Chromospheric Activity at the Smallest Scales Obtained by HINODE
- Small-Scale Activities in Penumbrae -

Y. Katsukawa and J. Jurcak (NAOJ)

2nd HINODE Science Meeting

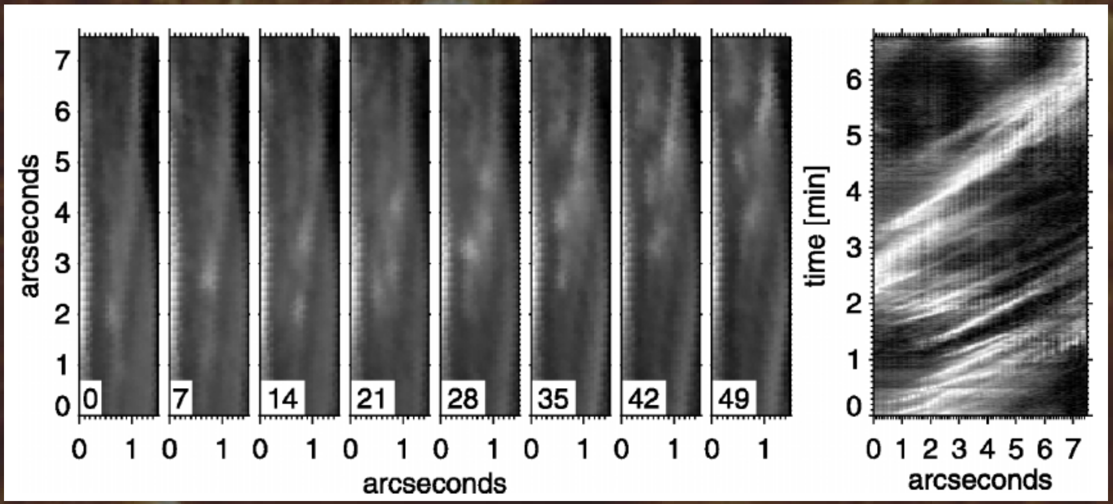
Sep 29 - Oct 3, 2008

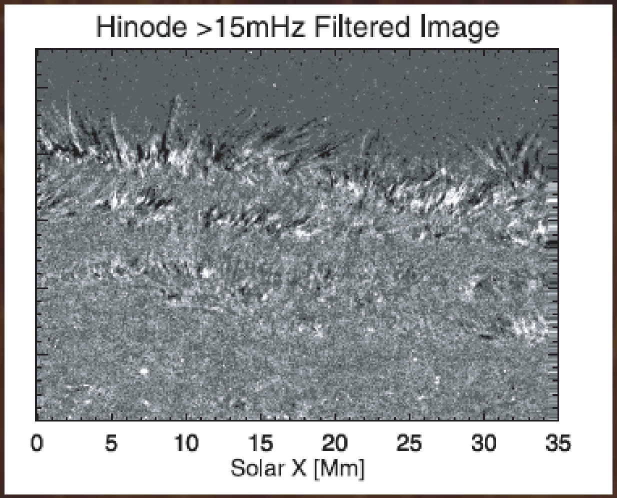
Very fast events in the chromosphere

- Recent progress of high resolutional observations with ground-based telescopes and HINODE has enabled us to see very fast events in the chromosphere.

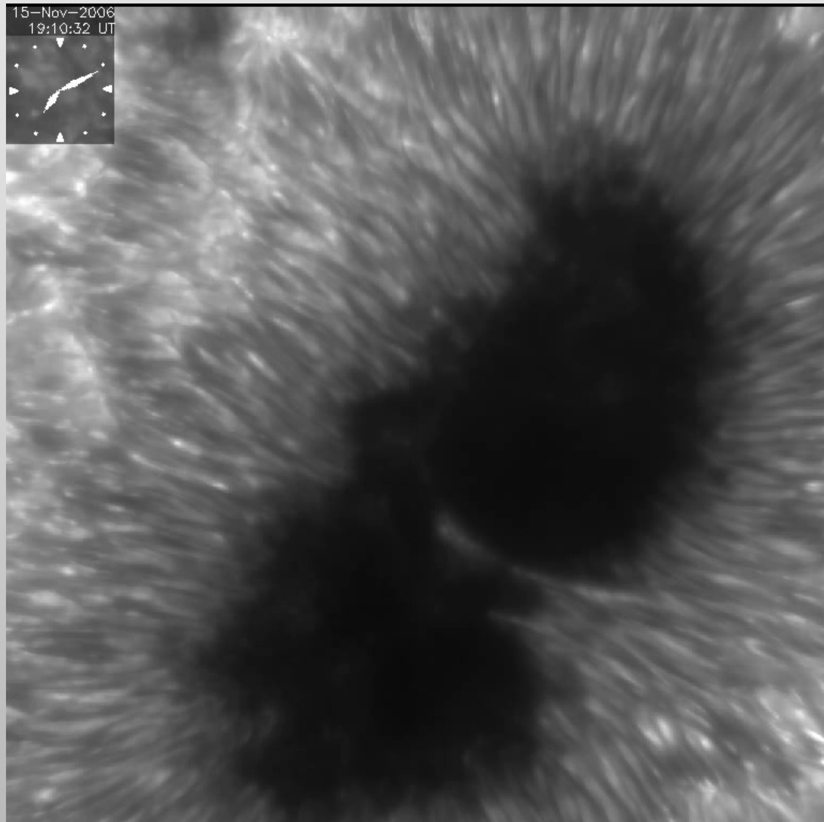
- van Noort and Rouppe van der Voort (2006)
  - Small features (100-300km) moving at velocities 40 - 240km/s

- De Pontieu et al. (2007), Langangen et al. (2008)
  - Transient and fast spicules (type-II)
  - Apparent velocities of 50–150 km/s, a few 100km thickness
  - Lifetime shorter than 1min

