On the nature of the spectral line broadening in solar coronal dimmings

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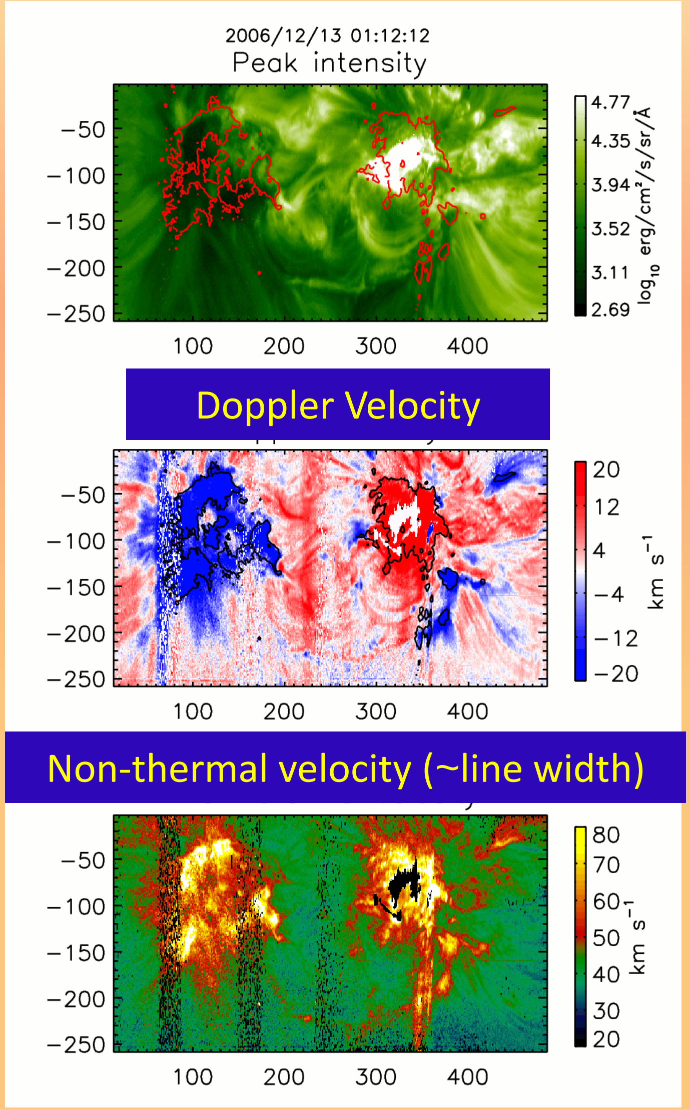
A coronal dimming on December 13, 2006 (**X3.4 flare**)

(EIS/Hinode, Fe XII 195 Å)



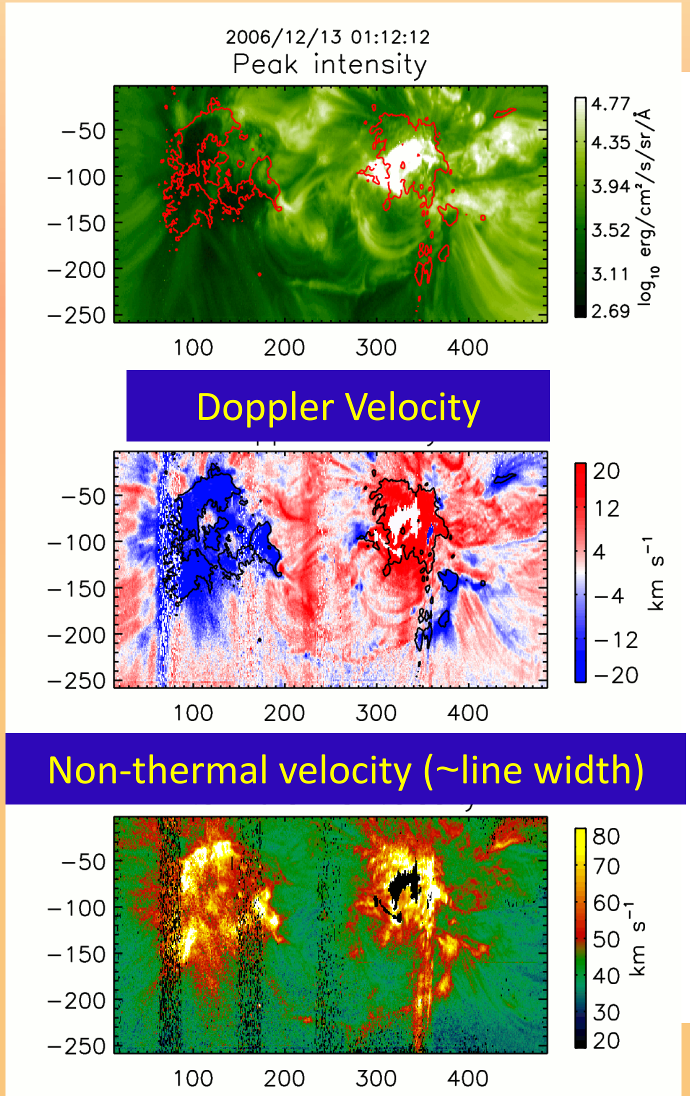
- A well studied eruption, with known properties in the dimming area:

