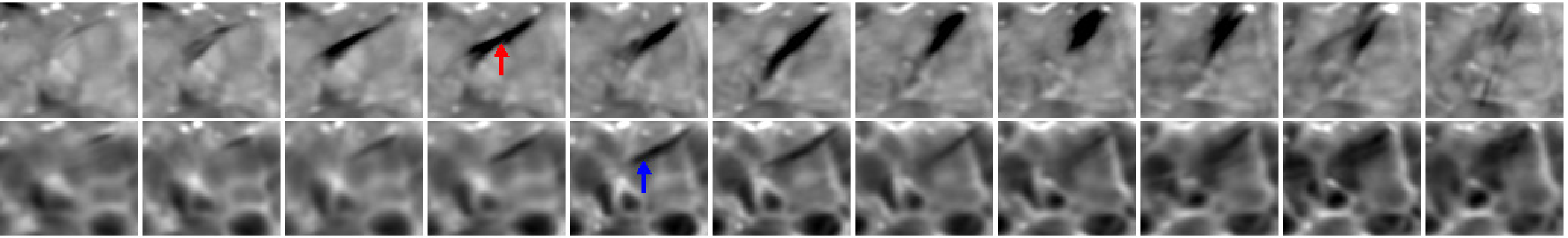

Spectral Inversion of the Hα and Ca II 8542 Å Lines Observed by SST/CRISP in Chromospheric Jet

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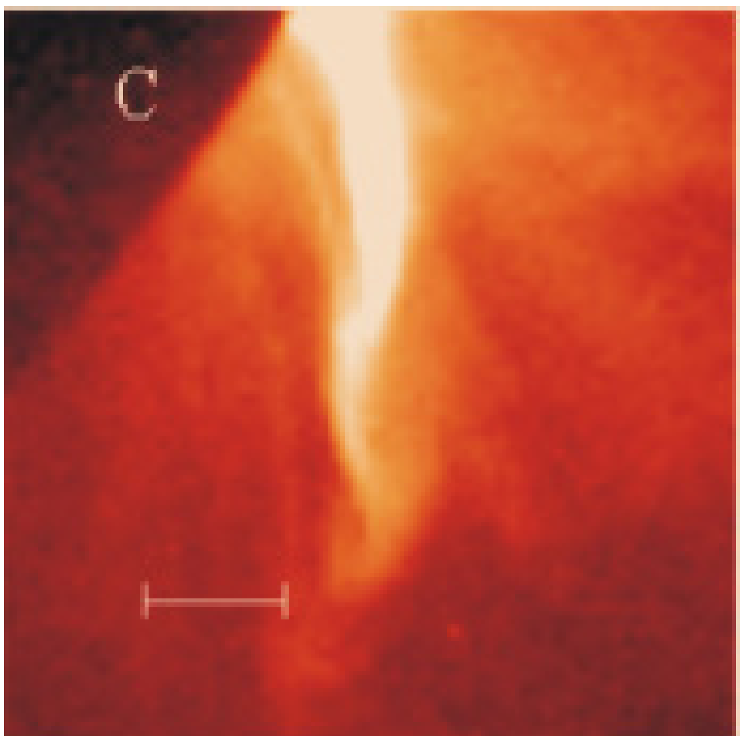
Our mysterious Sun: magnetic coupling between solar interior and atmosphere