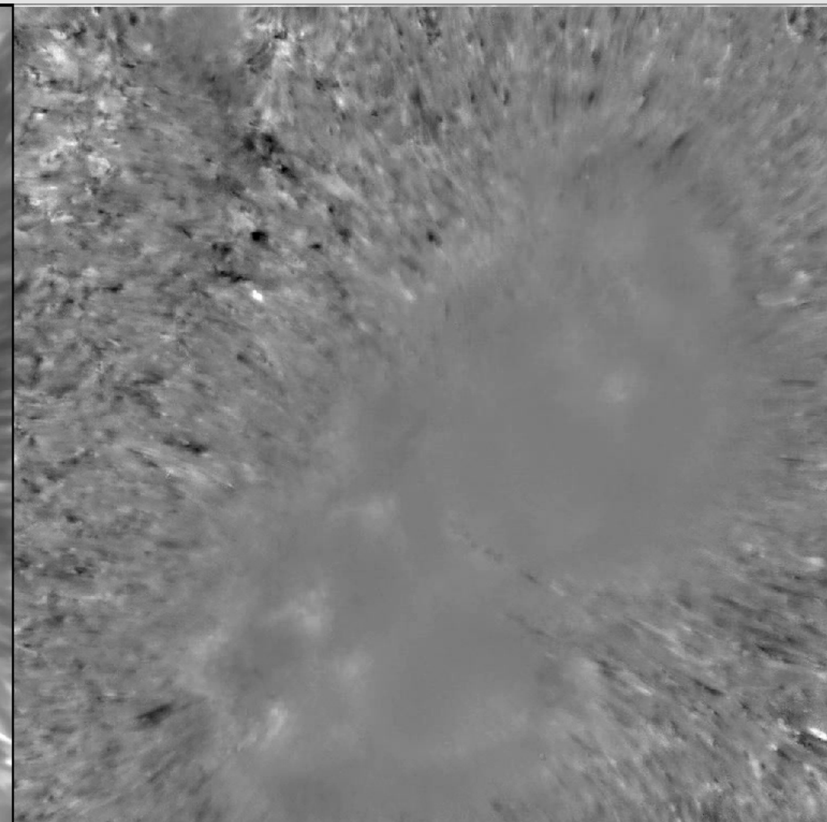




Jet-like brightenings in penumbrae



CaII H Intensity

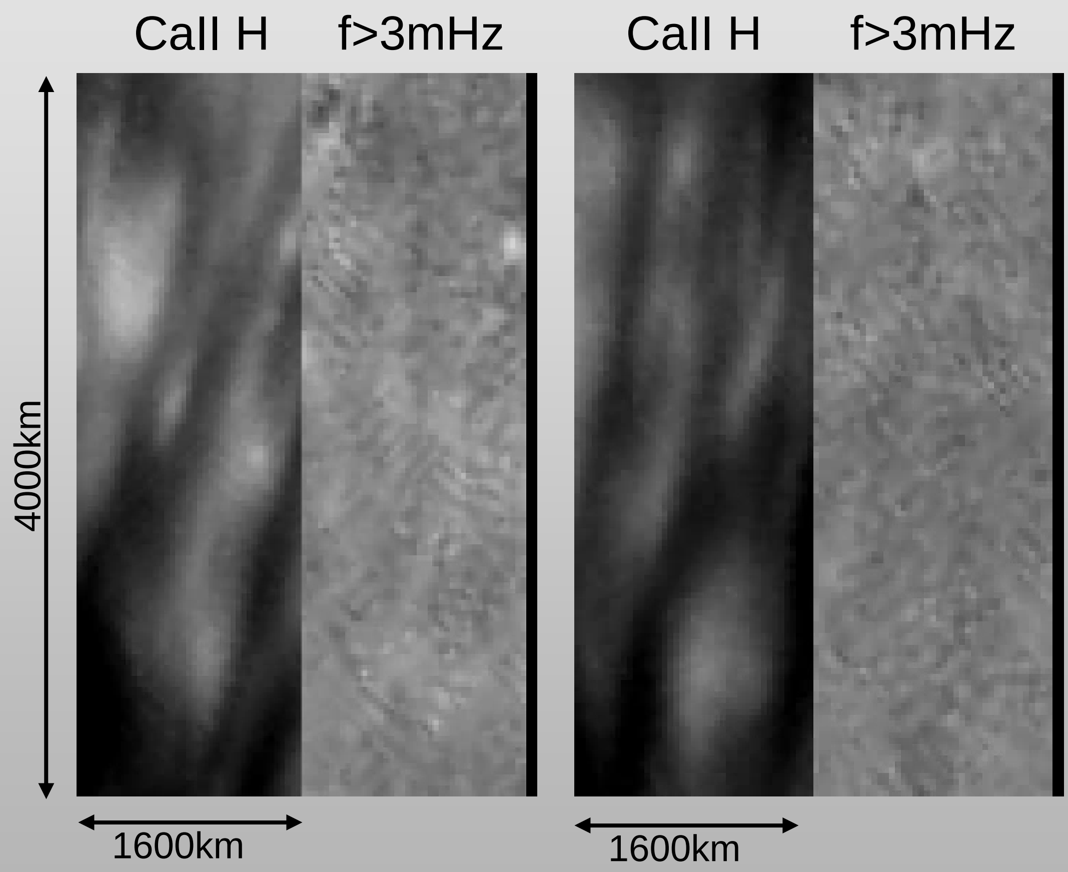


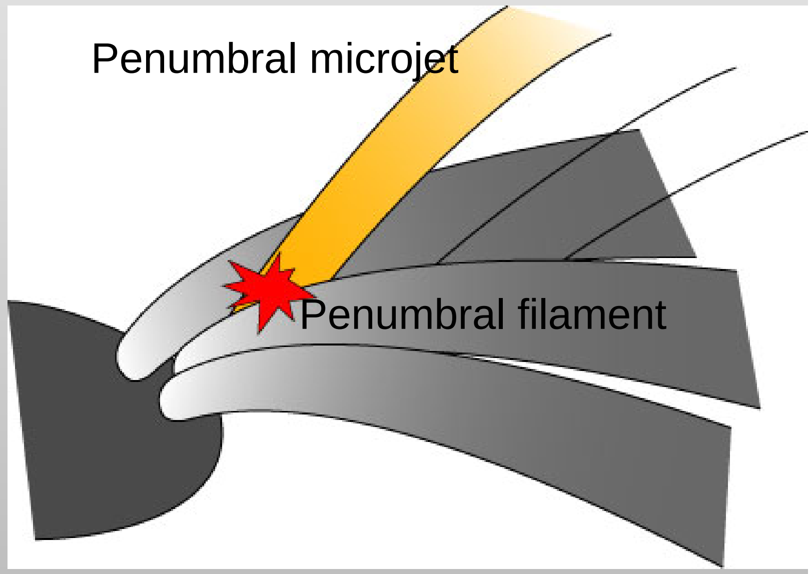
High-pass filtered (>3mHz)

Penumbral microjets
(Katsukawa et al. 2007)

Length: 1000 - 4000km   Lifetime: <1 min
Width: 300 - 400km   Apparent velocity: 50~100km/s

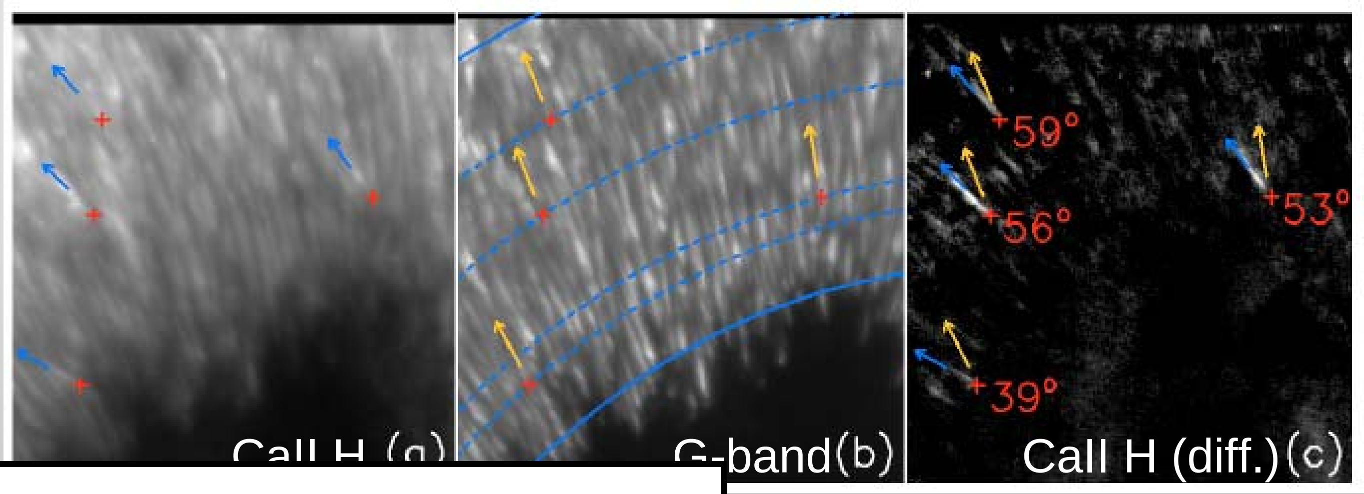
Detailed structure of penumbral micro-jets

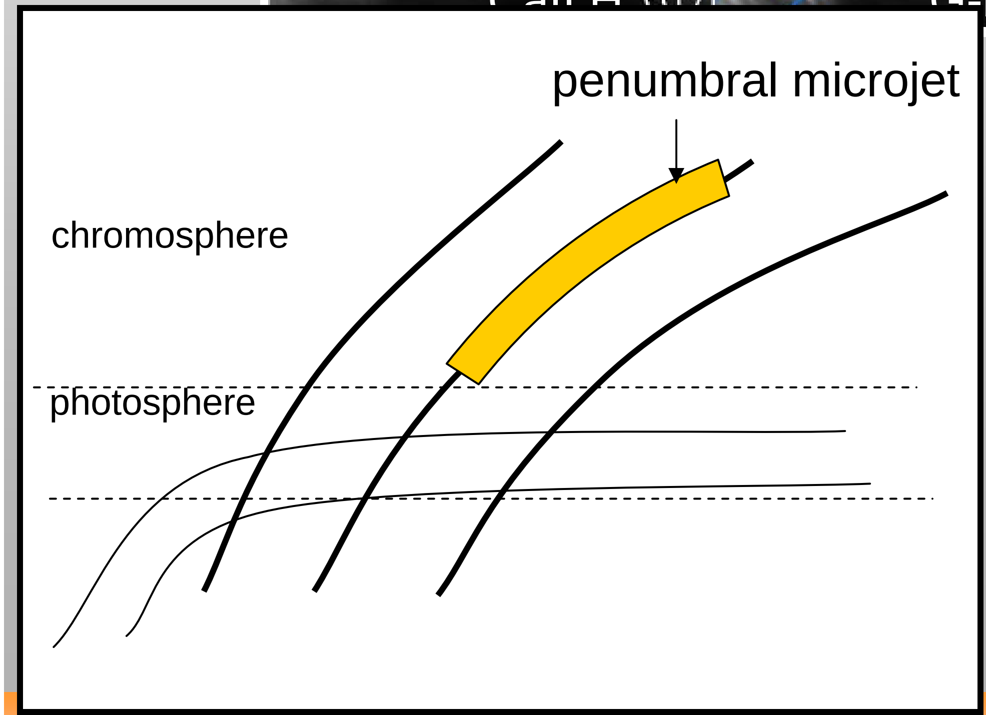




- Emanate from between two penumbral filaments, suggesting the penumbral microjets are following background vertical fields.
- Happen near penumbral grains migrating to an umbra.