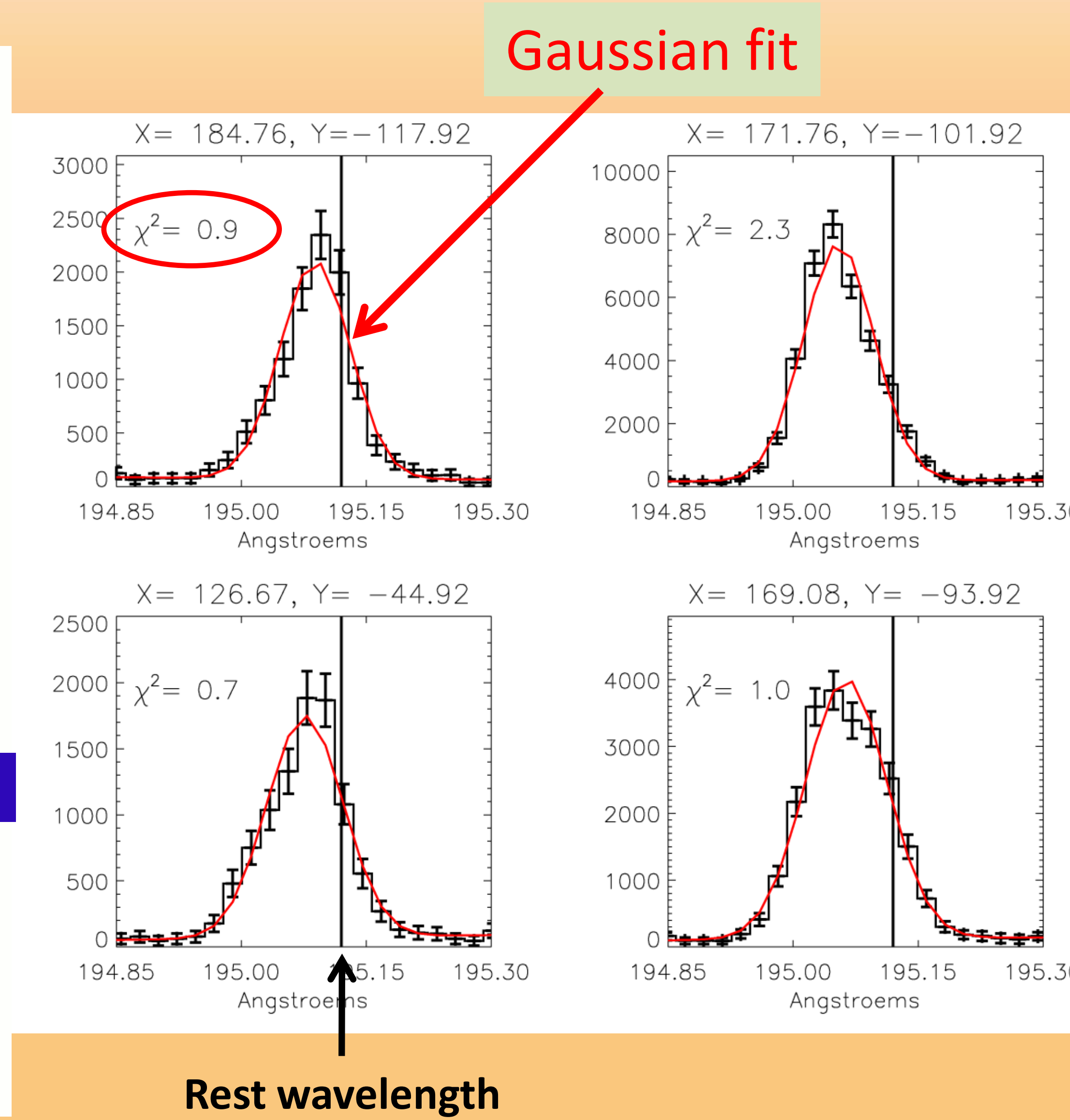
  → Blue-shift (e.g. Harra et al. 2001)

  → Increased line widths (e.g. McIntosh 2009)

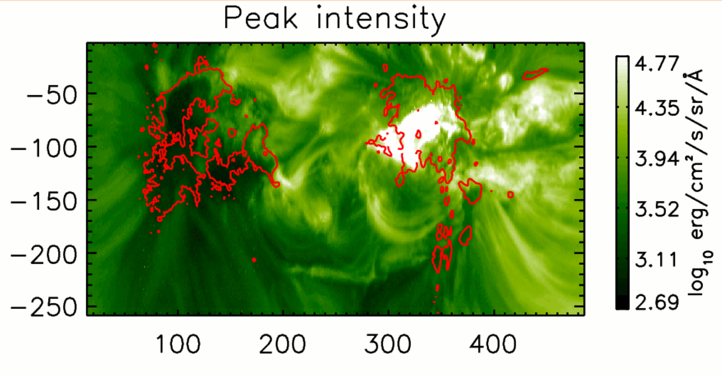
Asymmetric line profiles in the dimming

(Fe XII 195 Å)

