Inferring the nature of Penumbral Microjets

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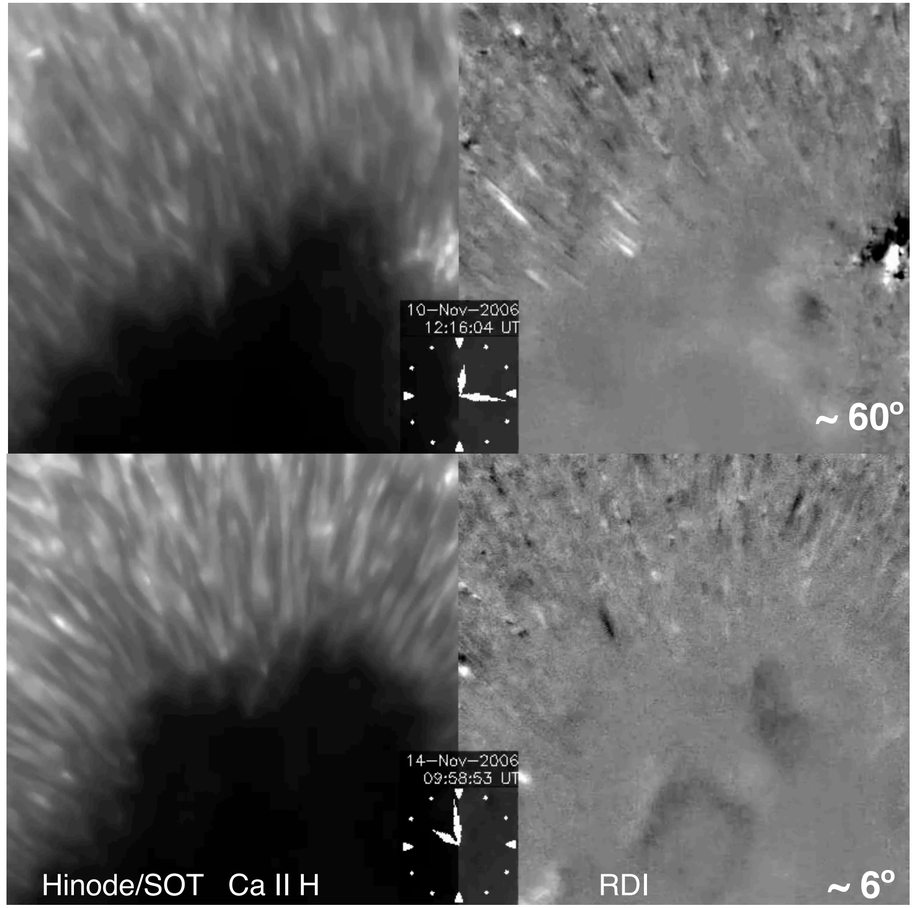
IRIS-10 Meeting

Penumbral Microjets (PMJs): **Short-lived, small, bright jetlike transients with rise speeds of 100 km/s in penumbral chromospheres**

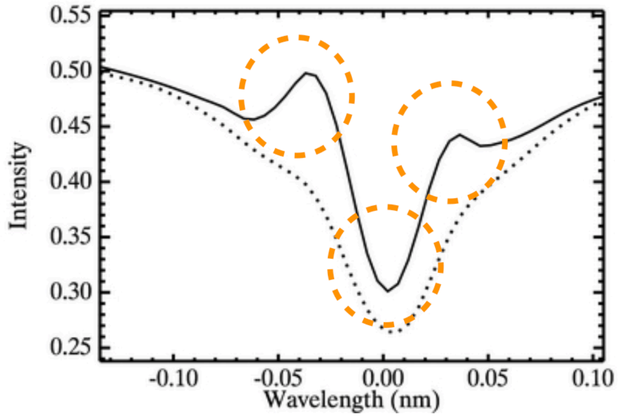
(Katsukawa et al. 2007)



Adapted from Katsukawa et al. (2007)

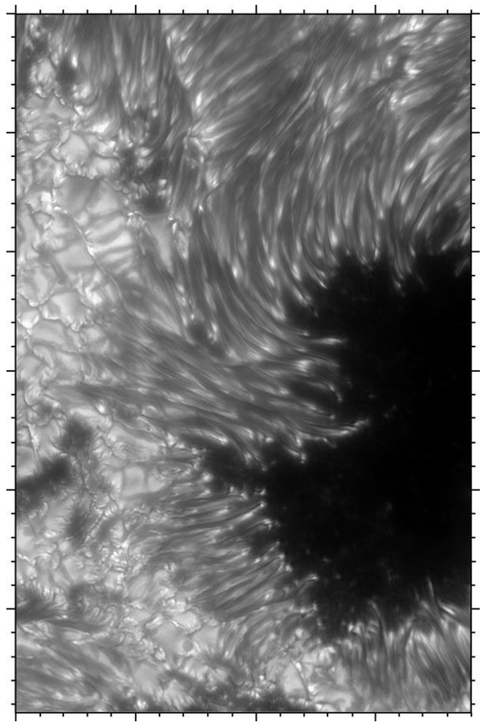
10-20% brighter than the surrounding penumbra

Length	1-4 Mm
Width	400 km
Lifetimes	60 s

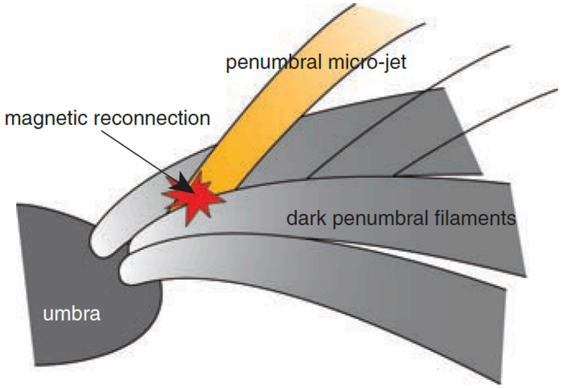


Adapted from Reardon (2013)

Magnetic reconnection in the photosphere: driver of PMJs?



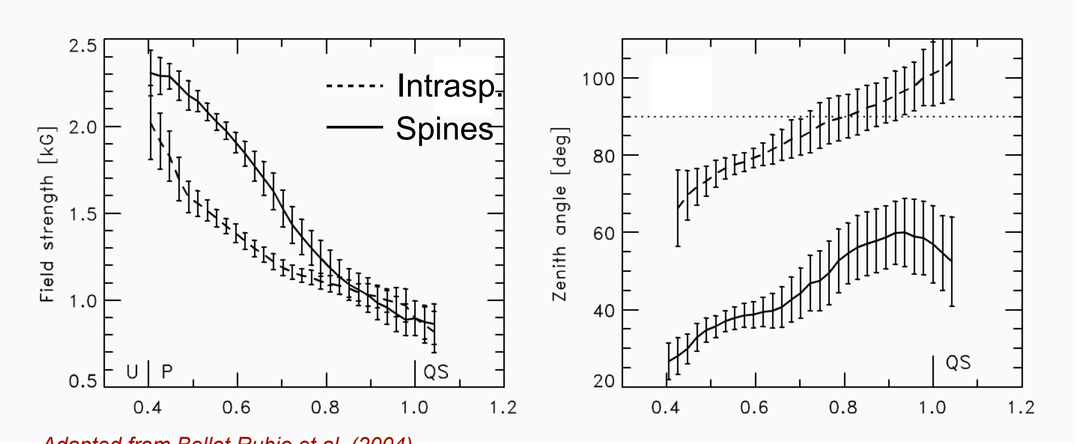
Scharmer et al. (2002)



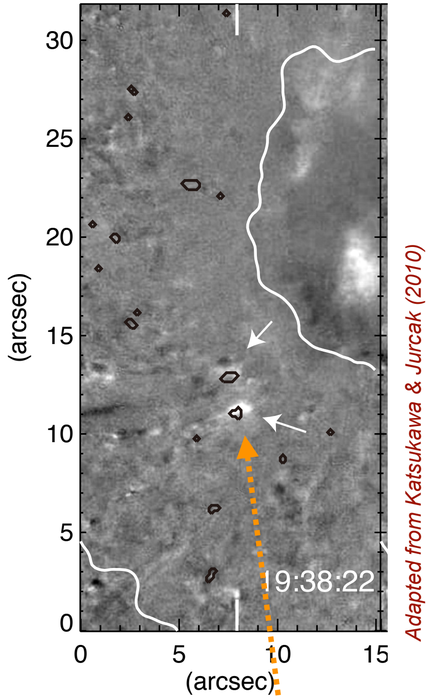
Katsukawa et al. (2007)