Geometry of penumbral microjets

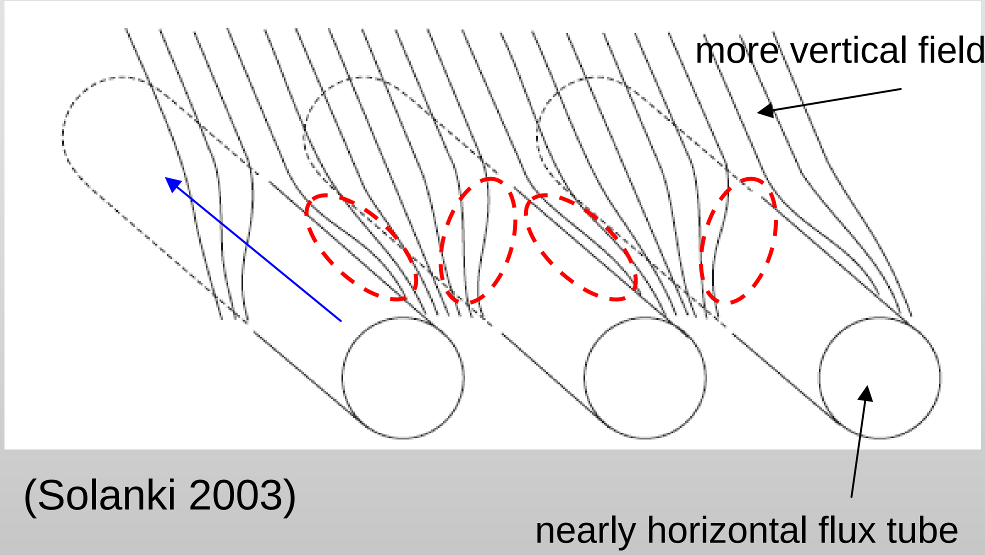




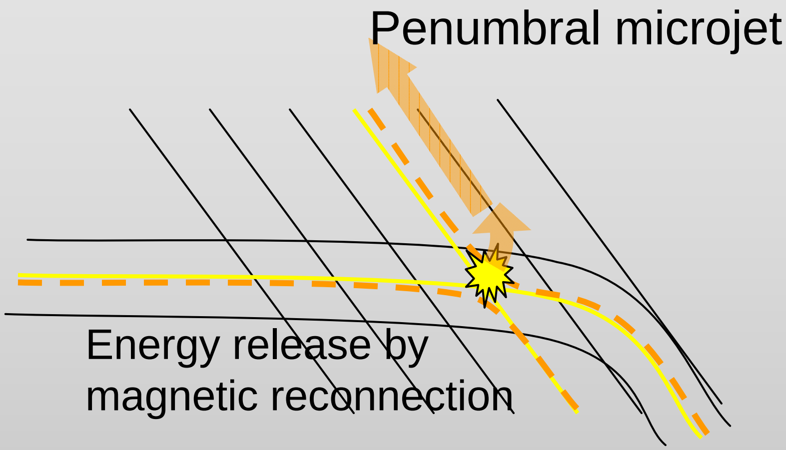
Jurcak and Katsukawa (2008)

- Inclination angles of the penumbral microjets are derived from angle differences between microjets and penumbral filaments.
- The angles are compared with magnetic field angles in the photosphere derived with SP.

Possible mechanism of the penumbral microjets

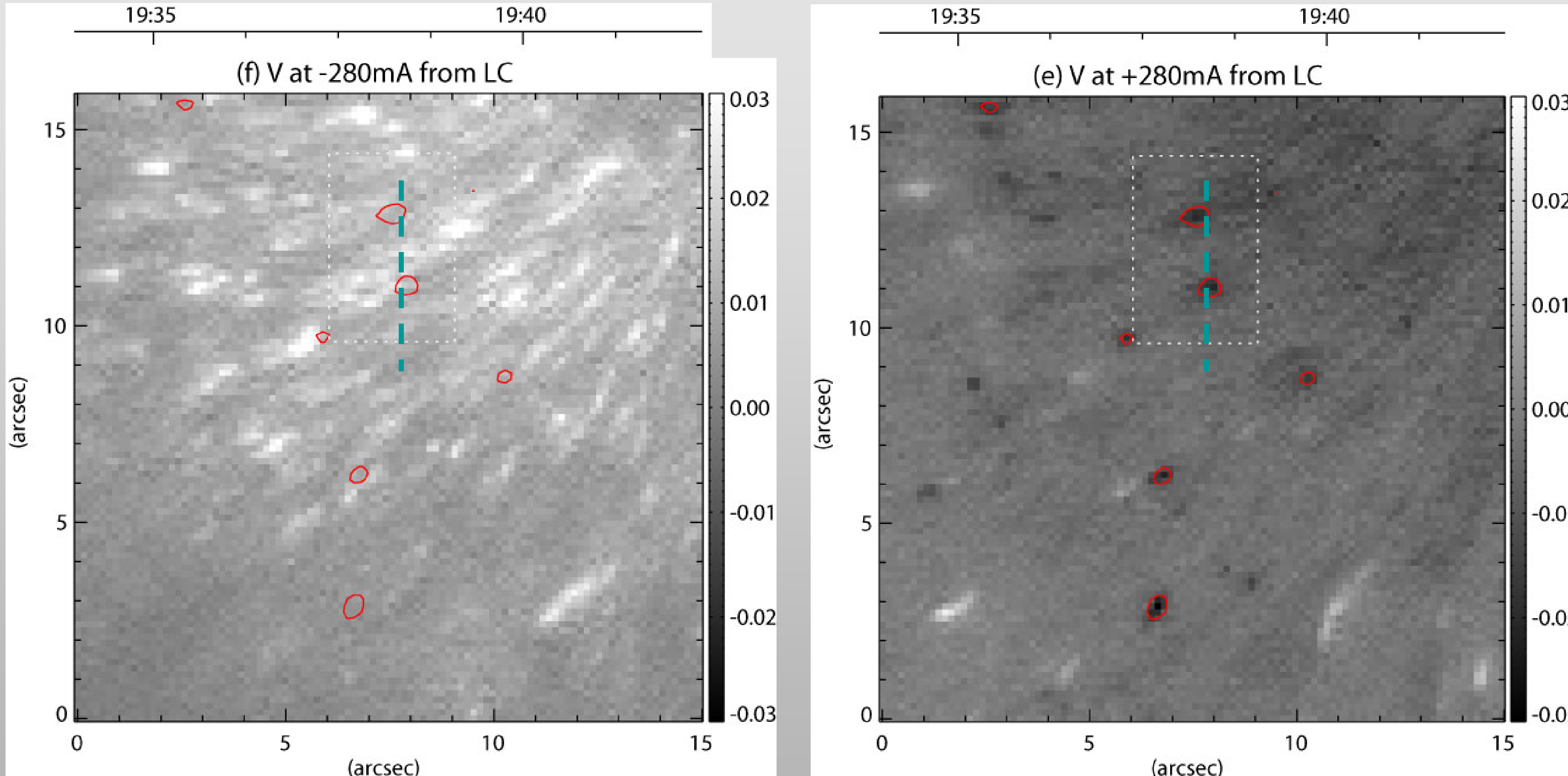


(Solanki 2003)



- The uncombed magnetic configuration may cause magnetic reconnection between the two magnetic components, and makes jet-like transient brightenings.
- The discovery of the penumbral microjets are important:
  - Consumption of magnetic energies and restructuring of sunspot magnetic fields
  - There is a possibility that we can directly measure magnetic configuration around magnetic reconnection sites.
- Are there any photospheric signatures?