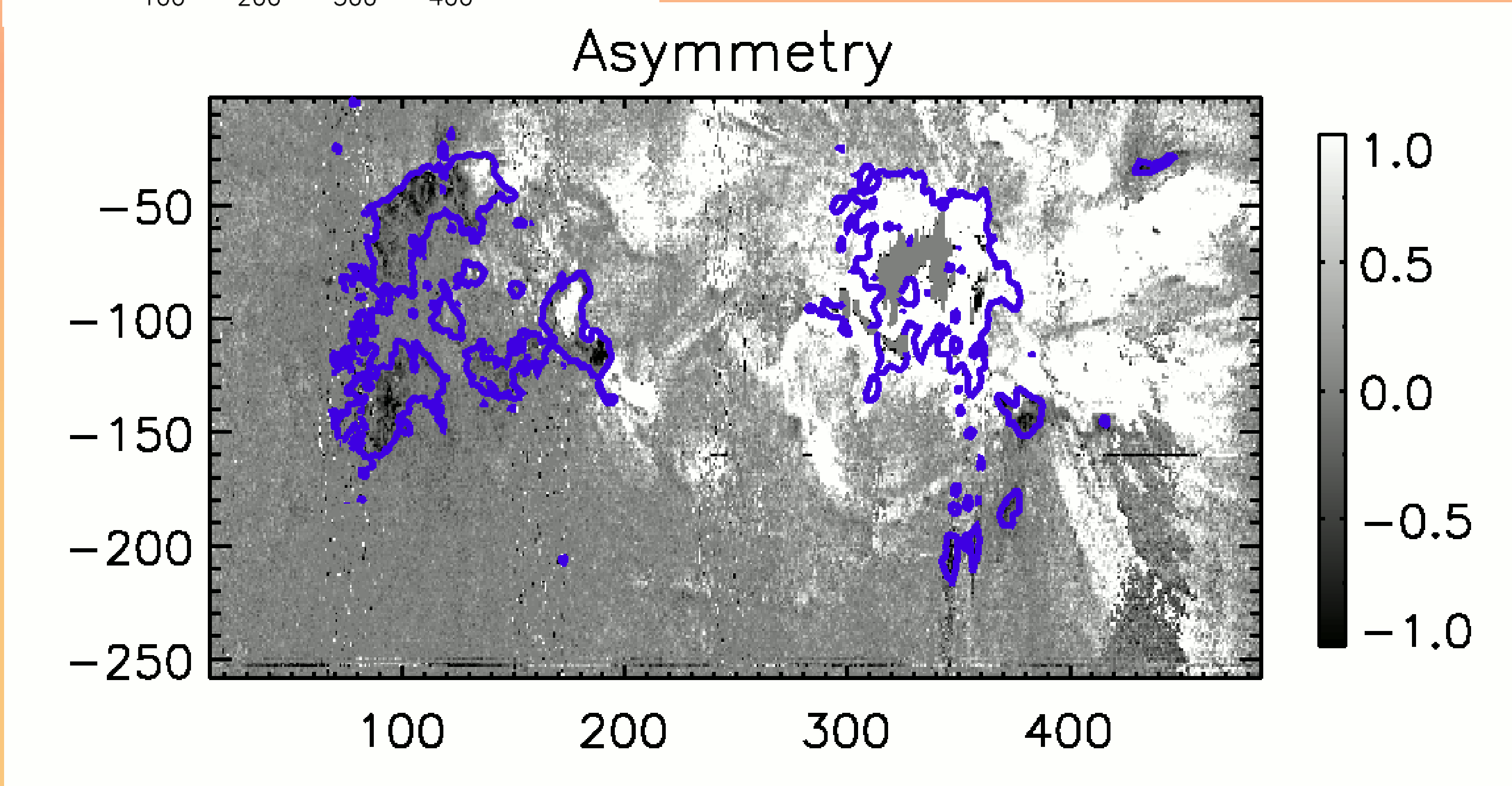




An empirical coefficient of Asymmetry

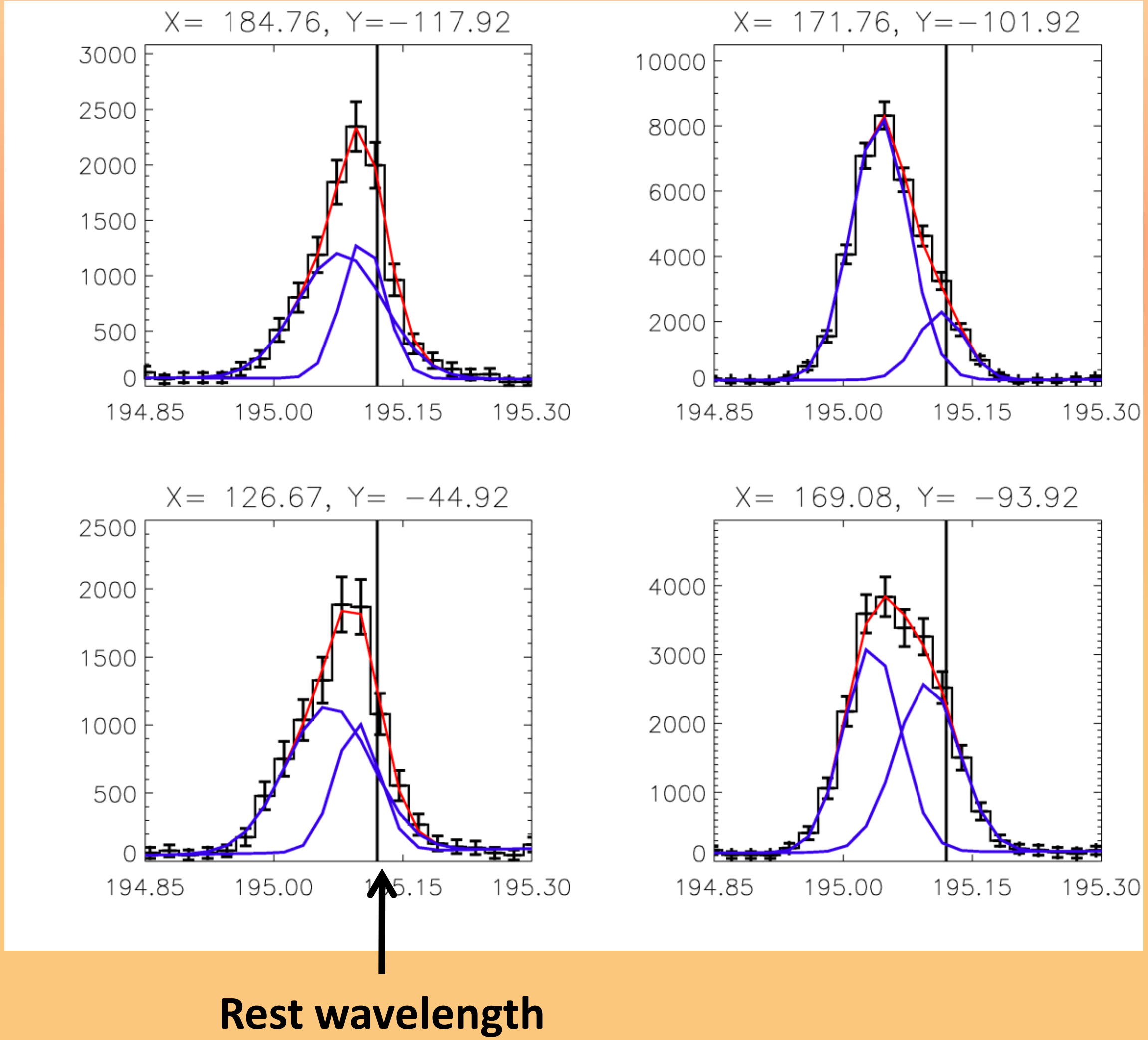


- Asymmetry in **dimmings** : McIntosh et al. 2010
- Asymmetry (multi-component lines) in an **AR** : Bryans et al. 2010



Interpretation: more than one component ?