Spine-Intraspine configuration

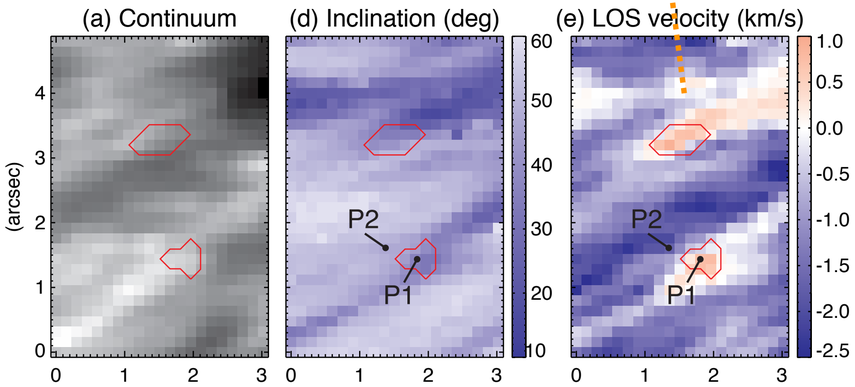
(Lites et al. 1993, Bellot Rubio et al. 2004; Langhans et al. 2005;…)



Adapted from Bellot Rubio et al. (2004)



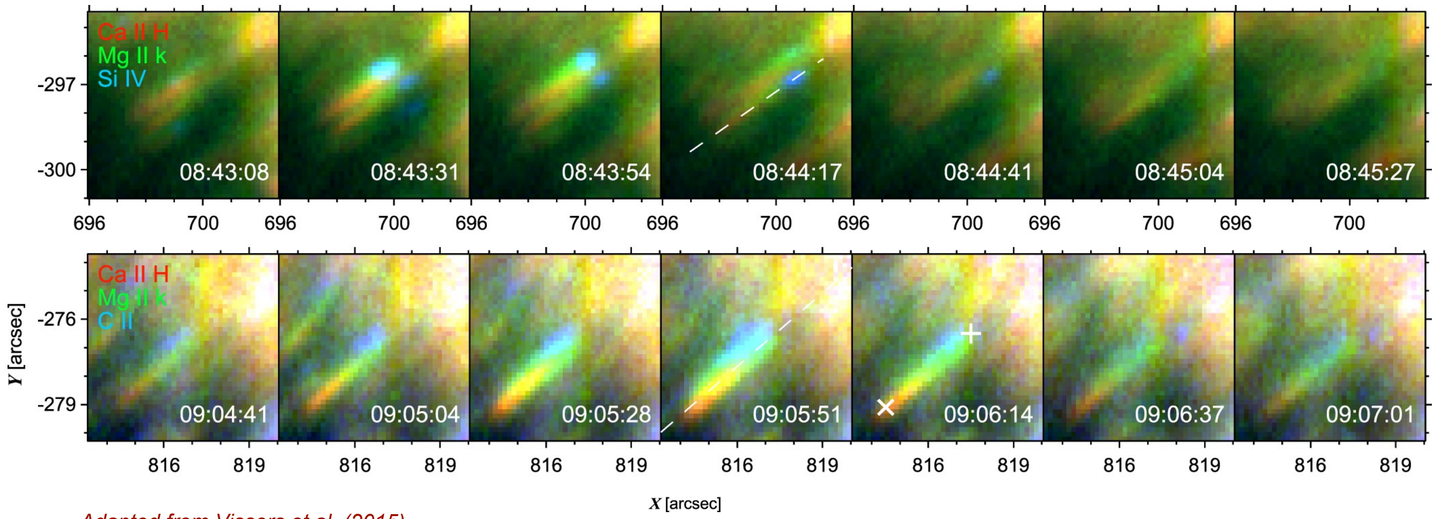
Adapted from Katsukawa & Jurcak (2010)



Adapted from Katsukawa & Jurcak (2010)

First IRIS observations of PMJs

SST/CRISP	8542 Å
SST/blue beam	Ca II H core
IRIS	C II 1330 Å Si IV 1400 Å Mg II k 2796 Å

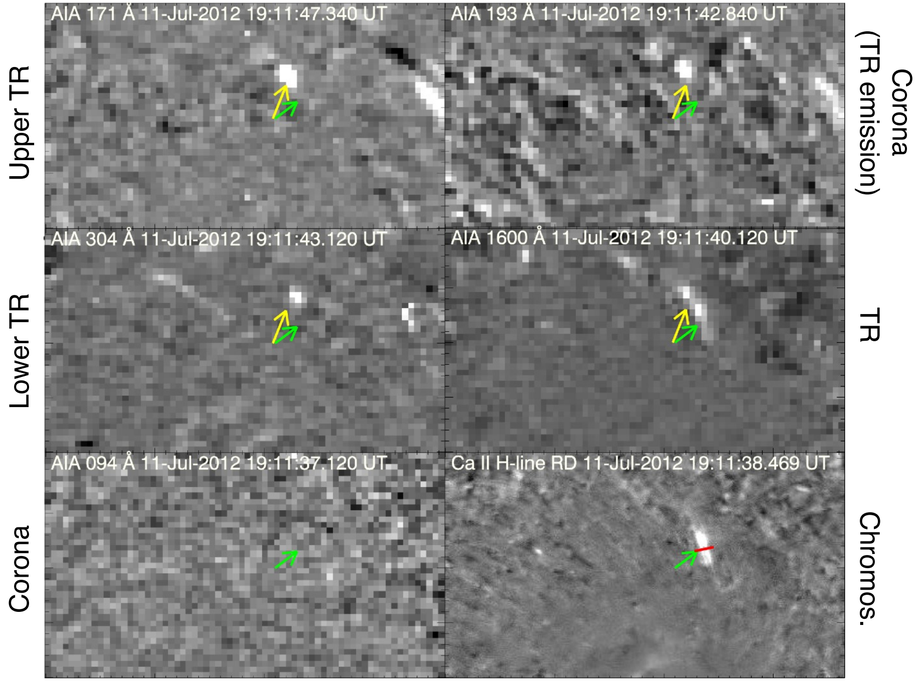


Adapted from Vissers et al. (2015)

Progressive heating to TR temperatures along the PMJs (Vissers et al. 2015)

Hint of **bi-directional flow** produced by magnetic reconnection

Coronal signatures?



Tiwari et al. (2016)

Scenario supported by the existence of:

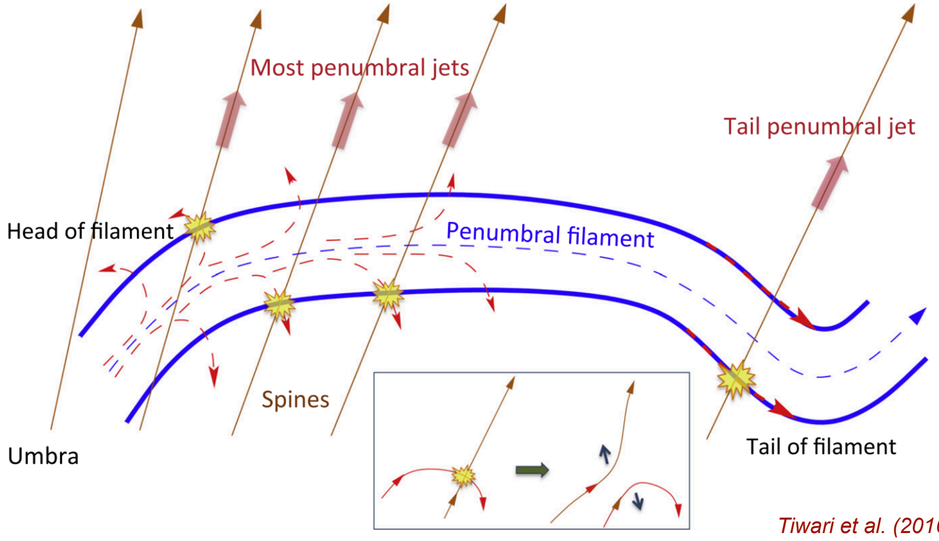
- **Lateral downflows** with **opposite polarity**
  (Ruiz Cobo & Asensio Ramos 2013; Scharmer et al. 2013; Tiwari et al. 2013)
- **Tail downflows** with **opposite polarity**
  (e.g., Tiwari et al. 2013; van Noort et al. 2013; Esteban Pozuelo et al. 2016)