HINODE SP observation of the photosphere

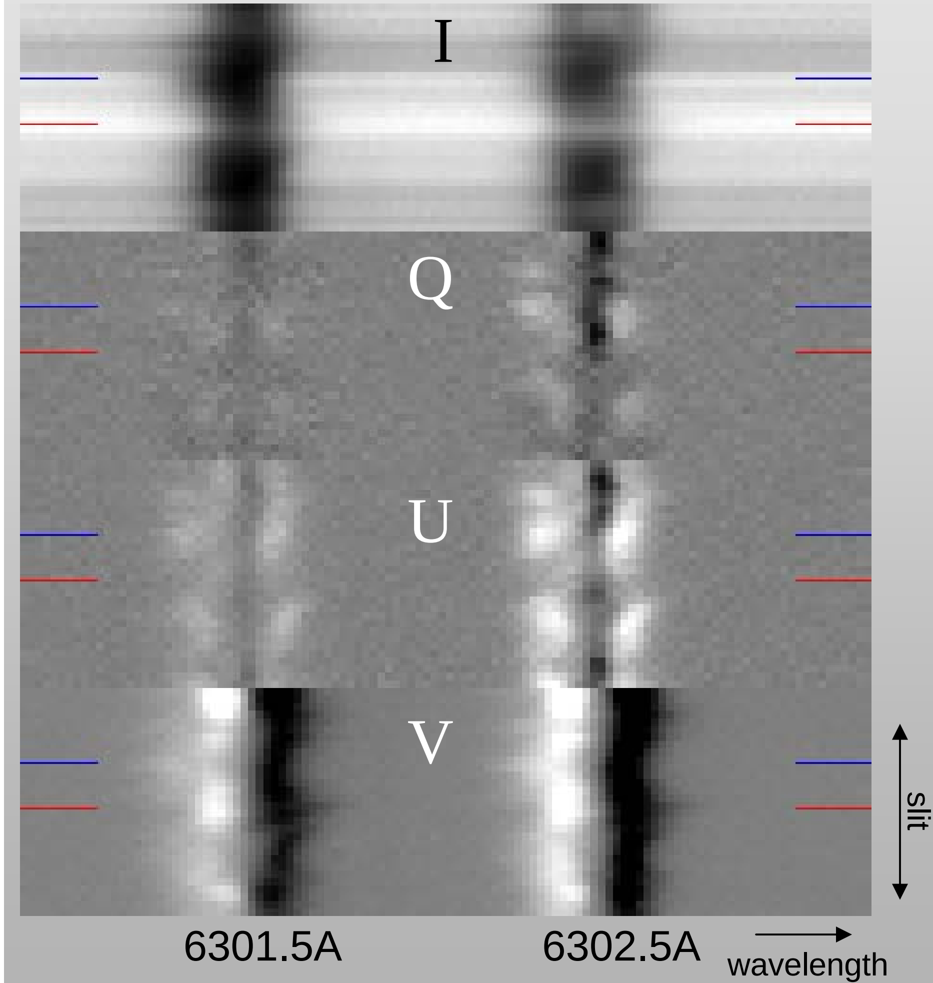


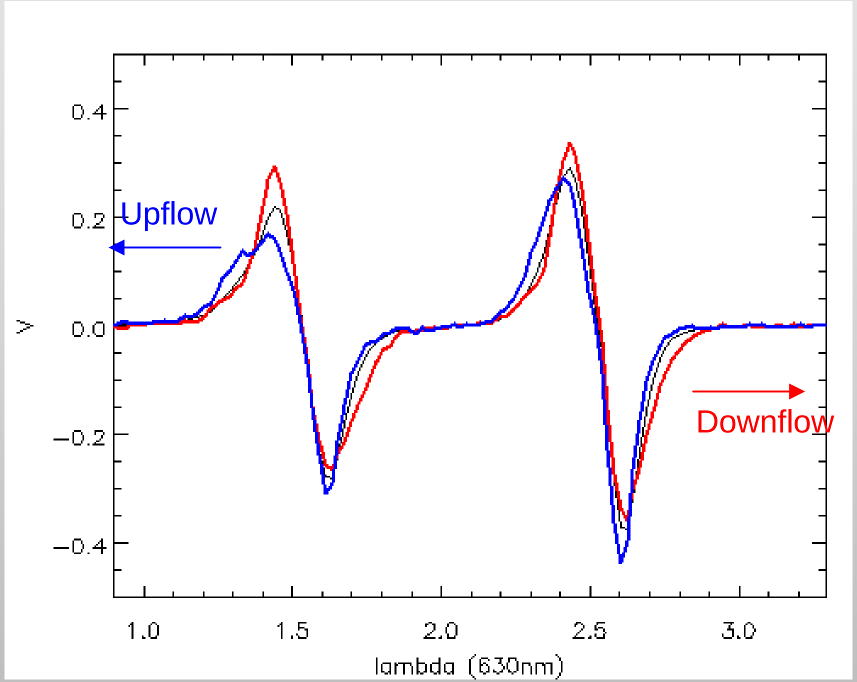
- There are small concentrations of large V signals at the red wing, which are created by red-shifted V profiles. Their sizes are ~0.5" or smaller.
- Located inside bright filaments having relatively vertical fields. Some of the patches are observed near the boundary of the filaments.

Blue wing

Red wing

Downflow patches in the penumbra

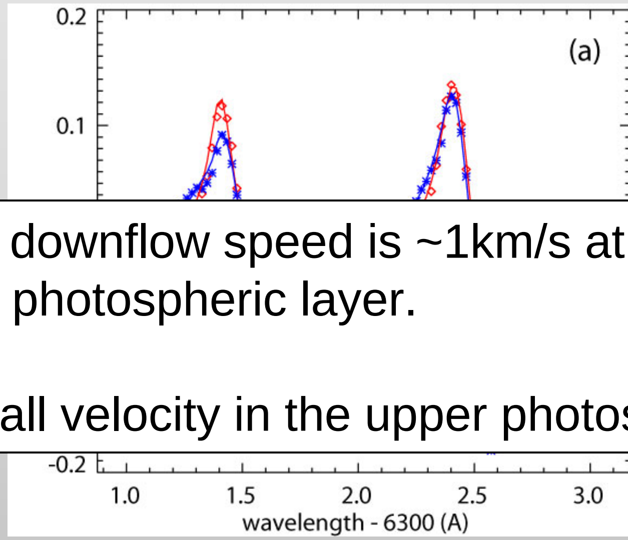




Blue: blue-shifted profile
Red: red-shifted profile

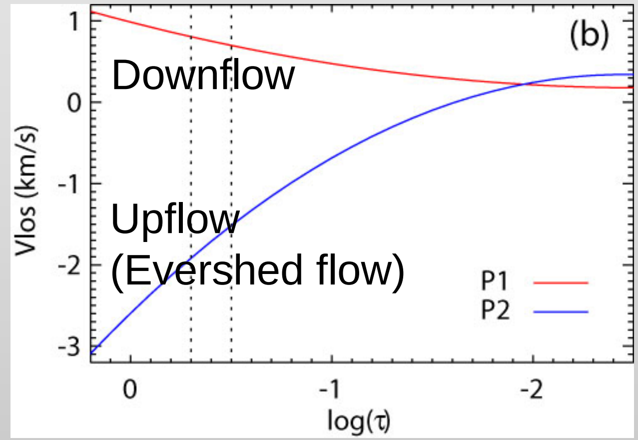
- Blue shifts by the Evershed flow dominates the profiles observed in the DC side penumbra.
- A significant red shift is observed in the patches.