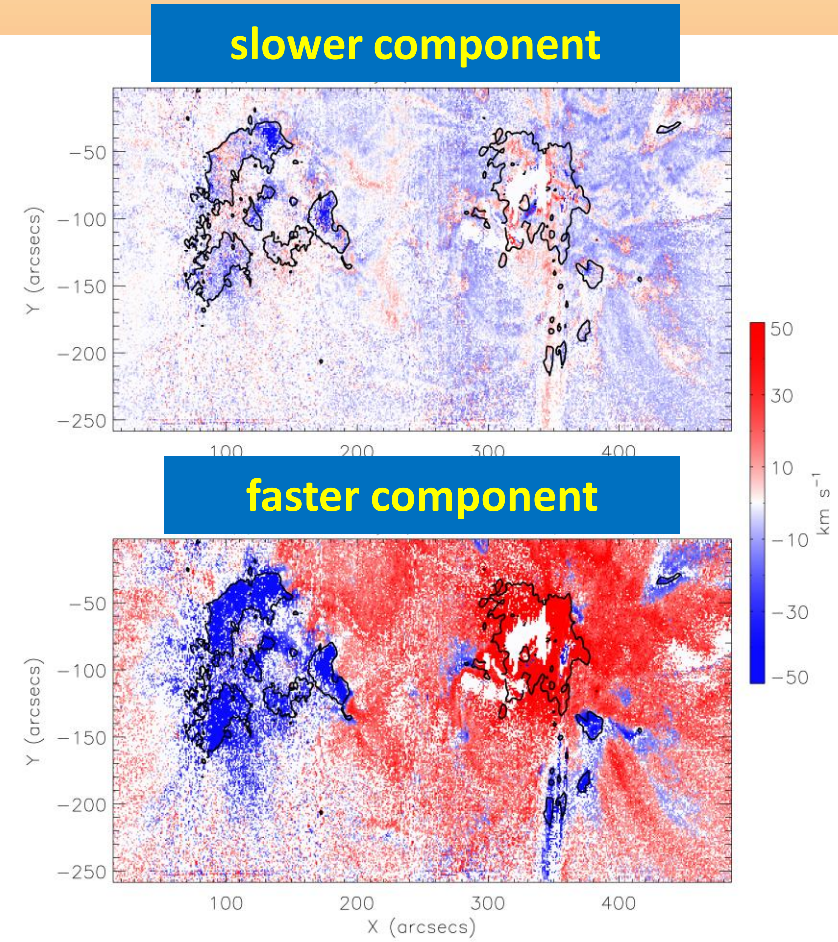
=> double-Gaussian fit



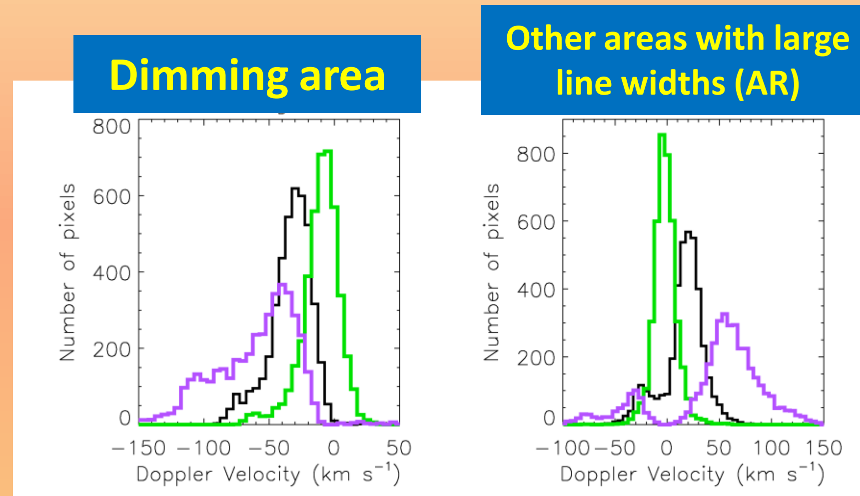
=> **Line broadening is caused by flow inhomogeneities** (and not just by Alfvén waves)**:**

- in the line-of-sight (LOS)
- within the spatial resolution (1”)
- within the exposure time (<30 seconds)

Doppler velocities with a double-Gaussian fit