Penumbral Jets (Tiwari et al., 2016)

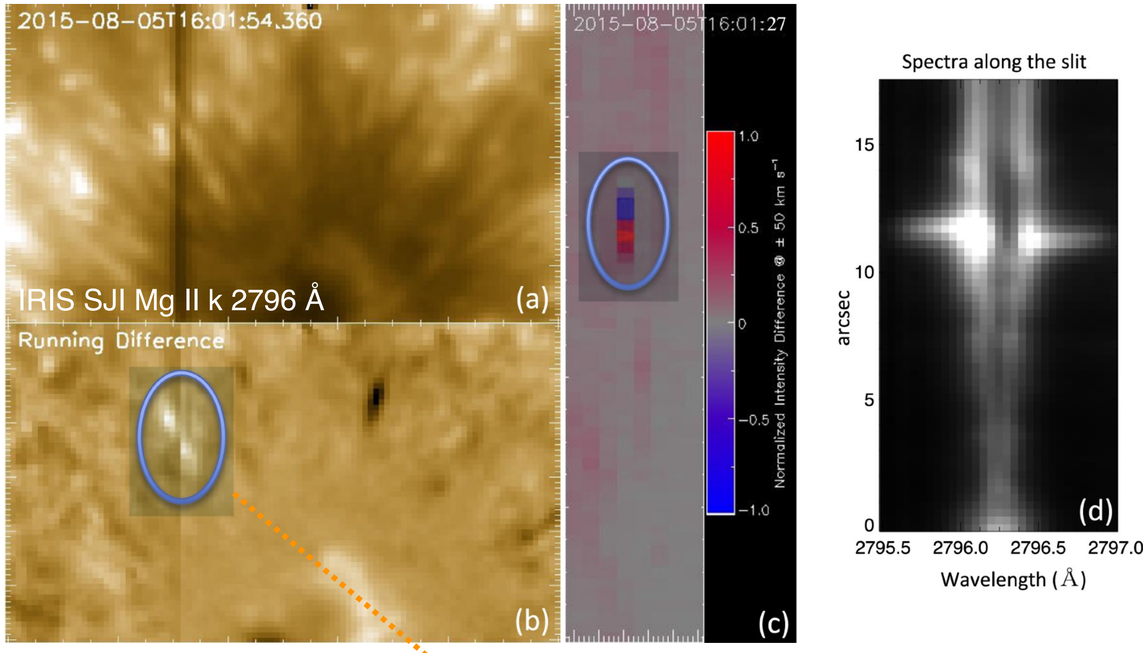
(Normal) PMJs

Large PJs

- Faster apparent speed (250 km/s)
- Wider than PMJs
- Brighter than PMJs
- Intermittent nature



Tiwari et al. (2016)



Tiwari et al. (2018)

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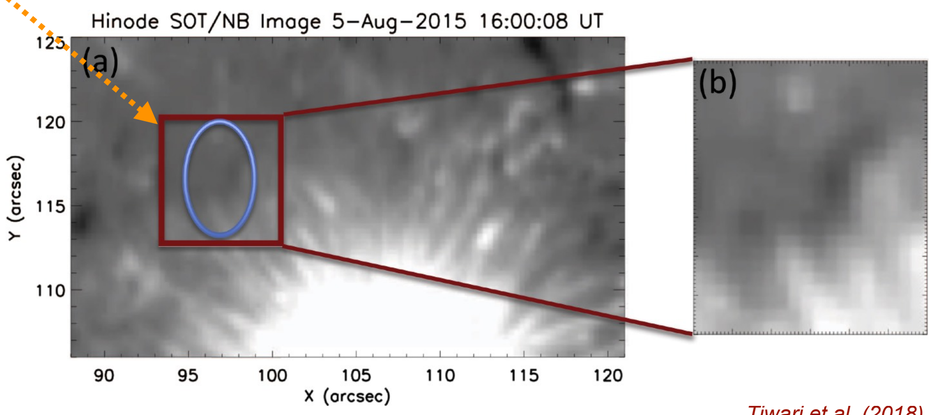

Tiwari et al. (2018)

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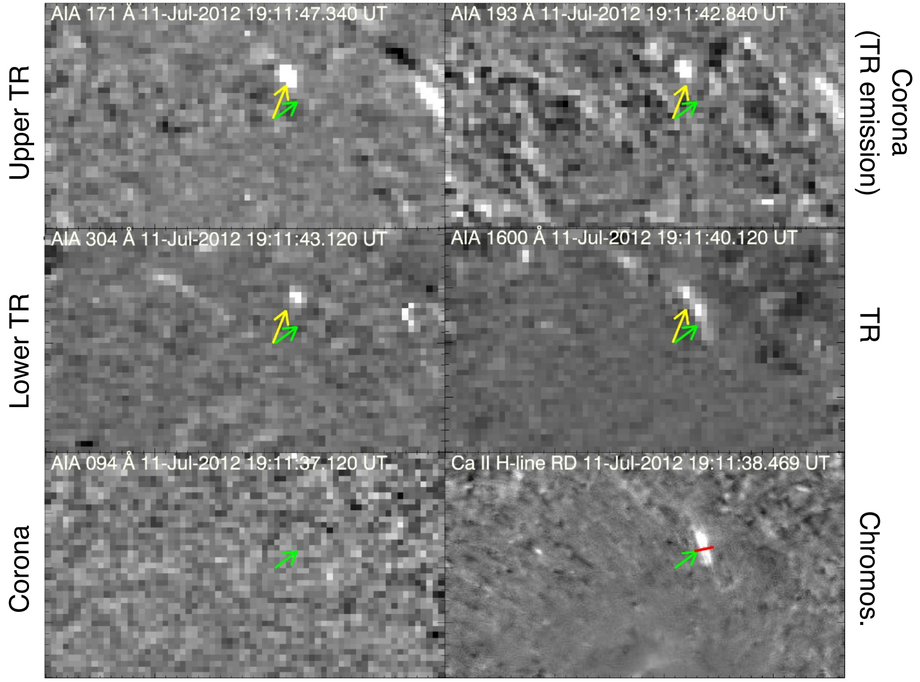
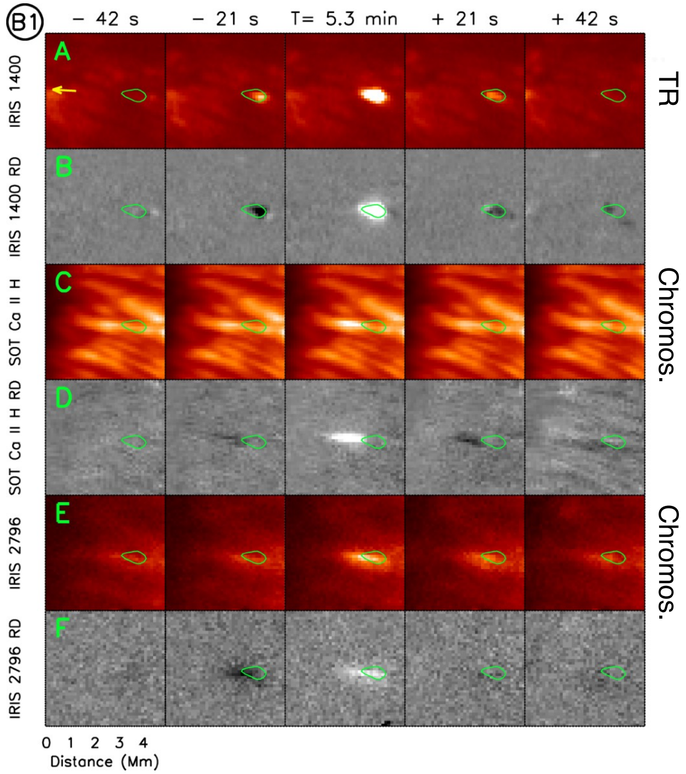


Tiwari et al. (2016)