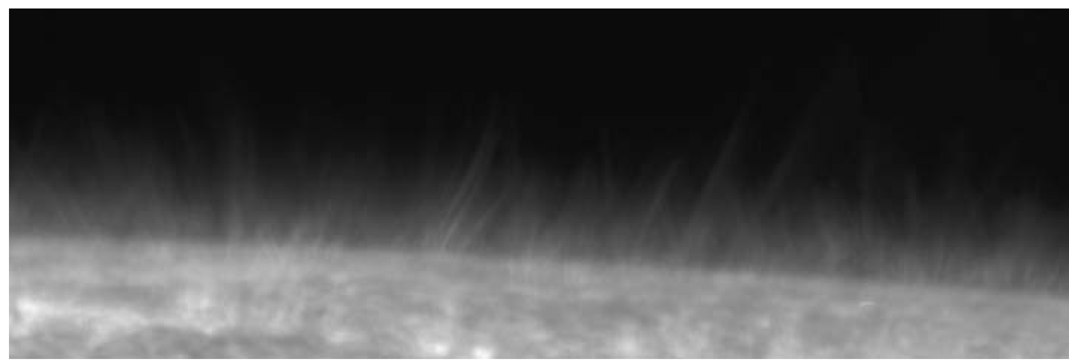
September 25-29, 2017, Tbilisi, Georgia

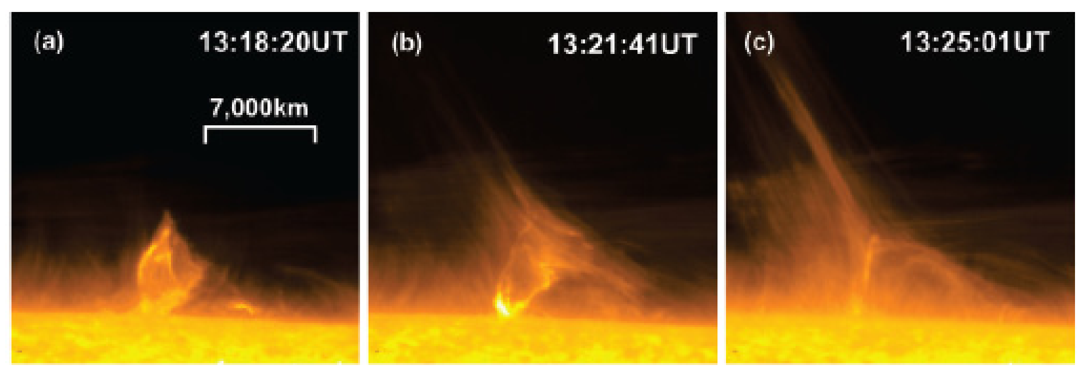
Jets in the Solar Atmosphere

Observations show various kinds of jets in the solar atmosphere:

- type I spicules : 20 - 25 km/s (Beckers 1968)
- type II spicules: 50 - 100 km/s (De Pontieu et al. 2007)
- RBEs/RREs: 50 - 100 km/s (Rouppe van der Voort et al. 2009)
- chromospheric anemone jets: 10 - 20 km/s (Shibata et al. 2007)
- macrospicules: 100 - 150 km/s (Pike and Mason 1998)
- Hα surges: 50 - 200 km/s (Canfield et al. 1996)
- X-ray jets: 200 - 600 km/s (Shibata et al. 1992)







