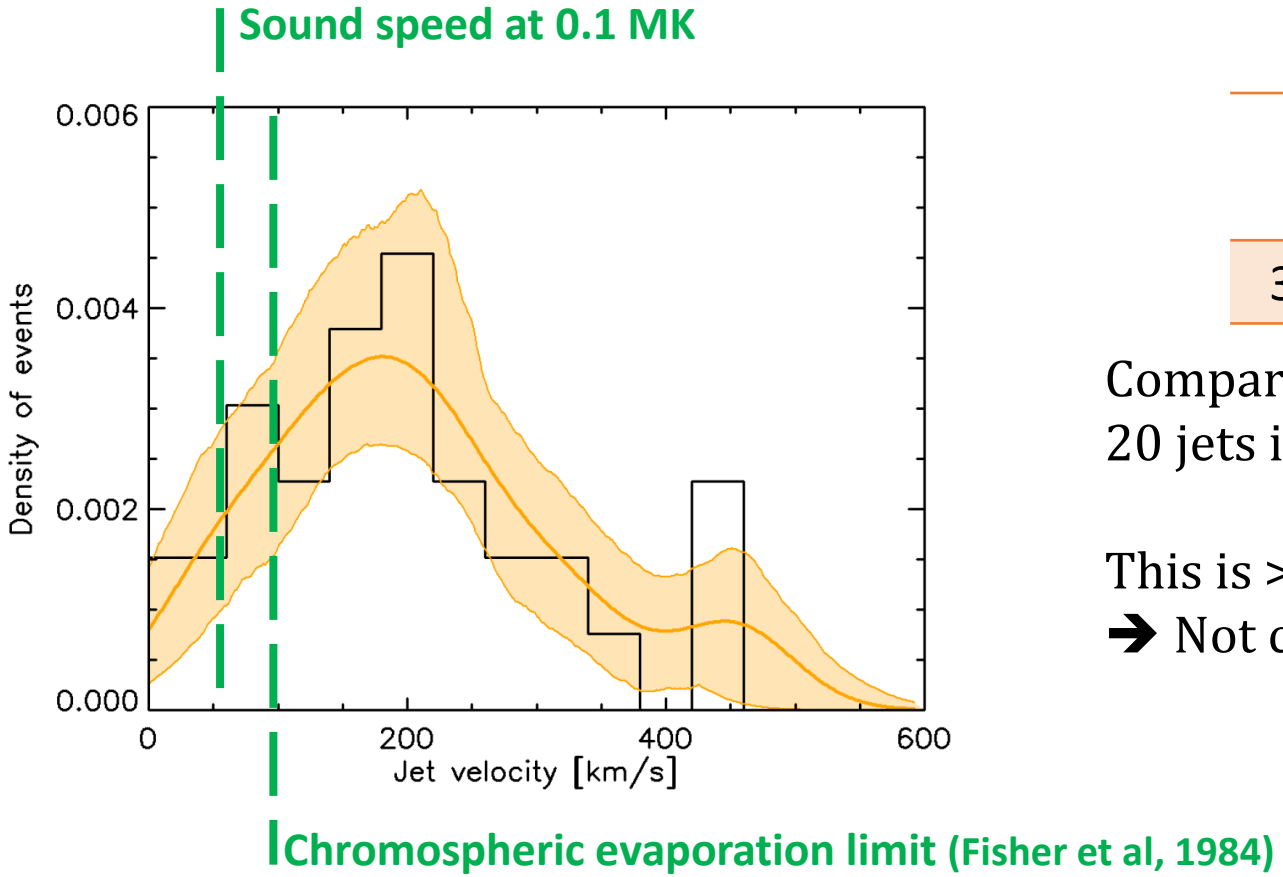

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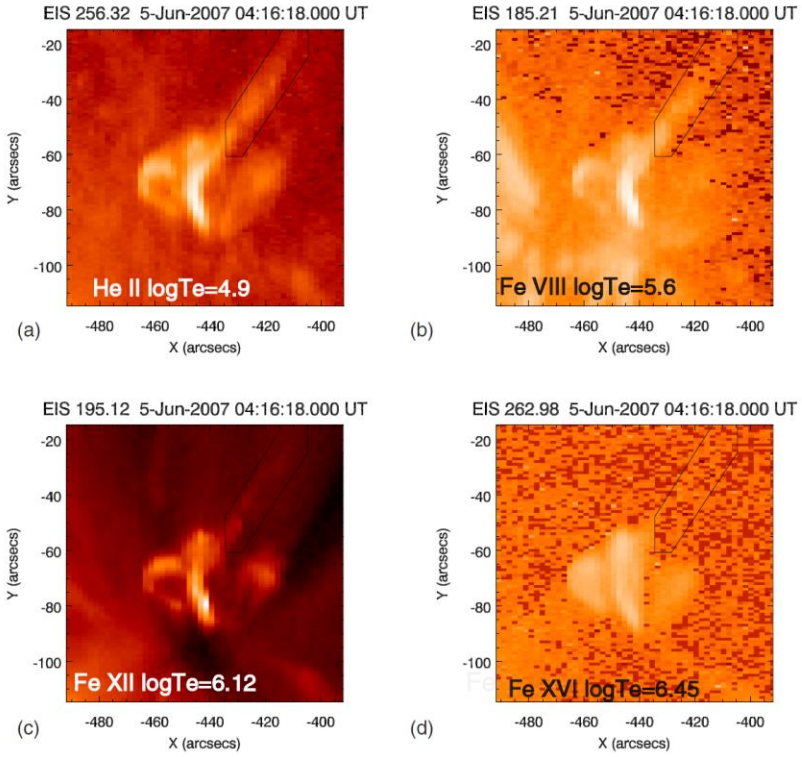