Histograms of velocities

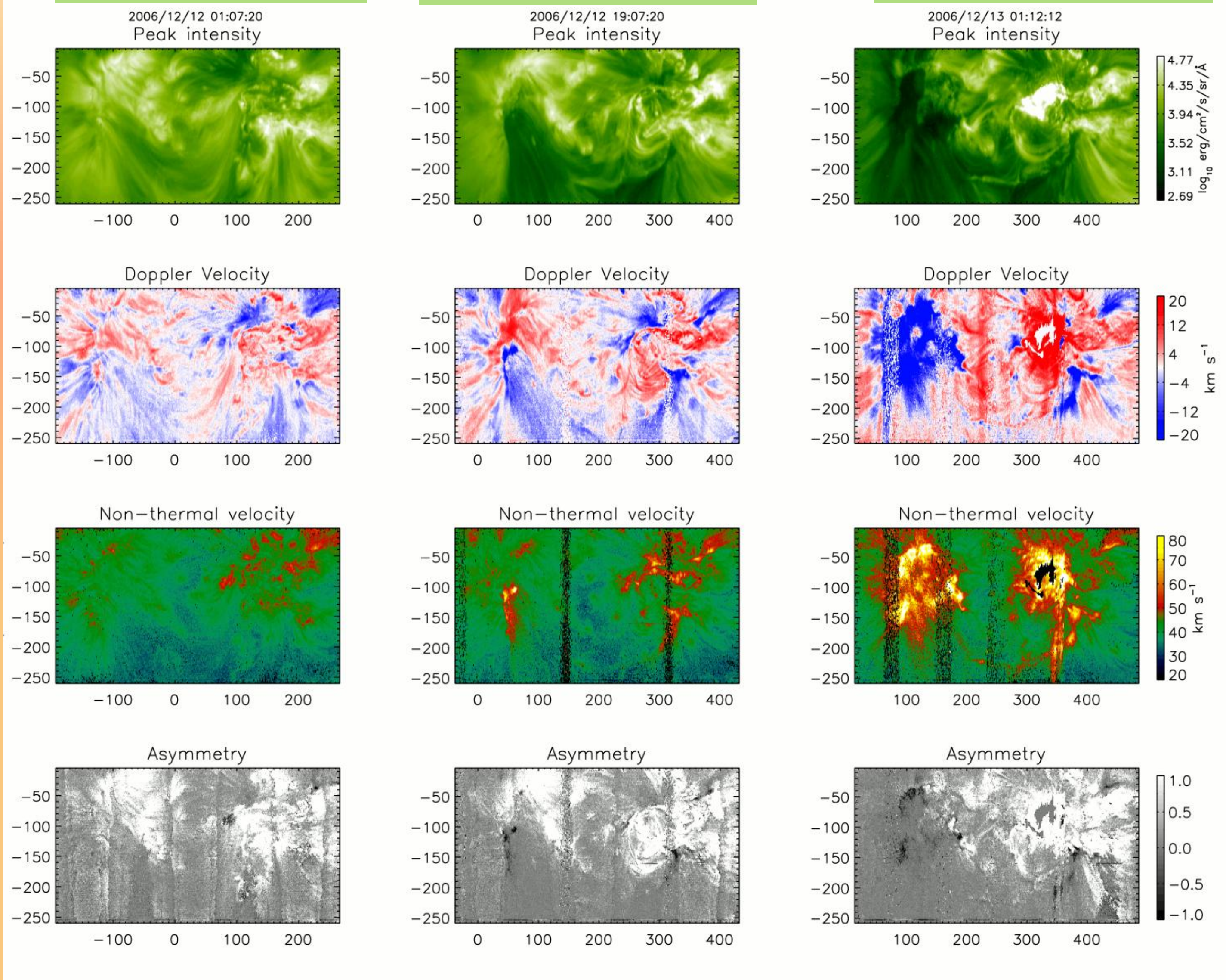


- **nearly-static** component
- **dynamic** component
- **Single-Gaussian fit** → underestimates the flows (≈ factor 2)
- Projected velocities of the dynamic component are subsonic

- **Upflow** in the dimming
- **Downflow** in loops (cooling ? Bradshaw, 2008)