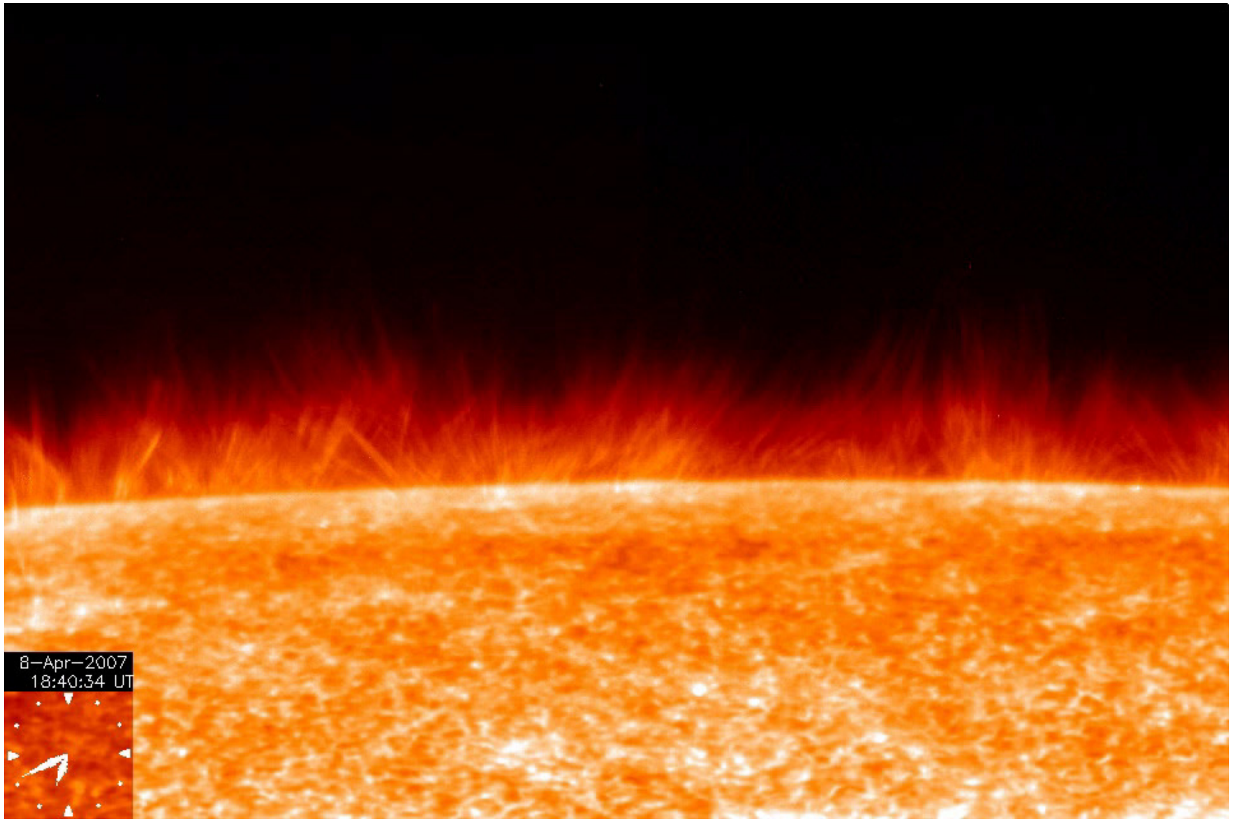
Type I and Type II Spicules

Type I spicules (Beckers 1972)

diameter: 400 - 1500 km
speed: 20 - 25 km/s
lifetime: 5 - 15 min

Type II spicules (De Pontieu et al. 2007)
RBEs (Rouppe van der Voort et al. 2009)

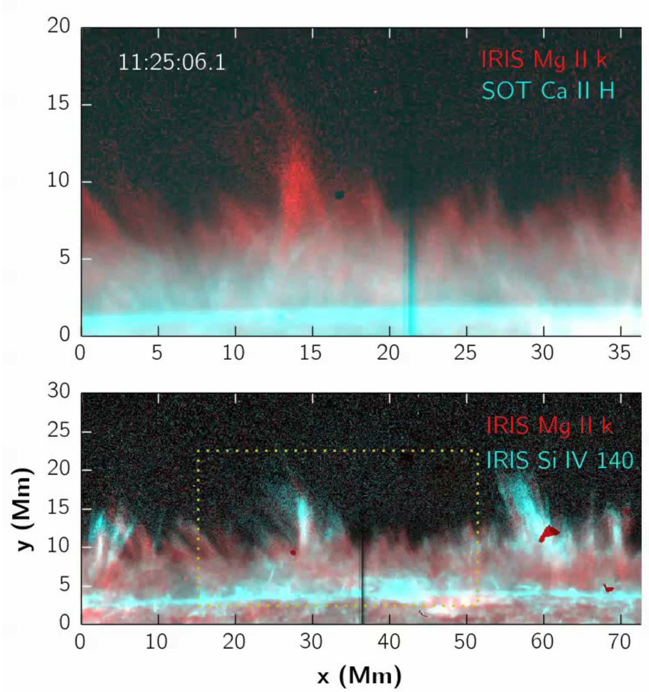
diameter: < 200 km
speed: 50 - 100 km/s
lifetime: 10 - 150 s



Heating Mechanisms of Type II Spicules

Short life time: fast heating to transition region temperatures (De Pontieu et al. 2007)?