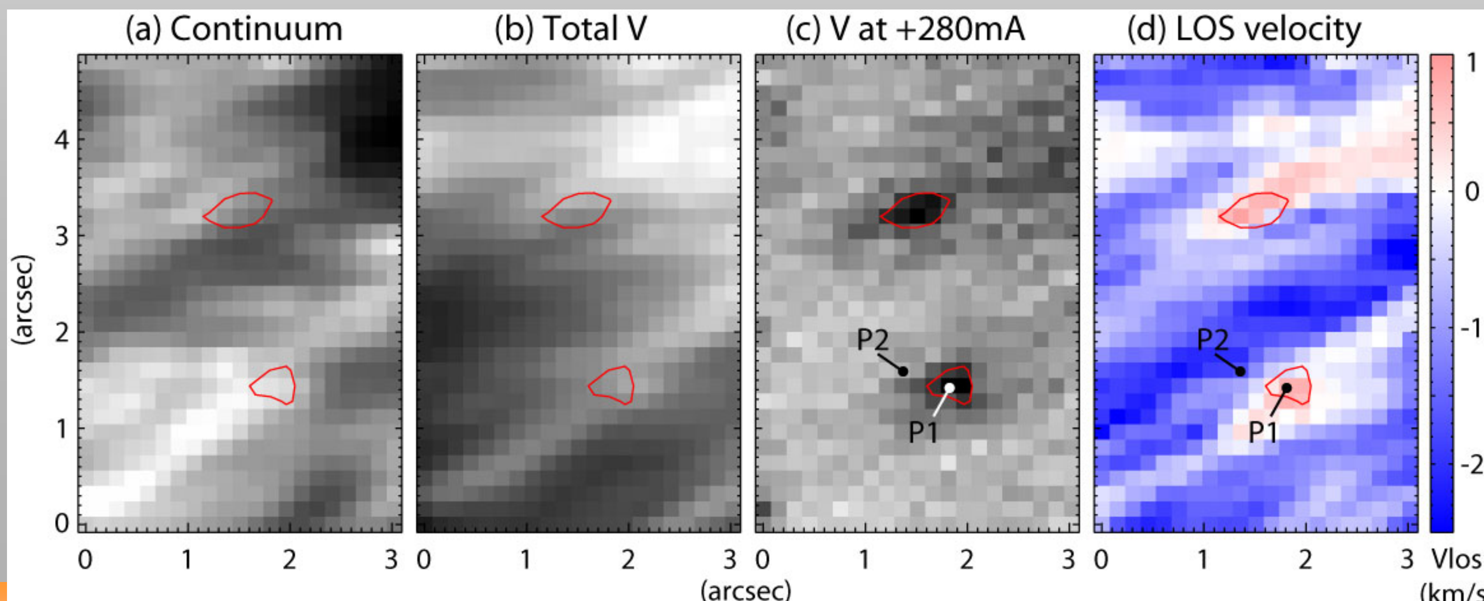
Downflow velocity derived with the Stokes inversion



- The downflow speed is ~1km/s at the lower photospheric layer.

- Small velocity in the upper photosphere.

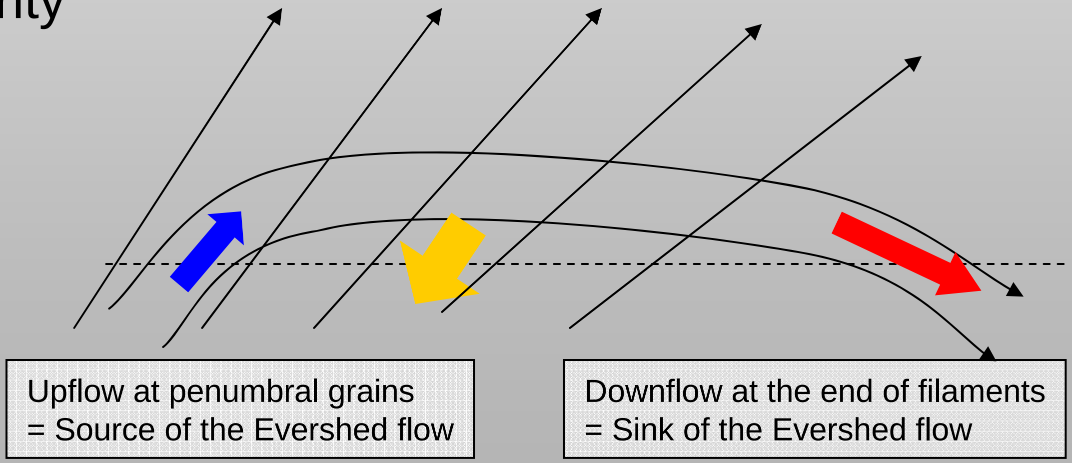




Properties of the downflow patches

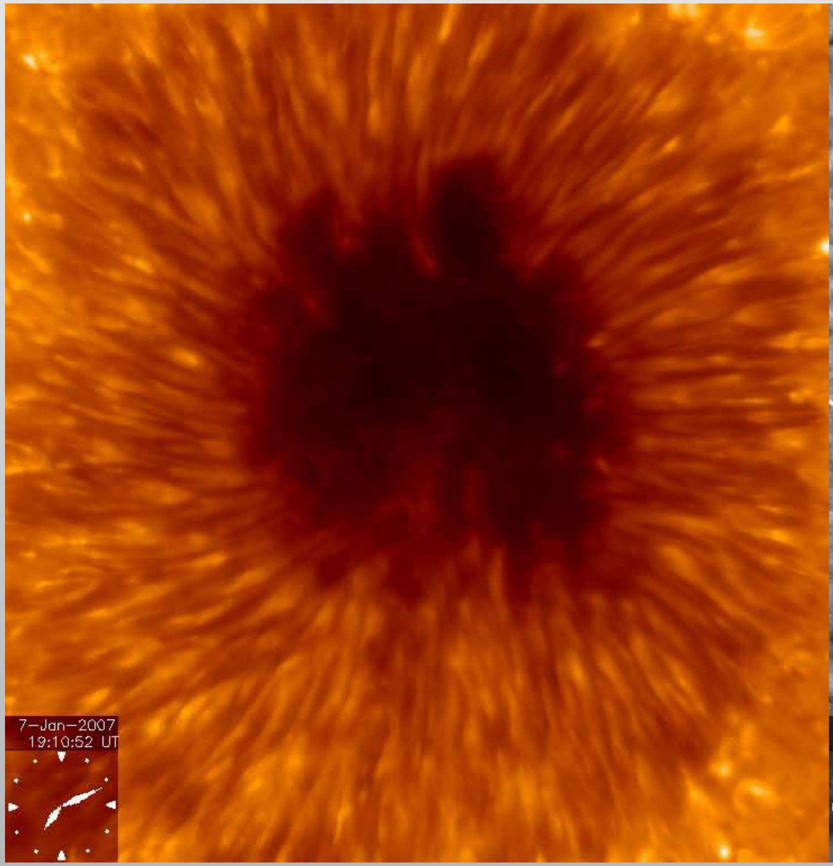
- Not all the penumbral filaments have the downflow patches. Less frequent than the structure made by the Evershed flow.
- Only observed in the center-side penumbra.

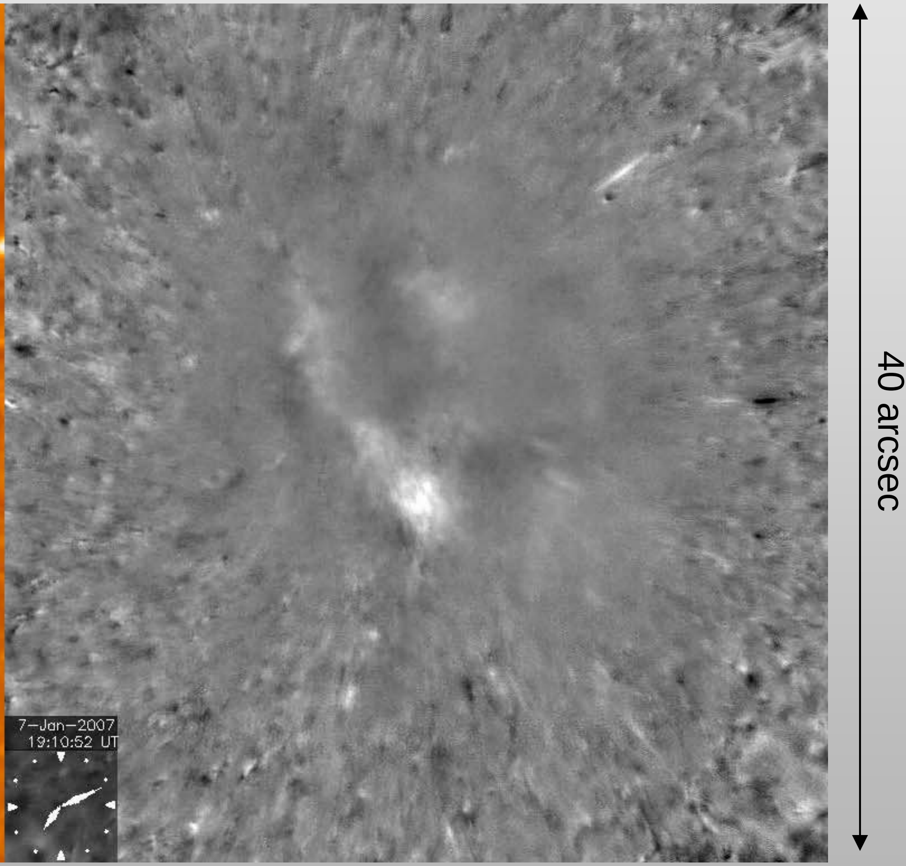
- Flow in a penumbra
  - Upflows in penumbral grains with the same polarity
  - Downflows near the boundary of a penumbra with the opposite polarity



- The observed downflows have the same magnetic polarity with the sunspot. Current standard models of penumbrae cannot explain the downflows with the same polarity.