Evolution through successive eruptions

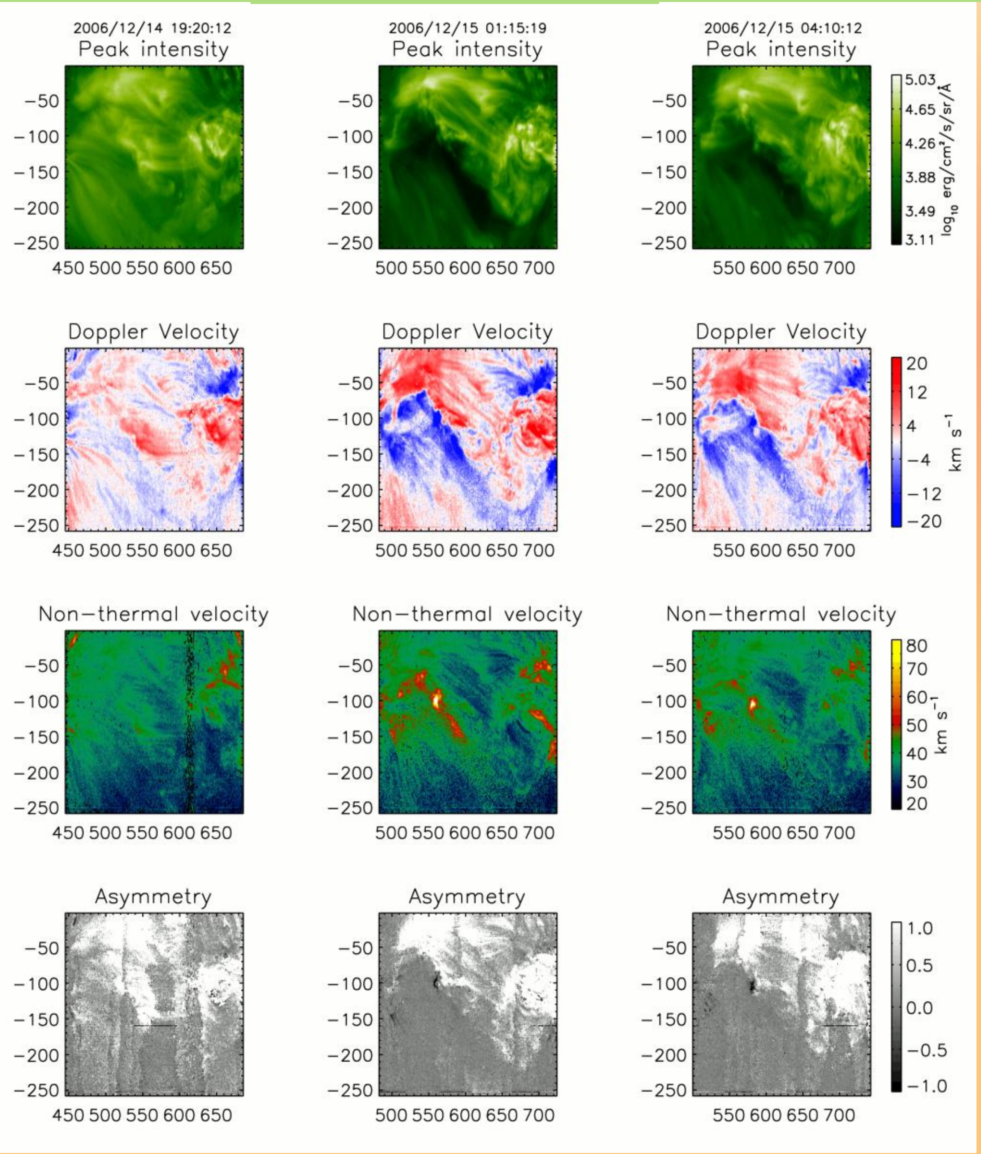
Pre-flare | **After a B7.7 flare** | **After a X3.4 flare**