Further supported by IRIS (Pereira et al. 2014).

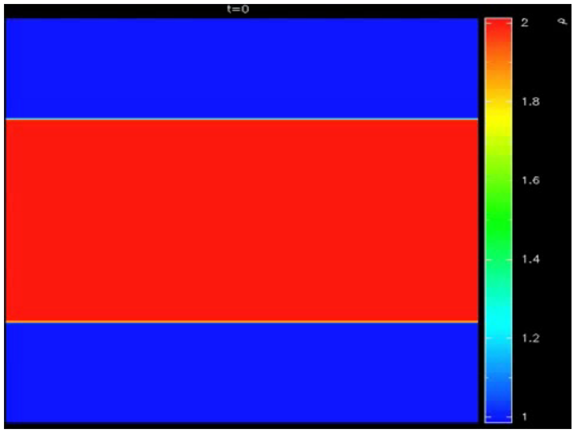


Mechanism for the fast heating remains unknown.

Thermal conduction: hours
Joule heating (spatial scale ≈ 200 km): days
Viscosity (spatial scale ≈ 200 km): months
Ion-neutral collisions (spatial scale ≈ 200 km): 1 hour

Ion-neutral collisions lead to fastest heating, but spatial scales must be smaller!

Energy of flow must be transferred to smaller scales, where it may dissipate and heat the structure.



Kelvin – Helmholtz Instabilities?
Kuridze et al. 2016
Zaqarashvili et al. 2010, 2014
Soler et al. 2012

Aims of This Study

- to identify chromosheric jets in on-disk data obtained by the CRisp Imaging Spectropolarimeter (CRISP) on the Swedish 1-m Solar Telescope

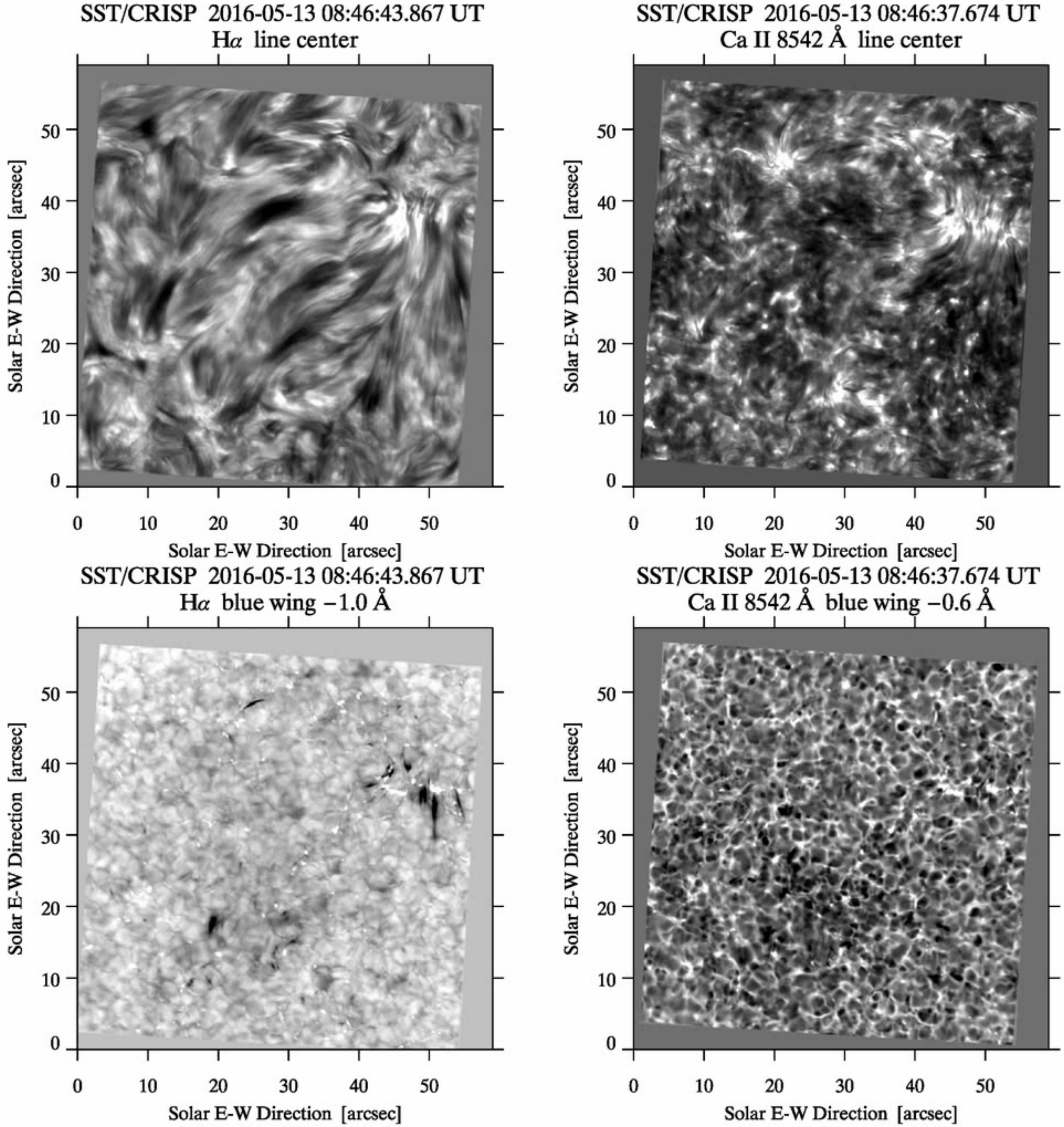
- to infer physical characteristics of a typical jet with **a modified cloud model** (Liu & Ding 2001) yielding:
  - the Source function S
  - the Line center optical thickness τ_0
  - the Doppler width $\Delta\lambda_D$
  - the Line-of-sight velocity v_{LOS}