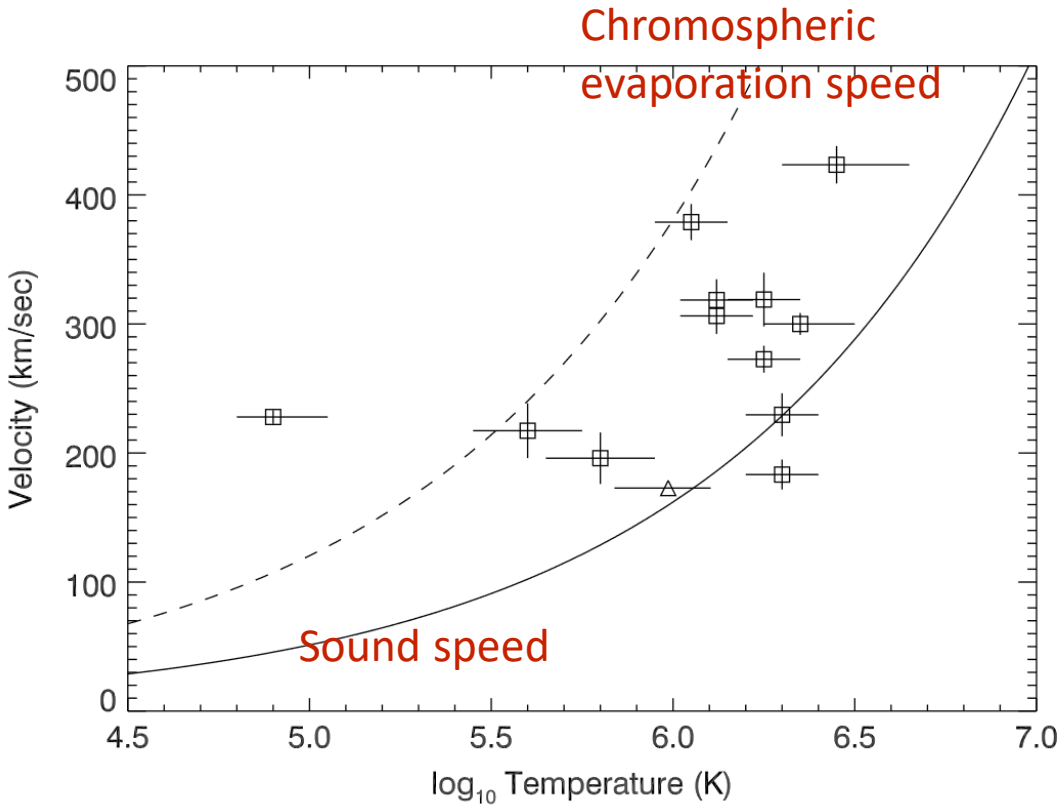
This is > sound speed (50 km/s at $T=10^5$ K)
➔ Not compatible with chromospheric evaporation?