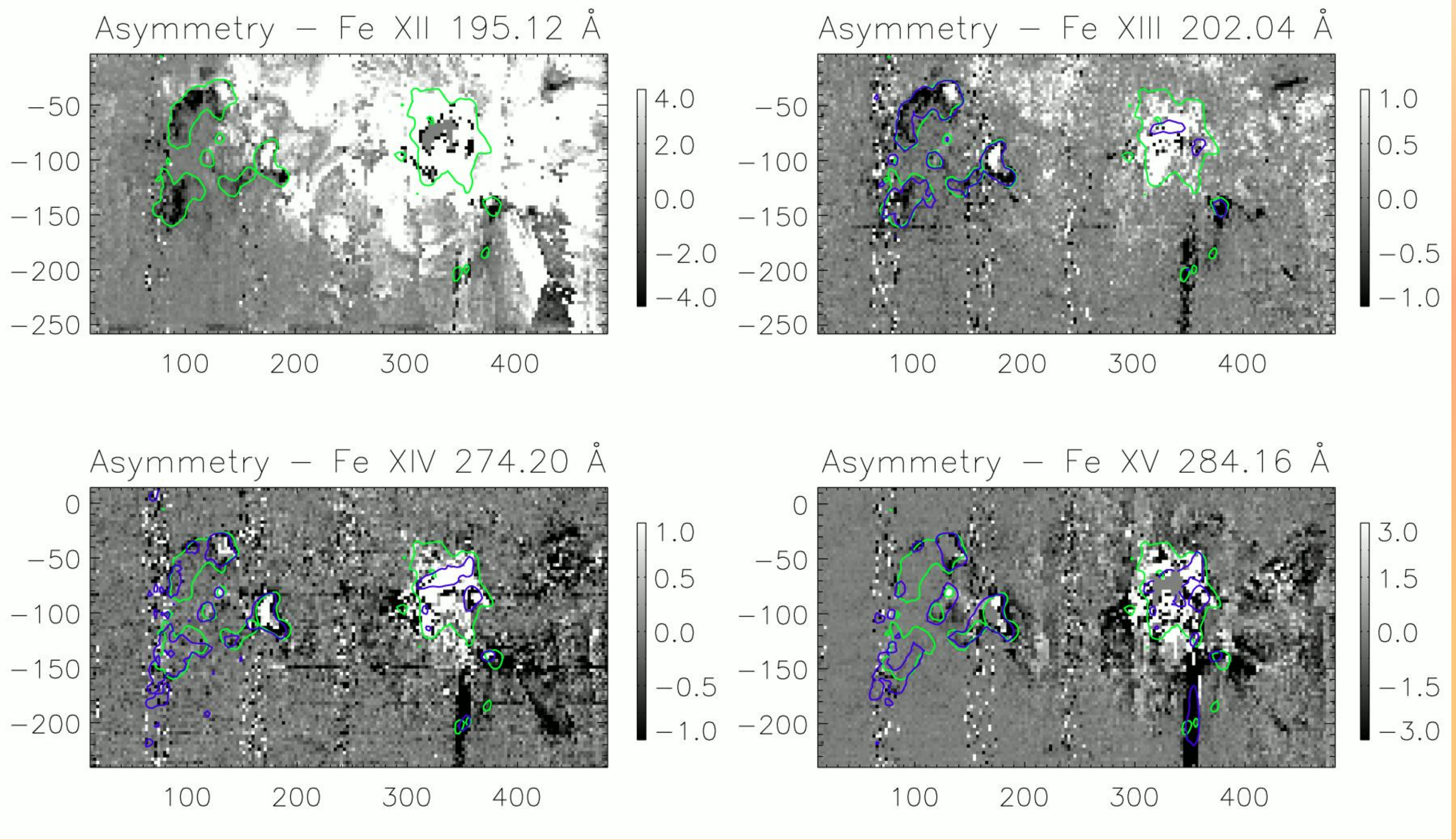
Evolution through successive eruptions

(following day)

Pre-flare **After an X1.5 flare** **Partial recovery**



Other spectral lines



$\Rightarrow$ Effect of line blending is ruled out

(Rebinning does not produce additional asymmetry)

Interpretation ?

- **Nature of the static component ?**
  $\longrightarrow$ Really a static plasma or flux tubes with no projection of their flow velocity on the LOS ?
- **Nature of the dynamic component ?**
  – In the loops: cooling and draining material ? (Bradshaw 2008)
  – In the dimming: asymmetry gets larger and more extended after the successive eruptions.
    1) Flow (dynamic component) already present before the eruption ? Then made more visible because:
       – Field lines are more aligned with LOS after the eruption ? (McIntosh et al. 2010)
       – Removal of the static material (appear in darker areas !)
    2) Flow only present after the eruption ?
    3) Only some field lines contain significant flow ?
    4) Transient features travelling along the field lines ? (there is a radial pattern following the fanning out structure) $\Rightarrow$ can explain the static component

More than 2 components ? (acceleration of a transient feature?)

Conclusions

- We interpreted the broad and asymmetric line profiles observed in dimmings (and loops) as due to **inhomogeneities of flow** $\Rightarrow$ the "unresolved velocity" cannot be all the time interpreted in terms of Alfvén wave

- A static + a dynamic component are present in the same pixel. The dynamic component is found:
    - in the red wing in loops
    - In the blue wing in the dark area, after the eruption

  Single-Gaussian fits underestimate the Doppler velocity

- More pixels may contain multi-component line profiles, but they are not "detectable" (difference in velocity is too small)