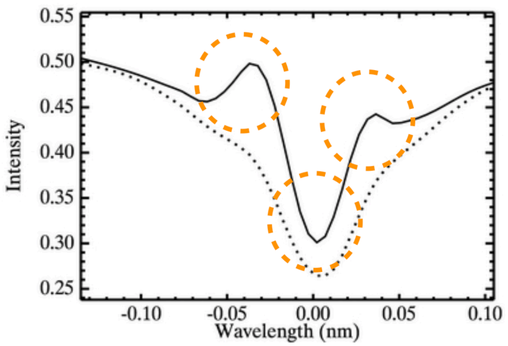
Adapted from Samanta et al. (2017)

BDs could originate from a **magnetic reconnection** at **low coronal** heights

- **PMJs** are the **downward counterpart** reaching the **chromosphere**

(Samanta et al. 2017)

Statistics on basic properties

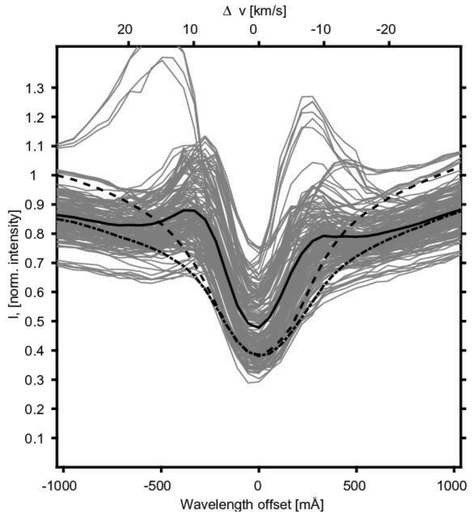


Adapted from Reardon (2013)

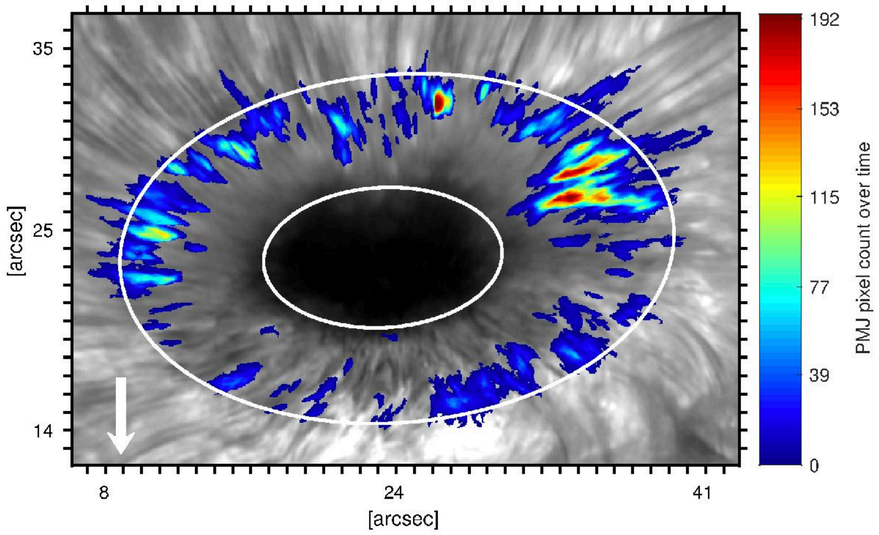
k-NN algorithm

Detection of a great sample of PMJ on a penumbra

(Drews & Rouppe van der Voort 2017)



Drews & Rouppe van der Voort (2017)



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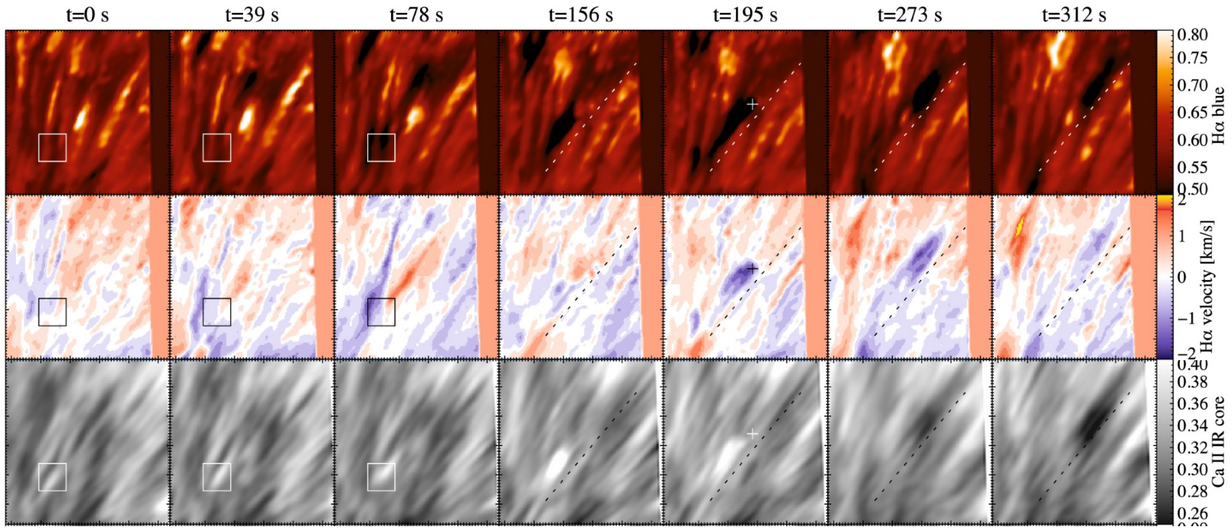


Adapted from Bühler et al. (2019)

Length	640 km	Lifetimes	90 s
Width	210 km		

(Drews & Rouppe van der Voort, 2017)

PMJs leave an **imprint** in **H-alpha wings**
(Bühler et al., 2019)

Length	2000 km	Lifetimes	160 s

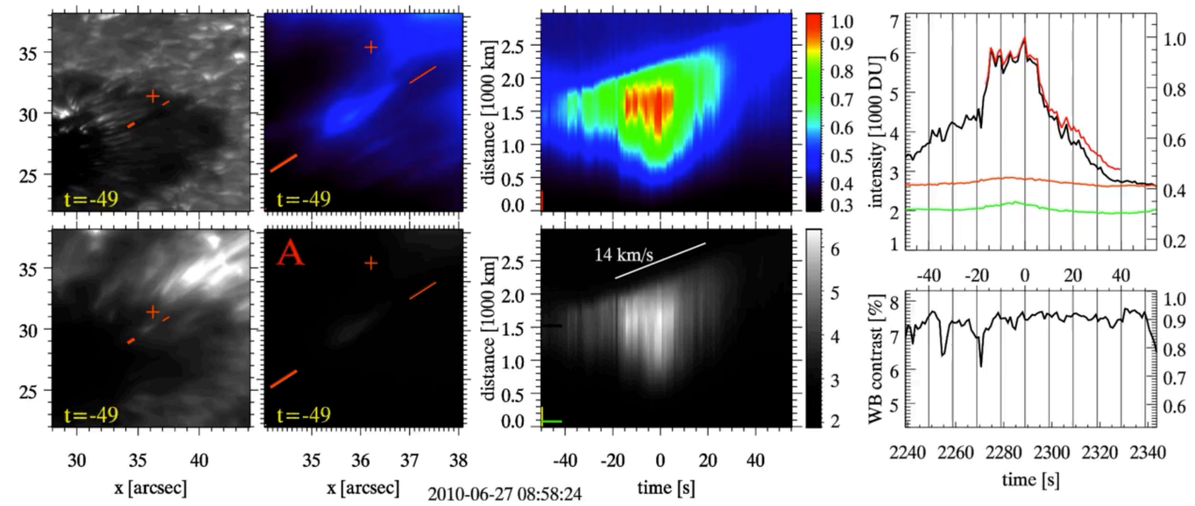
PMJs evolution at high temporal cadence

- Coherent, rapid and uniform increase in intensity over the length of a pre-existing fibril.
- Not clear whether brightening grows from bottom to top.
- After brightening, different scenarios are observed at the top of the PMJ, it may: rise, retract, or not move. Visually, the whole PMJs seems:
    - To have a proper motion (if the bottom also rises)
    - To shrink (if the bottom does not move)
- Some PMJs undergo splitting

(Rouppe van der Voort & Drews, 2019)