- to prepare basis for spectral inversions of large volumes of CRISP data aiming:
  - to infer temporal evolution of S, τ_0, $\Delta\lambda_D$, and v_{LOS} for large sample of chromospheric jets,
  - to look for the Kelvin-Helmholtz Instabilities manifesting through increased non-thermal broadening of spectral lines.

Observations and Data Reduction

- coordinated SST-IRIS campaign in 13 - 19 May 2016 **supported through SOLARNET**
- data taken on 13 May 2016 between 08:46 UT and 10:02 UT in the quiet chromosphere close to disk center by SST/CRISP
- Hα scanned in the range ±1.4 Å around center in 15 points separated 0.2 Å
- Ca II 8542 Å scanned in the range ±1.2 Å around center in 25 points separated 0.1 Å with one extra point at –1.5 Å
- temporal cadence of the Hα and Ca II 8542 Å line scans: 12.4 s
- data reduction: Luc Rouppe van der Voort, the CRISPRED pipeline (de la Cruz Rodríguez et al. 2015) and MOMFBD (van Noort et al. 2005)

SOLARNET


SST/CRISP 2016-05-13 08:46:43.867 UT
Hα line center
SST/CRISP 2016-05-13 08:46:37.674 UT
Ca II 8542 Å line center
SST/CRISP 2016-05-13 08:46:43.867 UT
Hα blue wing −1.0 Å
SST/CRISP 2016-05-13 08:46:37.674 UT
Ca II 8542 Å blue wing −0.6 Å
Solar E-W Direction [arcsec]
Solar E-W Direction [arcsec]
0
10
20
30
40
50

Spectral Inversion by Cloud Model

The classical cloud model

In this model by Beckers (1964), the line intensity $I(\Delta\lambda)$ at $\Delta\lambda$ from the line center is given by the formula:

$$I(\Delta\lambda) = I_0(\Delta\lambda)e^{-\tau(\Delta\lambda)} + S\left[1 - e^{-\tau(\Delta\lambda)}\right]$$

where: $I_0(\Delta\lambda)$ is the intensity of background profile

S is the constant source function

$\tau(\Delta\lambda)$ is the optical thickness given by: $\tau(\Delta\lambda) = \tau_0\varphi(\Delta\lambda, \Delta\lambda_D, v_{LOS})$

where: τ_0 is the line center optical thickness

φ is the absorption profile (Gaussian or Voigt function)

$\Delta\lambda_D$ is the Doppler width

v_{LOS} is the line-of-sight velocity

The model adopts a mean profile over the quiet chromosphere as the background profile $I_0(\Delta\lambda)$.