Musset et al. (2020)

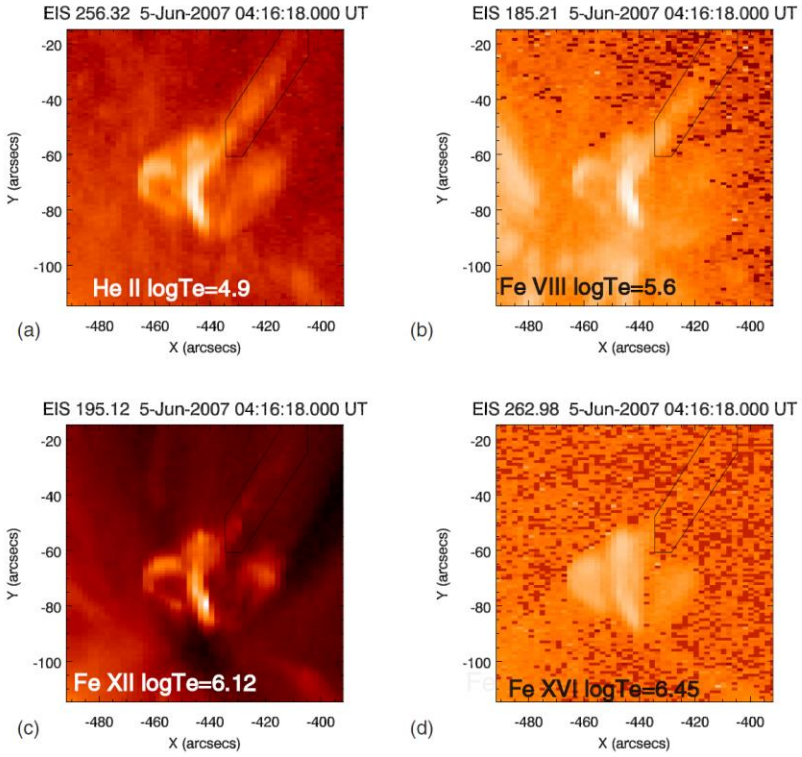
Coronal jet velocities: spectroscopic measurements