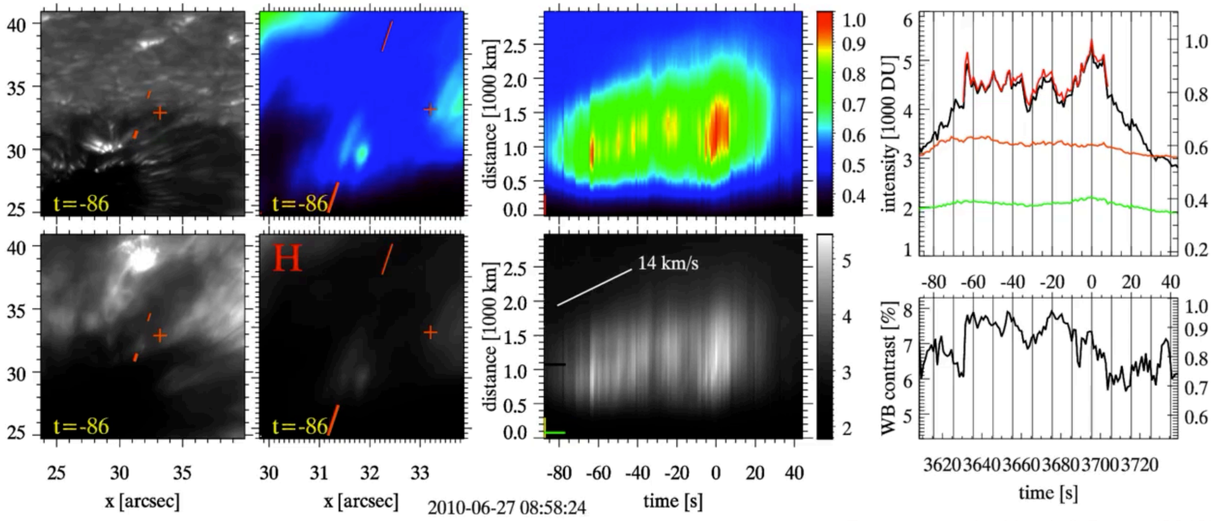
The importance of high temporal resolution when studying the dynamic solar atmosphere

Rising top + rising bottom ⟶ **Shrinking**



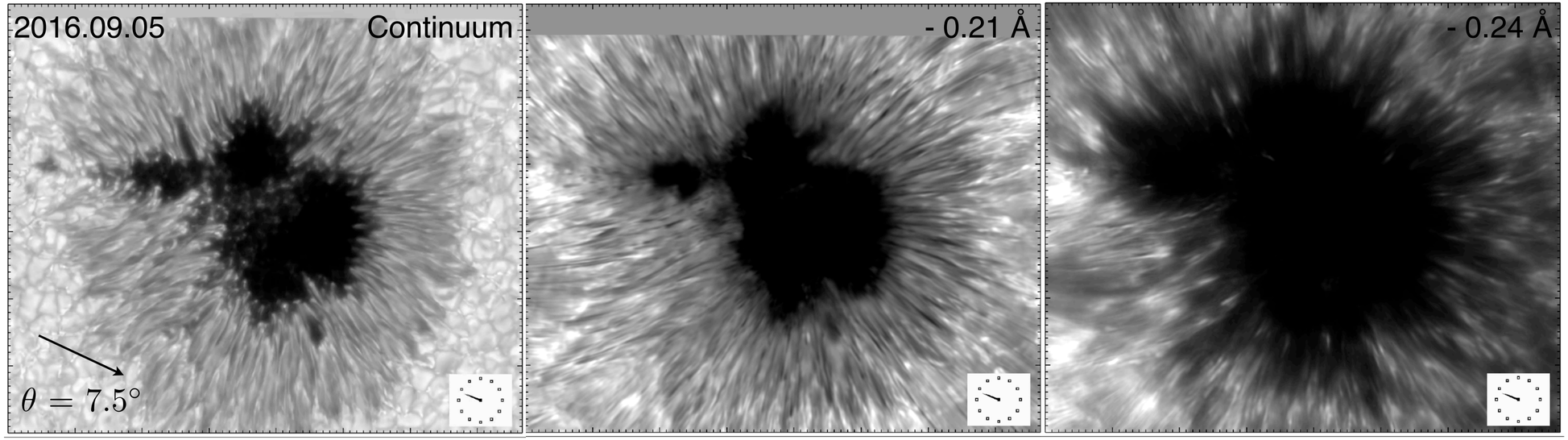
Rouppe van der Voort & Drews (2019)

Splitting



Rouppe van der Voort & Drews (2019)

SST/CRISP Fe I 6301 Å **SST/CRISP Ca II 8542 Å** **SST/CHROMIS Ca II K**



35 snapshots, cadence~**32 s**
FOV= 55”x55”, **0”.057/pixel**
CRISPRED
(de la Cruz Rodríguez et al. 2015)

81 snapshots, cadence~**14 s**
FOV=56”x43”, **0”.0375/pixel**
CHROMISRED
(Löfdahl et al., 2019)

Both datasets are aligned

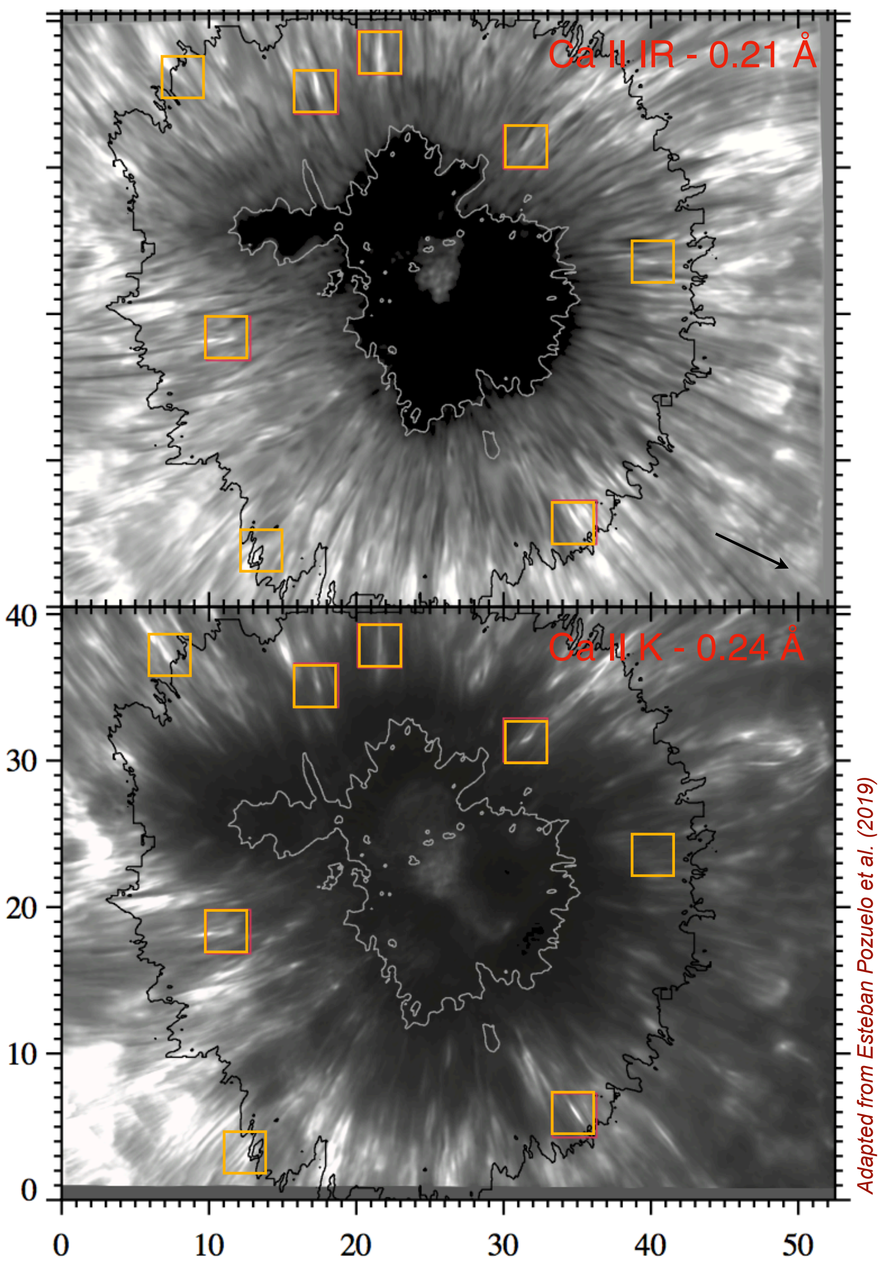
Detection of PMJs using CRISPeX

(Vissers et al. 2012)