The modified cloud model

Liu & Ding (2001) introduced the modified cloud model, in which the background profile $I_0(\Delta\lambda)$ is eliminated assuming its symmetry $I_0(\Delta\lambda) = I_0(-\Delta\lambda)$. In this model **the observed asymmetry** of the line profile $\boldsymbol{A(\Delta\lambda) = I(\Delta\lambda) - I(-\Delta\lambda)}$ is given as:

$$A(\Delta\lambda) = I(\Delta\lambda) - I(-\Delta\lambda) = \left[I(\Delta\lambda) - S\right]\left[1 - e^{\tau(\Delta\lambda) - \tau(-\Delta\lambda)}\right]$$

Spectral Inversion by Cloud Model

In this study we employ the modified cloud model, but assuming that:

- the background profile is asymmetric,
- the asymmetry of the background profile can be represented by asymmetry of mean profile.

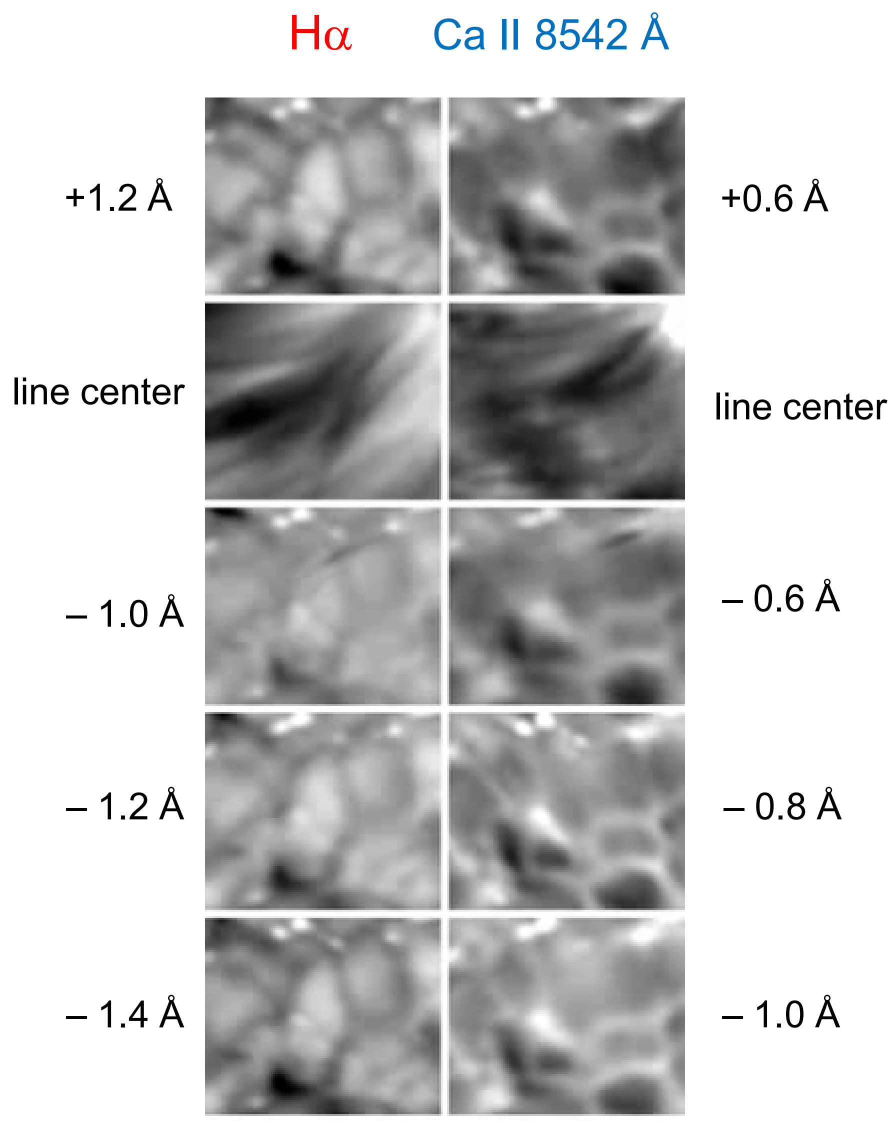
Then the observed asymmetry $A(\Delta\lambda)$ of line profile is given by the formula