Relation to chromospheric activities





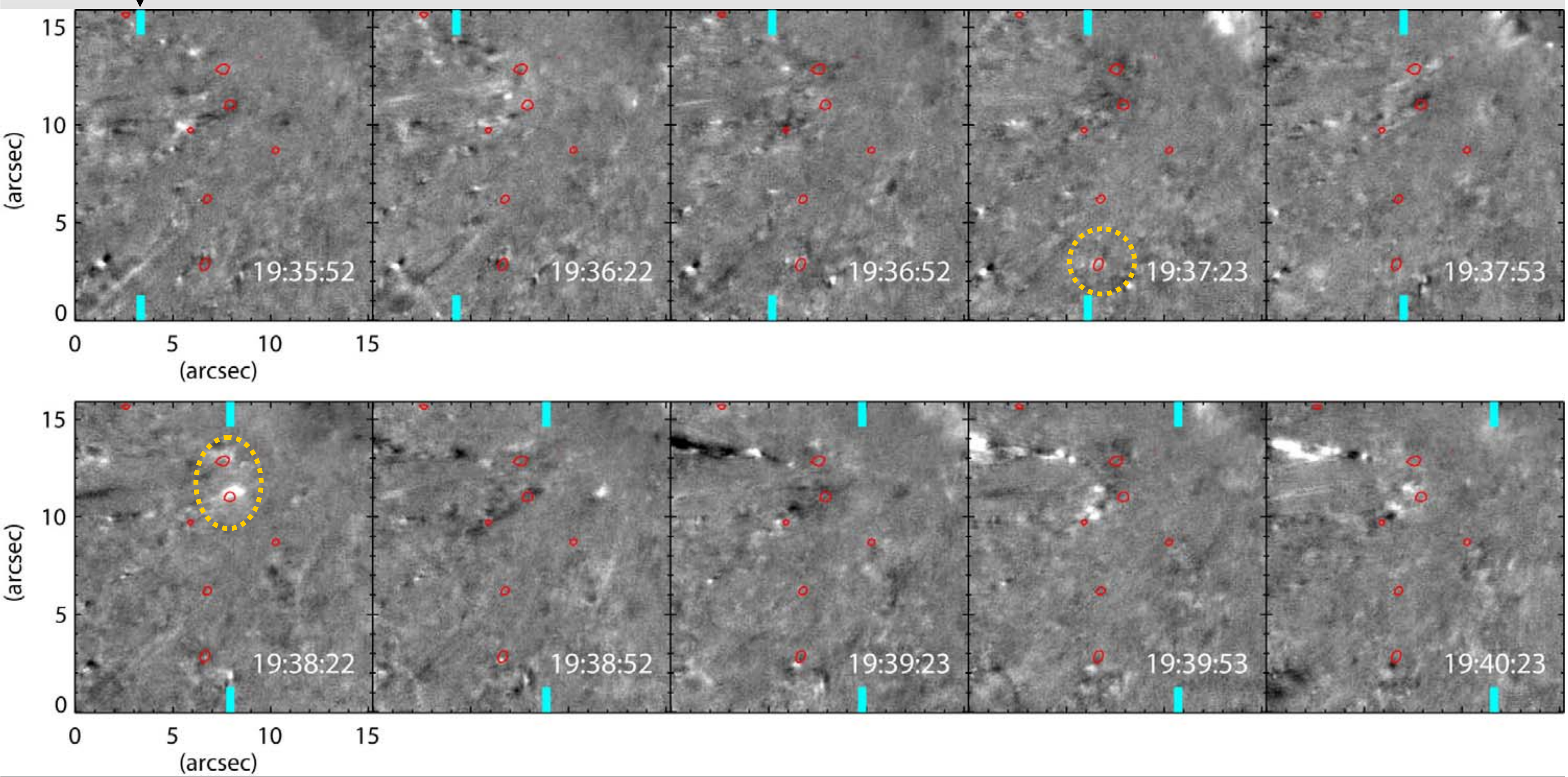
Ca II H

High-pass filtered (f> 5mHz)

- Penumbral microjets are easily identified in the high-pass filtered movie.
- Point-like brightenings dominates in the disk center side penumbra. This may be because the penumbral microjets are parallel to the LOS direction because of the projection effect.

Relation to chromospheric activities

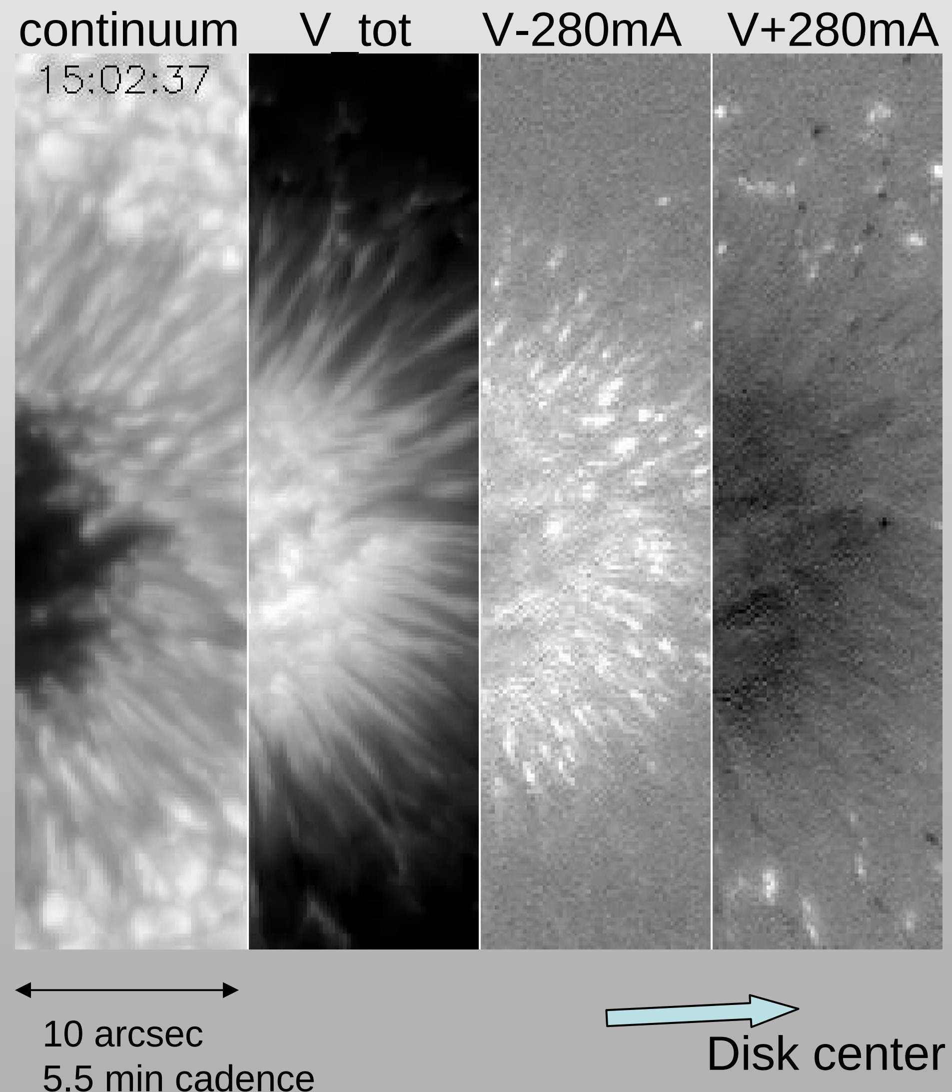
SP slit position



- It took about 8 minutes to cover the 15 arcsec ROI by SP. SP slit positions at each Ca II H exposure are shown.
- When brightenings happens just at the SP slit positions, the downflows in the photosphere tend to be observed. This suggests the downflow patches are a photospheric signature of chromospheric brightenings.