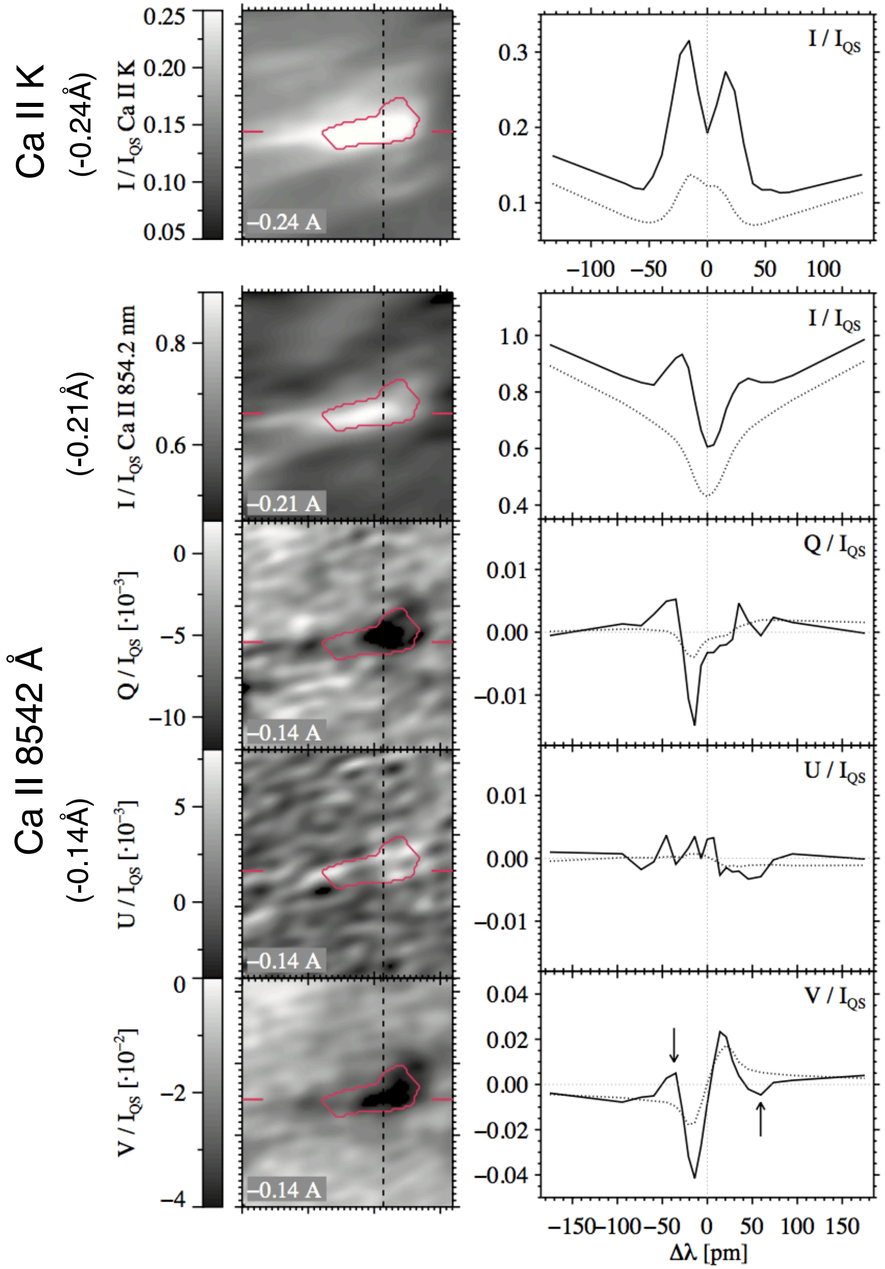
- Shape of Ca II 854.2 nm intensity profile
- Morphology
- Brightness
- Lifetimes

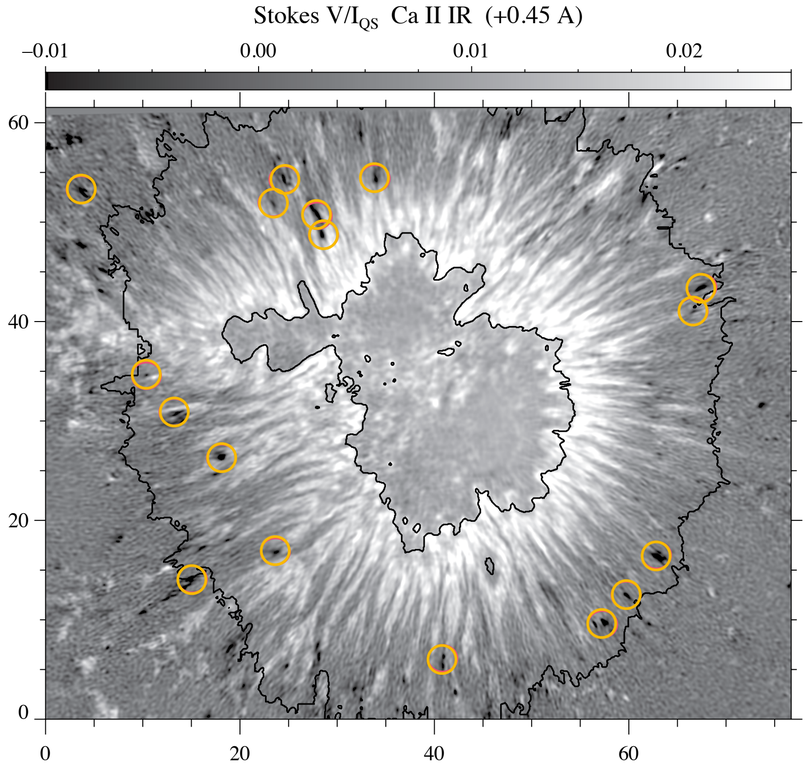
37 PMJs with a regular behavior over time

Length	1450 km	Lifetimes	1-6 min
Width	430 km	Intensity	10-60% I/I_{QS}

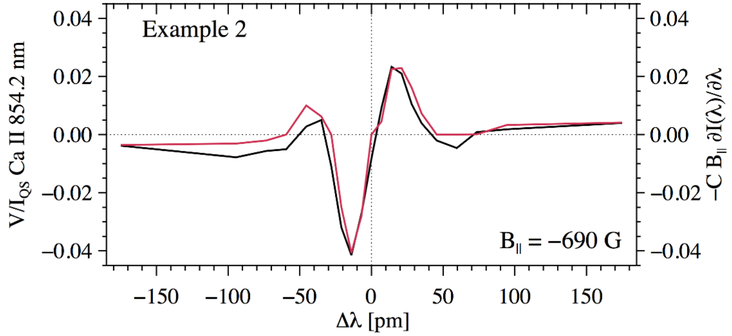


Adapted from Esteban Pozuelo et al. (2019)





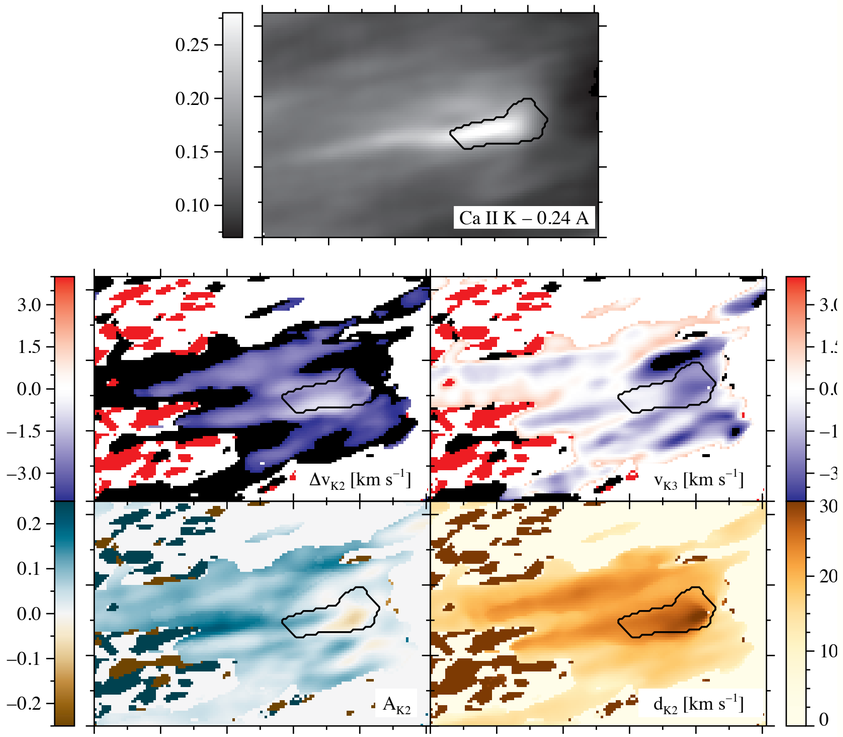
WFA $$V(\lambda) = -C_1 B_{\parallel} \frac{\partial I(\lambda)}{\partial \lambda}$$