$$A(\Delta\lambda) = [I(\Delta\lambda) - S]\left[1 - e^{\tau(\Delta\lambda)-\tau(-\Delta\lambda)}\right] + a(\Delta\lambda)e^{-\tau(-\Delta\lambda)}$$

where $a(\Delta\lambda)$ is the asymmetry of the mean profile.

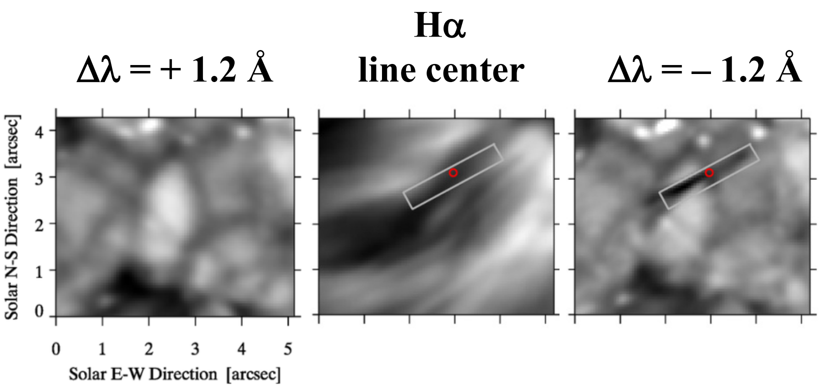
Then from the observables $A(\Delta\lambda)$, $I(\Delta\lambda)$, and $a(\Delta\lambda)$ one can compute S, τ_0, $\Delta\lambda_D$, and v_{LOS} by the Levenberg–Marquardt least-squares minimization method (Markwardt 2009).