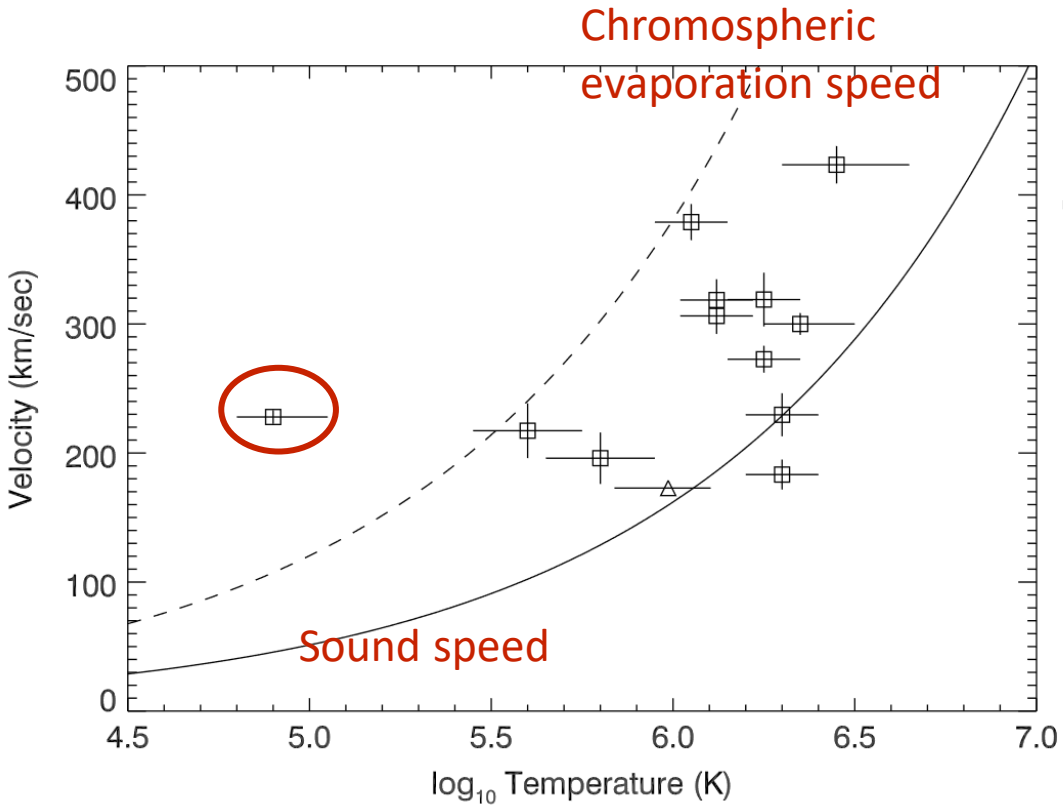




Matsui et al. 2012

Coronal jet velocities: spectroscopic measurements



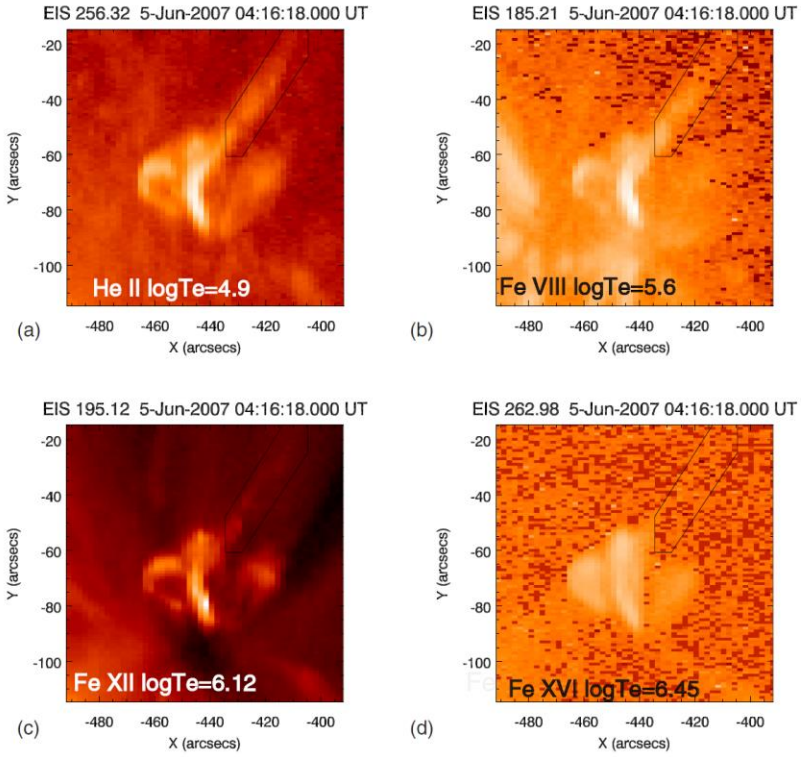


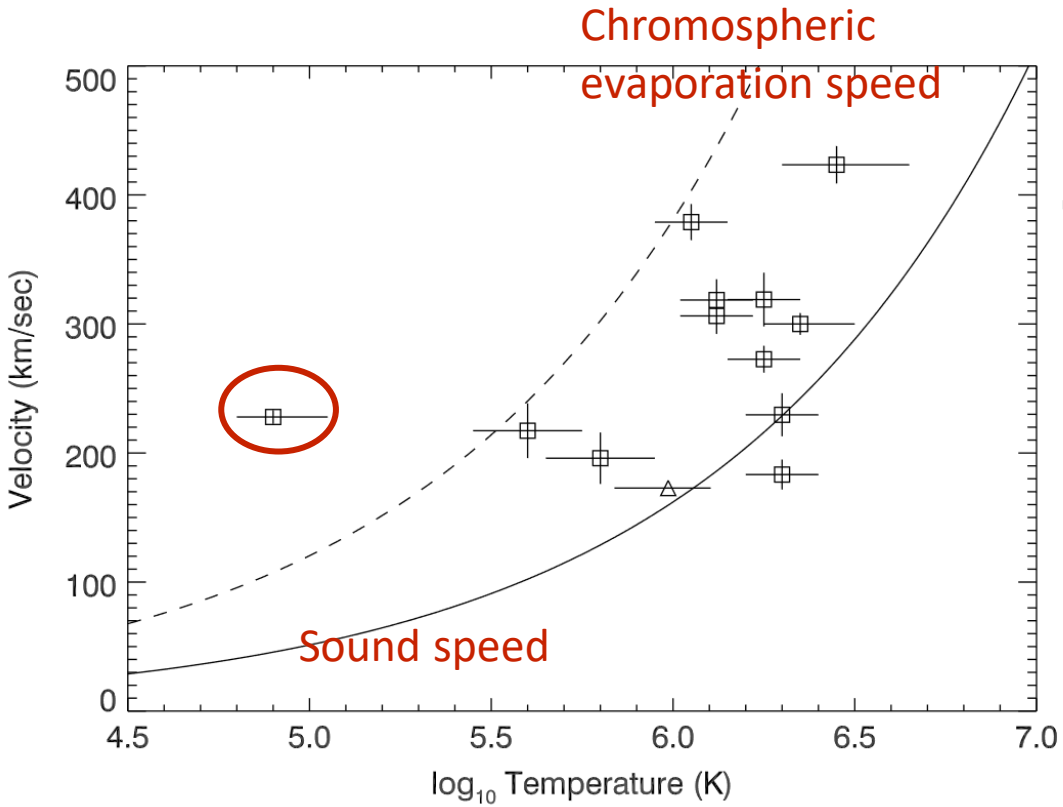
Matsui et al. 2012

The cool plasma goes faster than chromospheric evaporation velocity limit

→ Is cool plasma tracing the propagation of alfvenic perturbations?