Adapted from Esteban Pozuelo et al. (2019)

Ca II K line: powerful tool to v_{LOS} diagnostics

(Björgen et al. 2018)



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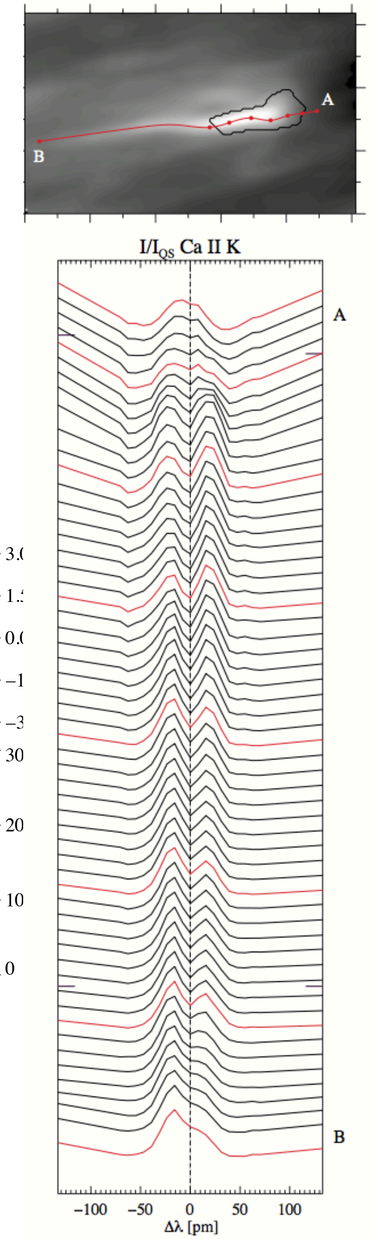

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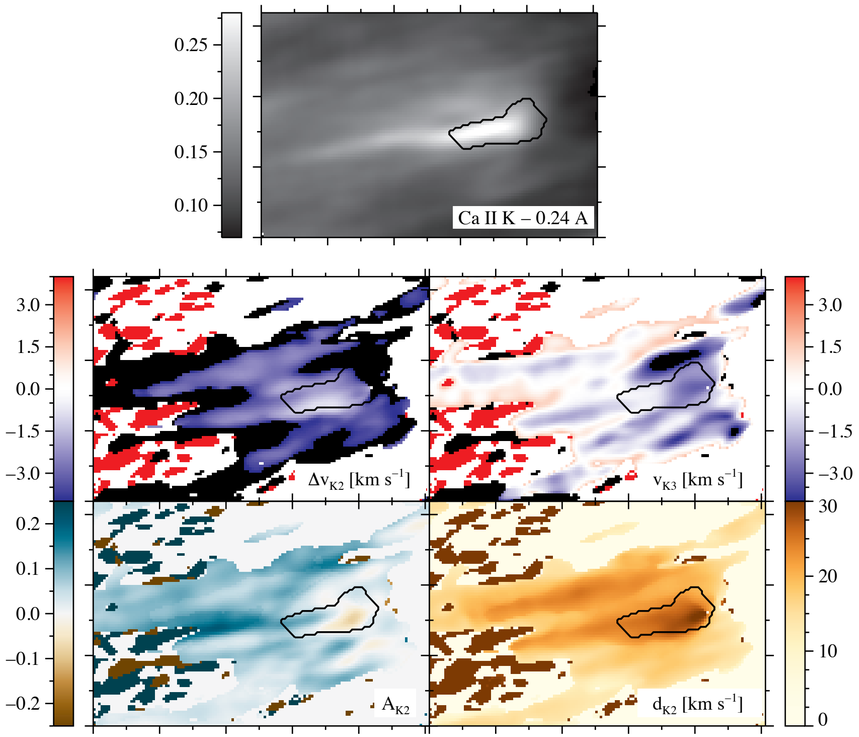

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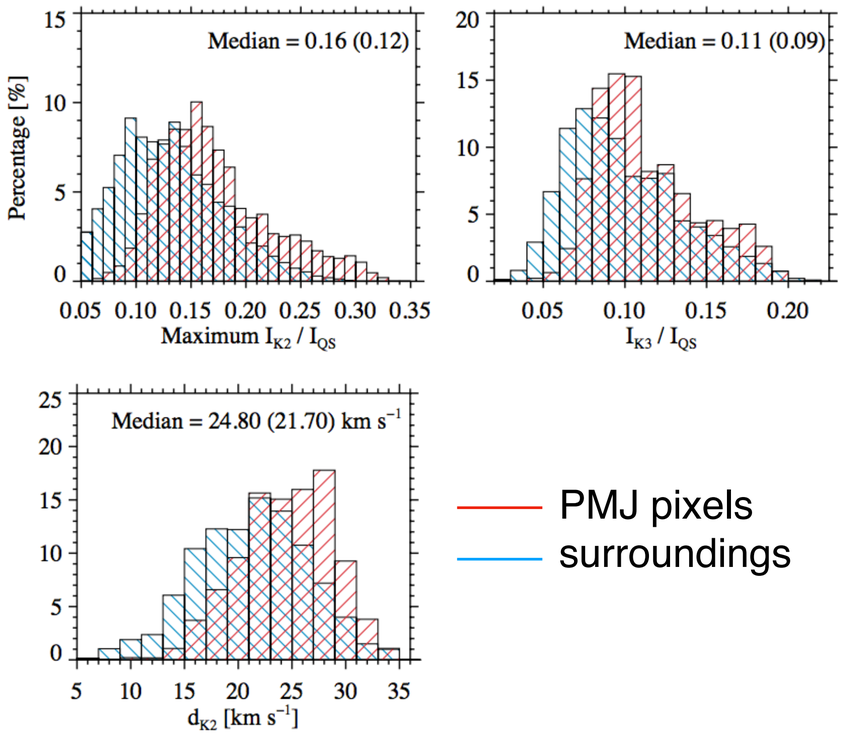


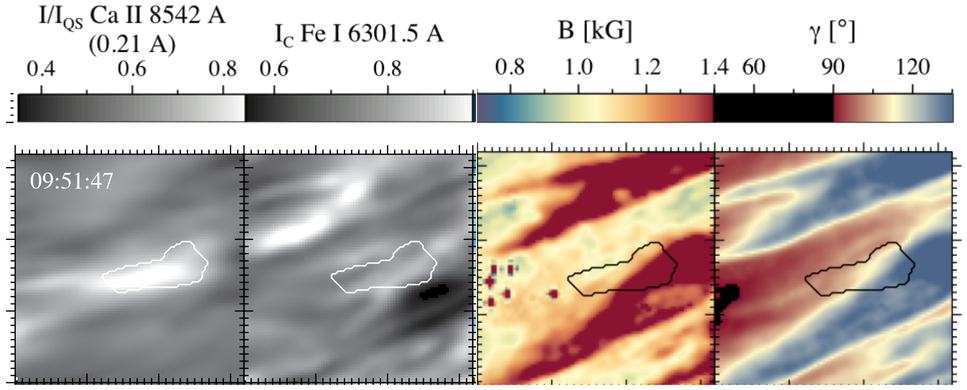
Adapted from Esteban Pozuelo et al. (2019)

PMJs:

Brighter in the K_2 and K_3 peaks
Stand out in the K_2 peak separations

Scenario on the photosphere

Milne-Eddington inversions of the Fe I 630 nm pair Stokes profiles



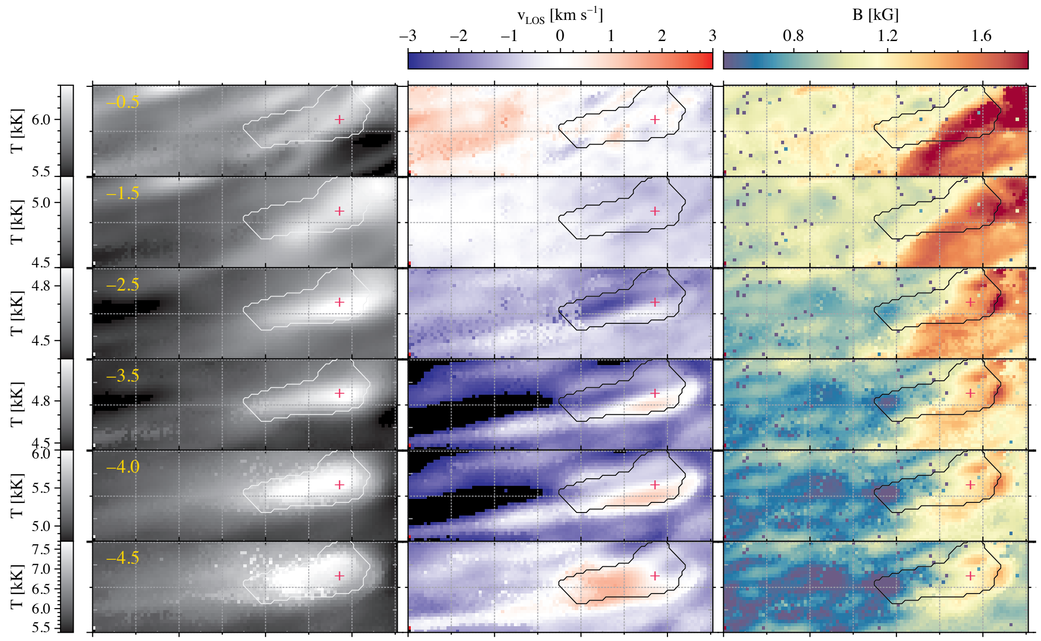
Adapted from Esteban Pozuelo et al. (2019)

Strong horizontal gradients in the magnetic field inclination.

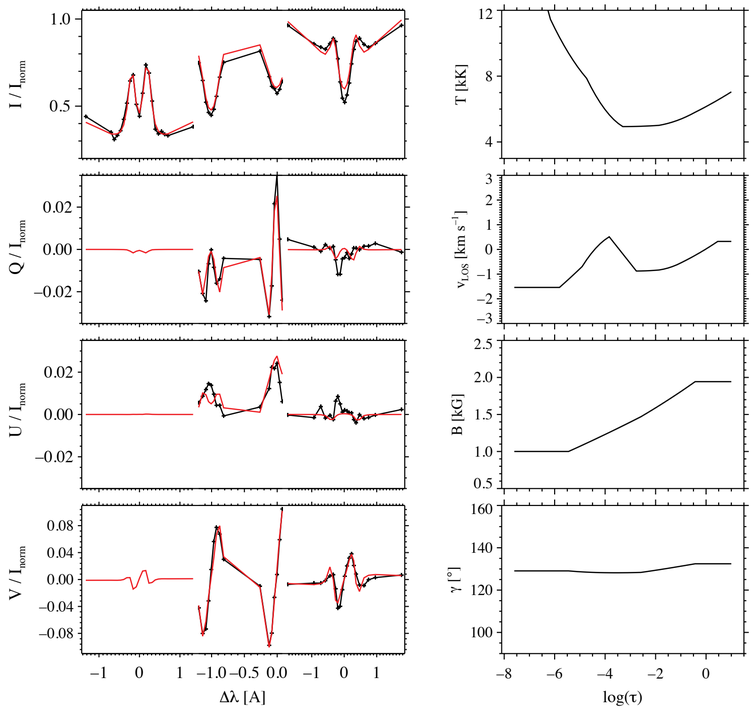
Susceptible of **harboring field lines that sink to deeper layers**.
Magnetic reconnections could occur between these field lines and the spines, as Tiwari et al. (2016) proposed.

Magnetic reconnections could occur **very deep** or at **smaller spatial scales**

Inversions of PMJs using the STiC code (de la Cruz Rodríguez et al. 2016)



Adapted from Esteban Pozuelo et al. (2019)



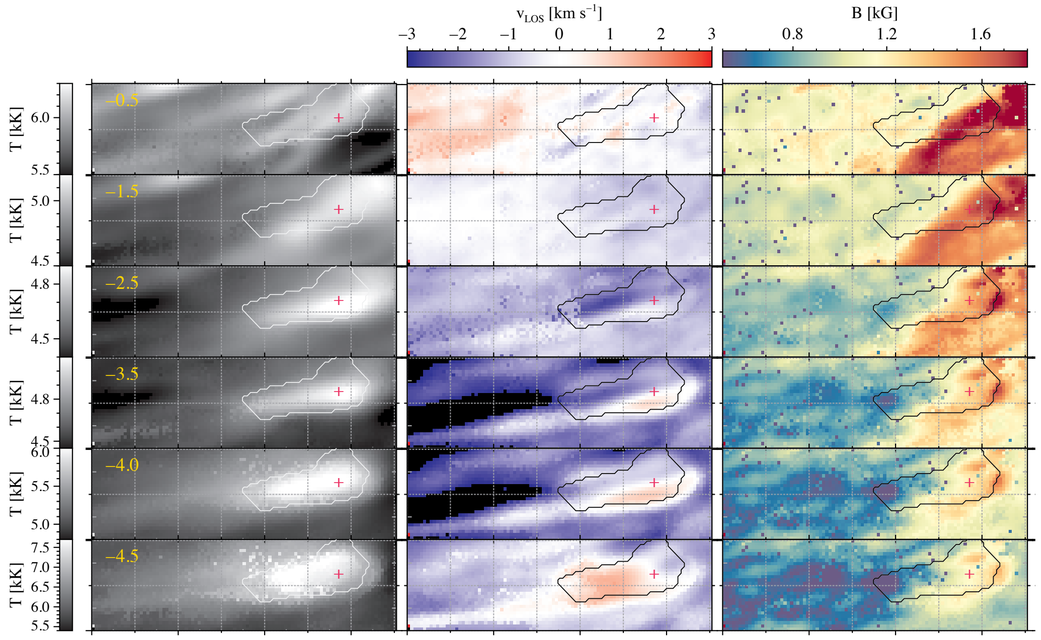
Esteban Pozuelo et al. (2019)

Rise speeds of order 100 km s^{-1}

$\theta = 7.5°$

Vertical gas motions: v_{LOS} ~ Apparent rise speeds
Horizontal gas motions: v_{LOS} ~ 15 km s^{-1}

PMJs may not be entirely related to gas motions induced by magnetic reconnection…



Adapted from Esteban Pozuelo et al. (2019)

Alternative? **Perturbation front** caused by **magnetic reconnections** in the deep photosphere that **propagates to upper layers**, such as currents

> Current heating: ↑ T at temperature minimum region
>
> ↑ collisions with electrons in the PMJ location might also enhance the coupling to the local conditions at higher layers comparatively to its surroundings

Summary

1. PMJs are **bright jet-like transients** popping up at the **chromosphere of sunspot penumbrae**.The **brightening is uniform** along the length of a **preexisting fibril**. **High temporal cadence** observations are crucial **to understand their evolution**.
2. PMJs appear on both penumbral sides above locations with **strong horizontal gradient of the magnetic field inclination -> magnetic reconnection as in Tiwari et al. (2016) in deeper layers or at smaller spatial scales?**
3. PMJs leave **similar imprints** between the **minimum temperature region** and the **mid chromosphere** and harbor **conspicuous polarization signals in Ca II 854.2 nm**. The multi-lobed Stokes V signals are caused by the characteristic shape of Stokes I.
4. PMJs are **hot features visible from the low chromosphere**, that expand and are hotter at larger heights. PMJs show a progressive heating to TR temperatures. They are related to **low LOS velocities**.
5. **Discrepancies between their LOS velocities and apparent speeds** could suggest that PMJs are not purely related to mass motions. Instead, we speculate that they might be produced due to **currents induced by magnetic reconnections that propagate to upper layers.**