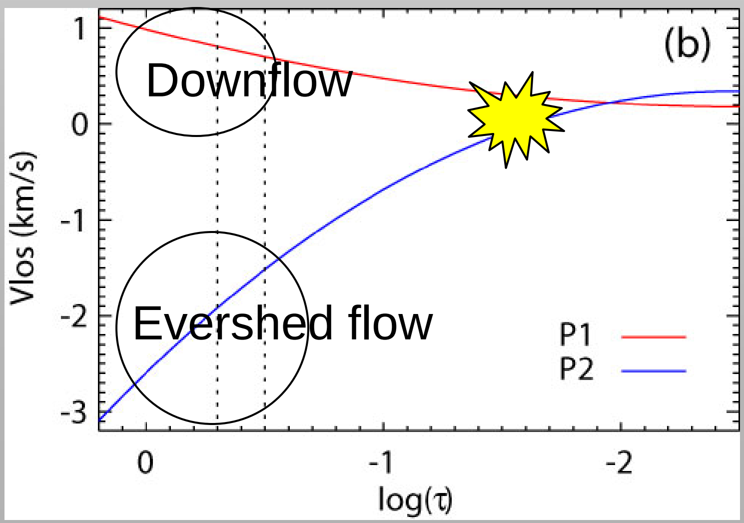
Temporal evolution of downflow patches

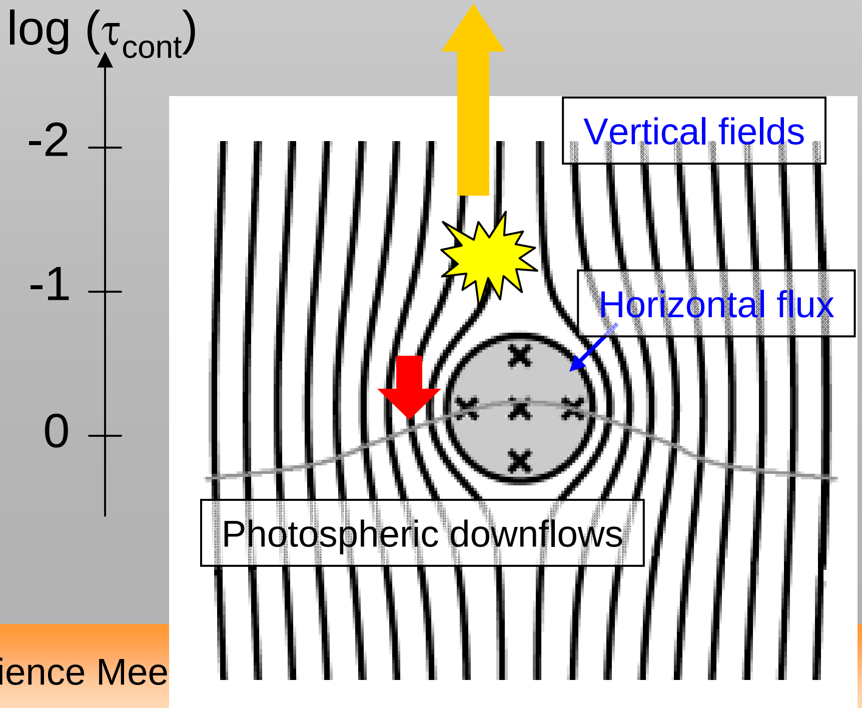
- The structures seen in the blue-wing move inward associated with penumbral grains, which are sources of the Evershed flows.
- The downflow patches in the red-wing images are more sporadic than the structure seen in the blue-wing.
- This suggests the downflow patches in the penumbra are associated with transient activities.



Summary: Photospheric magnetic reconnection

- The photospheric downflows in the penumbra are a possible photospheric signatures of transient brightenings in the chromosphere.
- The downflow is preferentially observed in the lower photosphere (0> log(τ_c)>-1), which suggests that magnetic reconnection happens somewhere in mid to upper photosphere. This is consistent with the concept of magnetic reconnection between horizontal flux tube and background vertical fields.
- The observed downflow speed (<1km/s) is much slower than the Alfven velocity. This might be because the outflow suffer significant deceleration due to high densities in the lower photosphere.

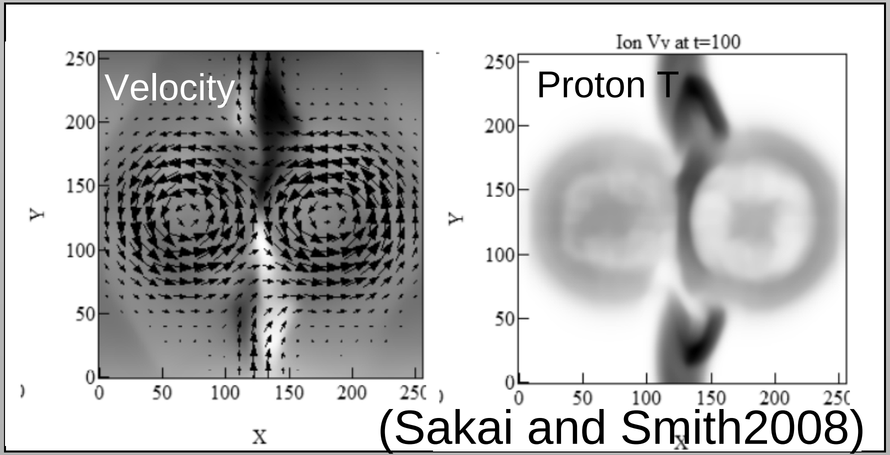




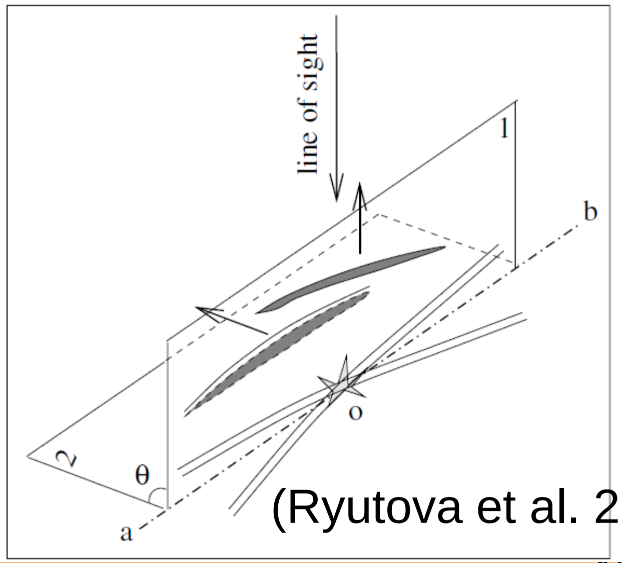
Summary: Photospheric magnetic reconnection

- An observations in Ca II 8542A with IBIS shows that brightenings are observed only at red and blue wings, and no brightenings at the CaII line center. The spectra are similar to those of Ellerman bombs (T6-4 Reardon et al.). This also supports the reconnection in the photospehre.

- How the photospheric reconnection drives elongated brightenings?
  – It is difficult to generate high speed jets directly by photospheric reconnection because of high plasma pressures/densities.
    (e.g. Numerical simulation by Sakai and Smith 2008)
  – Bow-shock heating (Ryutova et al. 2008)



(Sakai and Smith2008)



(Ryutova et al. 2008)