Coronal jet velocities: spectroscopic measurements





Matsui et al. 2012

The cool plasma goes faster than chromospheric evaporation velocity limit

→ Is cool plasma tracing the propagation of alfvenic perturbations?

Pariat et al (2016): 3D MHD simulations of jets:
primary driver of jets = propagating non-linear Alfvenic torsional wave that develops on the reconnected open field lines.
At low beta, the propagation speed of the wave was close to the ambient Alfven speed and was much higher that the bulk flow speed of the plasma

Observational constraints for jet models

- Jet velocities
- Timing between jet and signatures of particle acceleration
- Number of X-ray footpoints
- Energy budget between accelerated particles and jet

→ Constraints for jet models (interchange reconnection, breakout model, mini-filament eruption…)

Towards a coronal jet database

- Most jet studies focuses on a few cases; the few statistical studies have less than ~40 events
- Jets in the observations and simulations have various shapes, sizes, velocities

→ Need for an extended jet database

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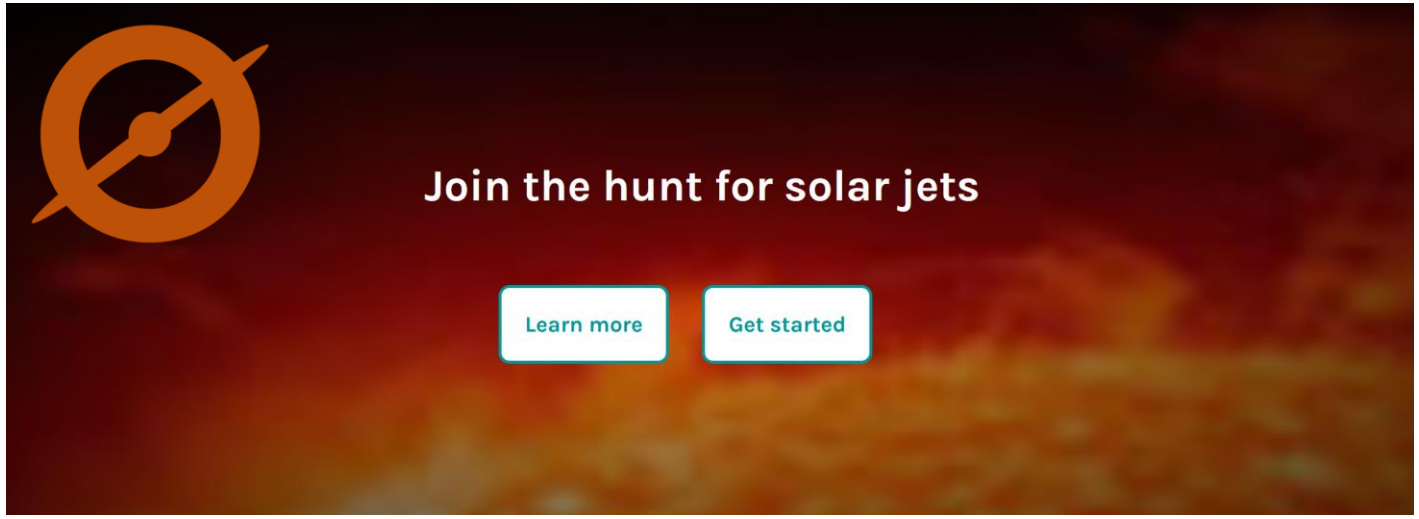
→ Need for an extended jet database

- **Citizen science** approach: volunteers inspect AIA 304 Å images/movies and report jets
- A **Zooniverse** project in collaboration with L. Glesener and L. Fortson (UMN), G. Fleishman (NJIT), N. Panesar and N. Hurlburt (LMSAL)



To be launched early 2021

Conclusion

- There is a clear link between coronal jets and the different signatures of energetic particles in the corona and the interplanetary medium, for a few case studies
- The link between particle acceleration and jet remains not well understood

→ Close-to-the-Sun in-situ and remote-sensing observations with Solar Orbiter and Parker Solar Probe, combined with radio observations from ground-based instrument, will provide new observations of faint events such as coronal jets event

➔Opportunity to revisit open questions

→To study the jets from a statistical point of view, and to address the wide variety of solar jets, a extensive database of jets is needed

Starting with 304 Å jets in the AIA data: a Zooniverse project (citizen science)