- The asymmetries appear in different spectral lines

  Effect of line blending is ruled out

- Sumitted to ApJ

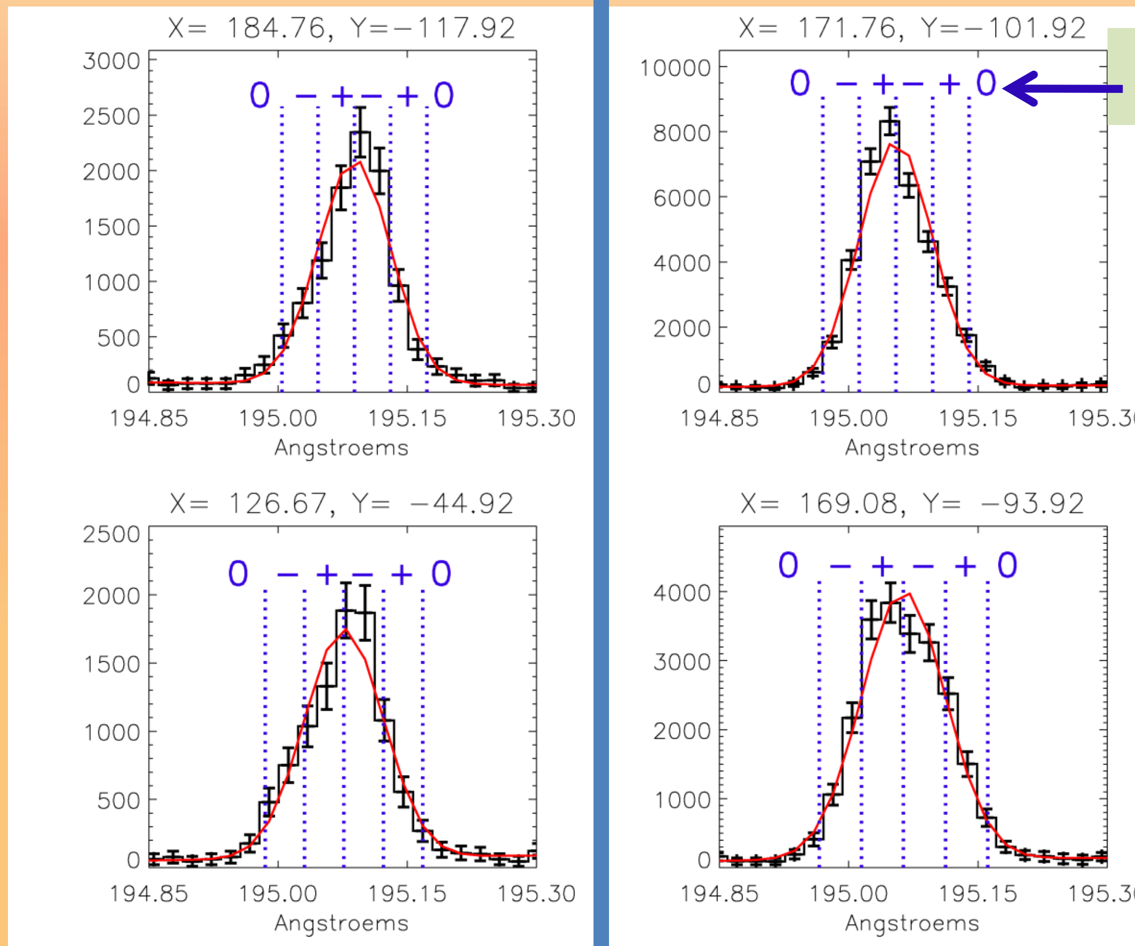
(additional slides)

An empirical coefficient to estimate the asymmetry

$$A = \frac{1}{N} \sum \varepsilon \times \mathrm{sgn}(\delta) \times \delta^2$$

Negative asymmetry (left-skewed profiles)	**Positive asymmetry (right-skewed profiles)**

Contribution ε



A= -1.3

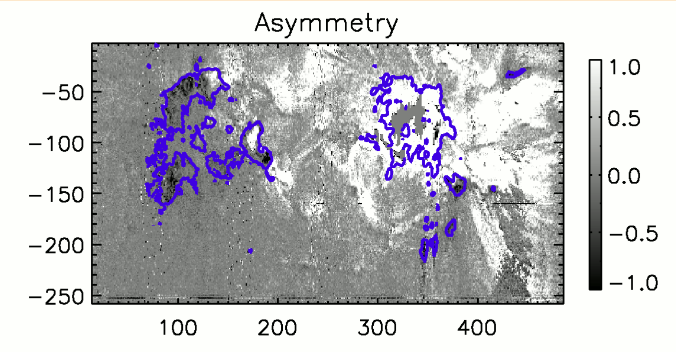
A= 3.3

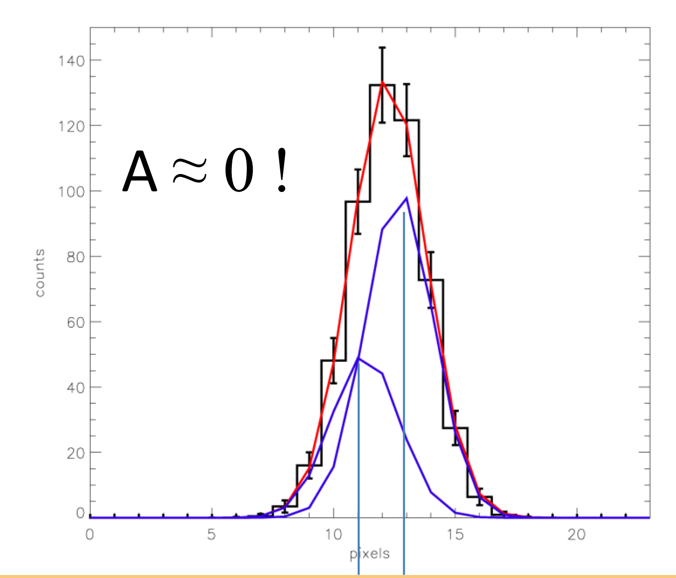
A= -1.0

A= 1.0

- <u>Dimming:</u>
  - ≈30% of clearly distorted profiles in large width areas
  - Left(right)-skewed in dark (bright) areas
  - The other 70% may be all double-component
  - Dynamic component is upflowing

  => there is a large flow (maybe) pushing the CME forward (McIntosh , 2009), BUT:
    - it is ≈ twice as large as previously measured
    - The broadening is not (totally) due to the Alfvén waves
- <u>Loops:</u>
  - Most of the profiles are right-skewed
  - Dynamic component is downflowing (draining cooling loops ? Bradshaw, 2008)





≈ 25 km/s