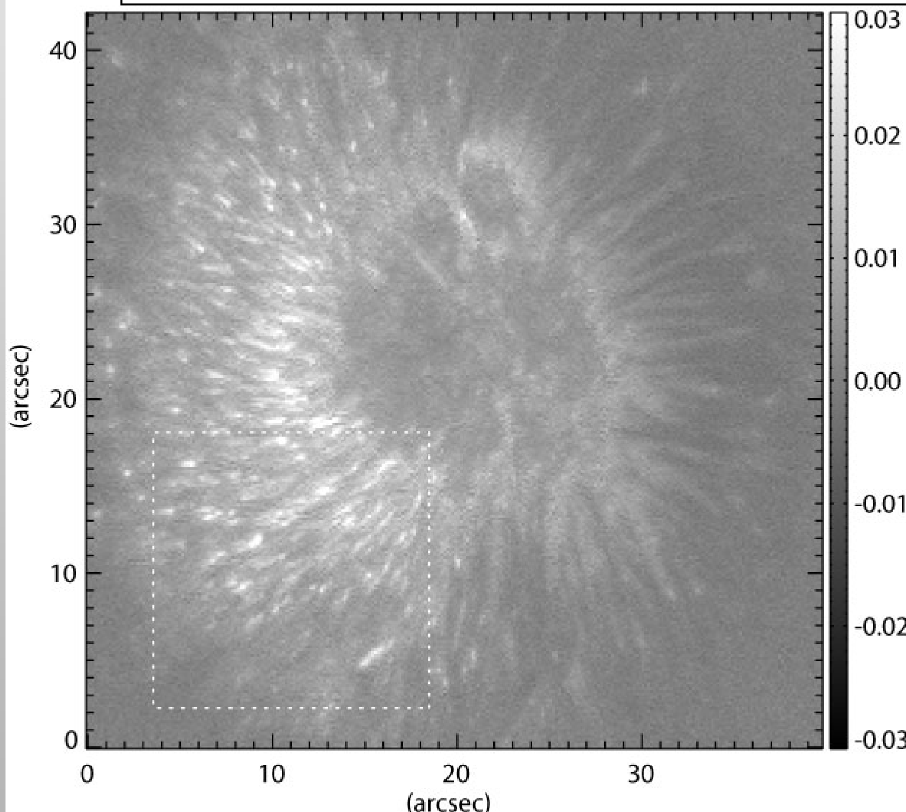
Thank you!

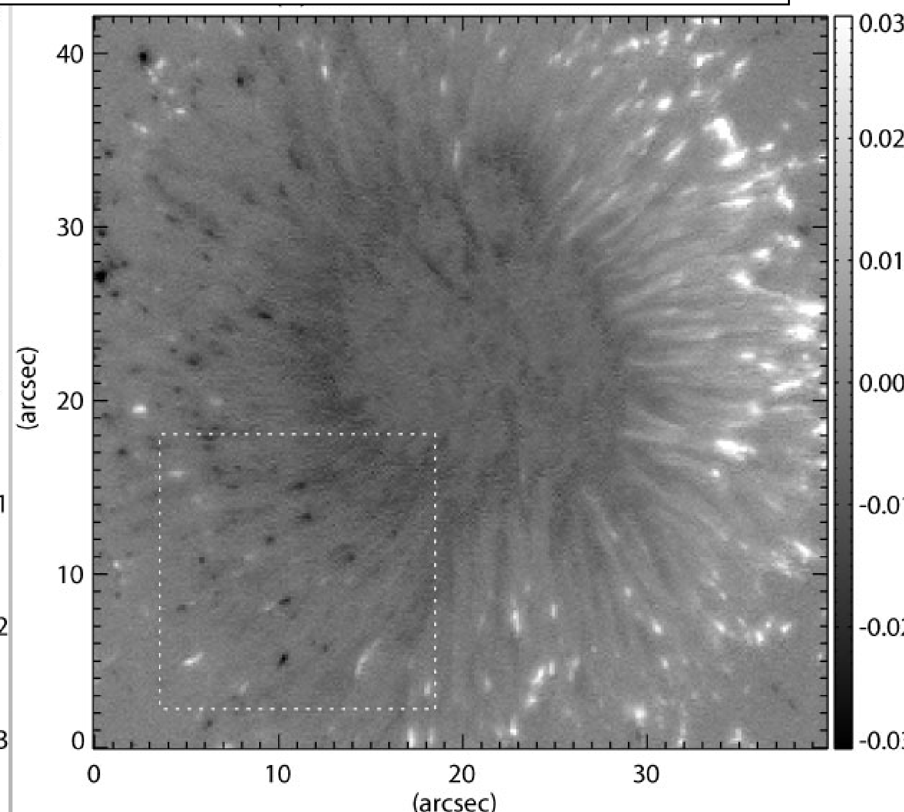
What we have obtained so far

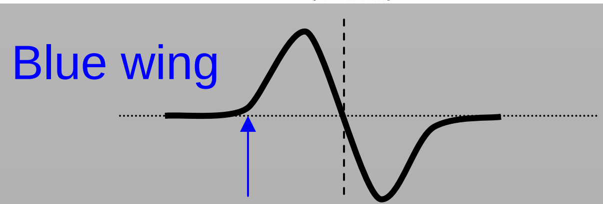
- Typical scale of penumbral microjets
  - 1000 - 4000km length, 300-400km width
  - Apparent velocity 50~200km/s along the microjets
  - Lifetime: shorter than 1min
- Locations of the penumbral microjets
  - Emanating from between two penumbral filaments (suggesting the penumbral microjets are following background vertical fields)
  - Happen near penumbral grains migrating to an umbra
- Occurrence rate and energy flux
  - $10^{-20} – 10^{-21}$ cm^{-2} sec^{-1}
  - $10^4 – 10^5$ erg cm^{-2} sec^{-1} (by assuming densities and temperatures), one to two orders of magnitude smaller than the energy flux required to heat the chromosphere/corona

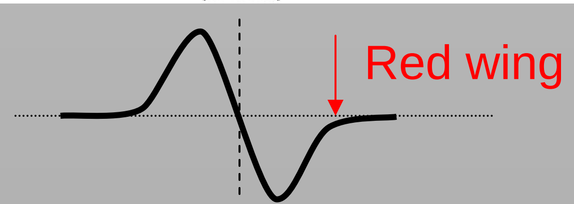
HINODE SP observation of the photosphere

- The clear difference between the blue and red wing images suggests that the V-signals are mainly created by Doppler shifts.

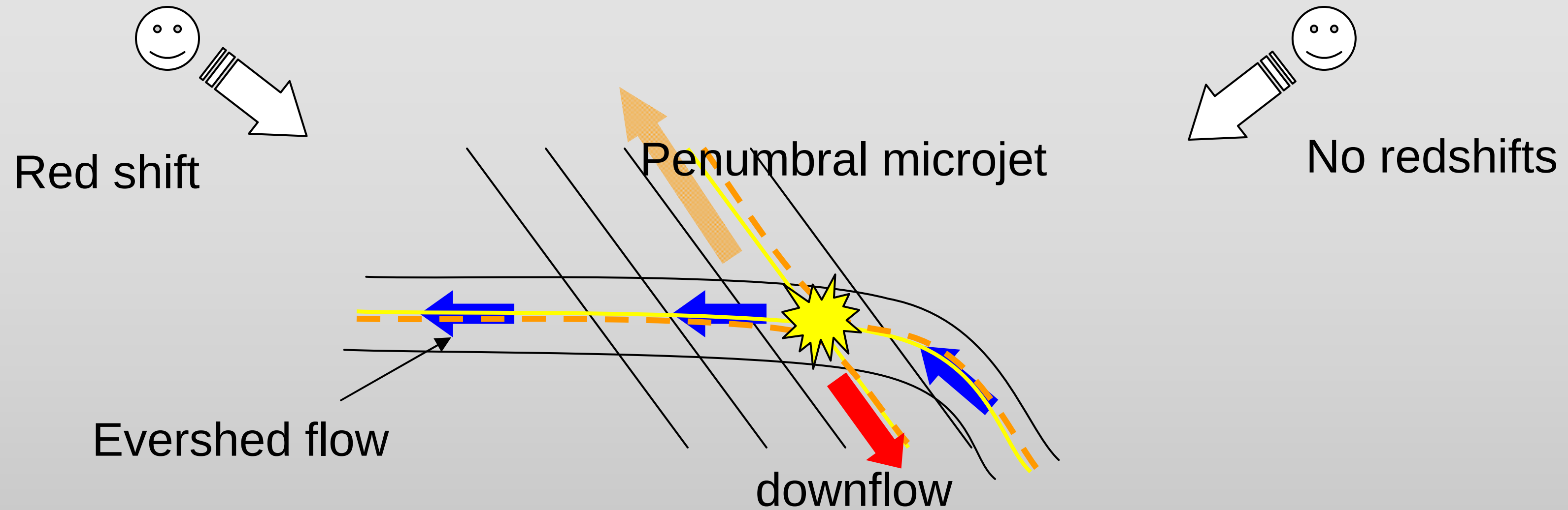








Center side vs limb side



- The difference between the DC-side and limb-side can be explained by inclination angle of the background vertical fields if orientation of the downflow follows the fields.

- The observed downflow speed ~1km/s is much slower than the Alfven velocity. This might be because the reconnection outflow suffer significant deceleration due to high density in the photosphere.

Na D Dopplergram