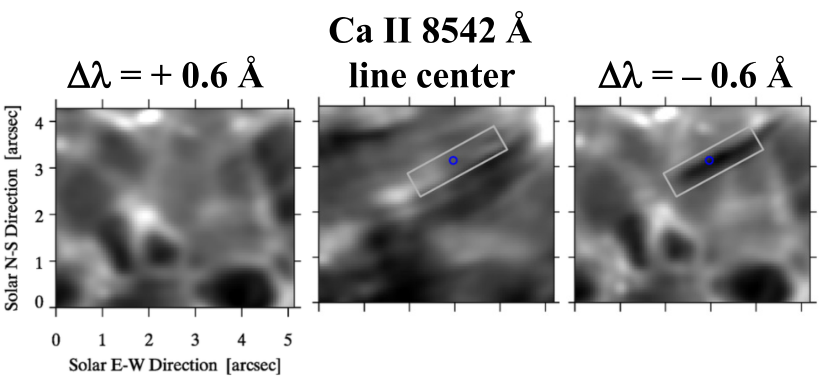
Evolution of selected chromospheric jet

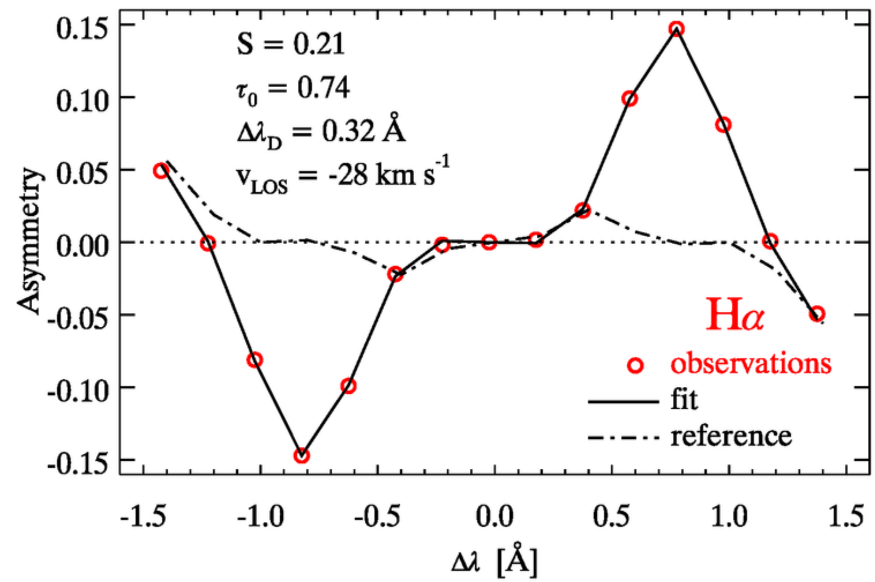


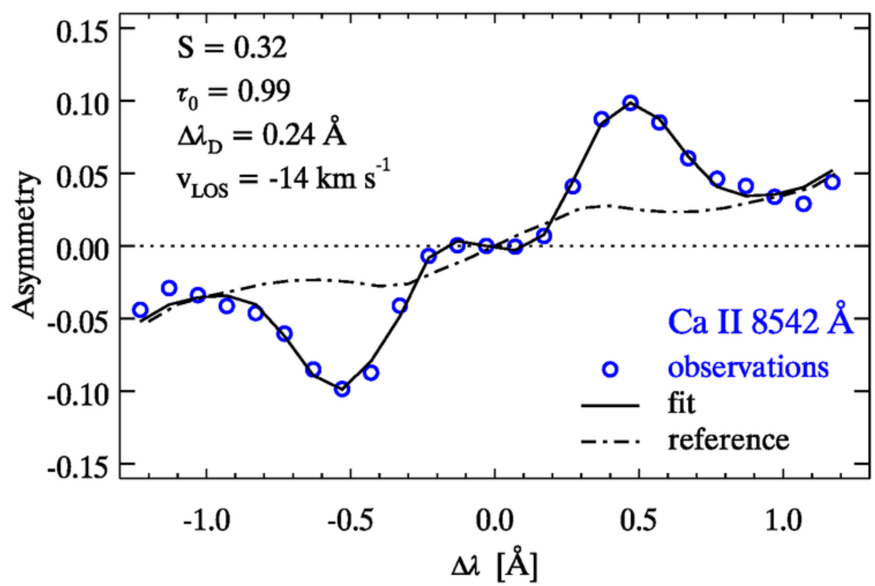
transverse motion

Example of the Hα and Ca II 8542 Å profile asymmetries



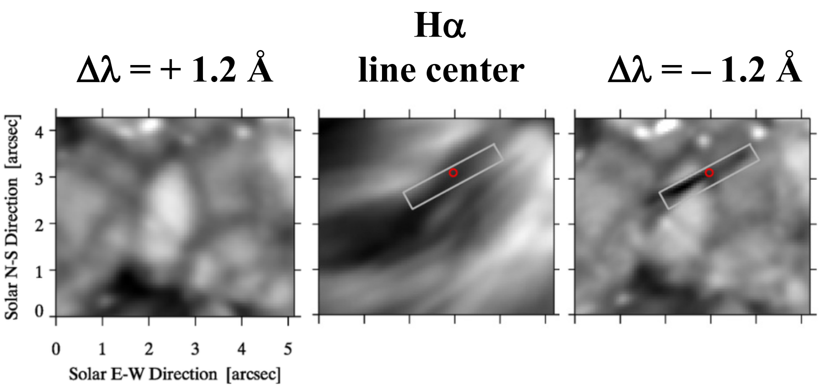


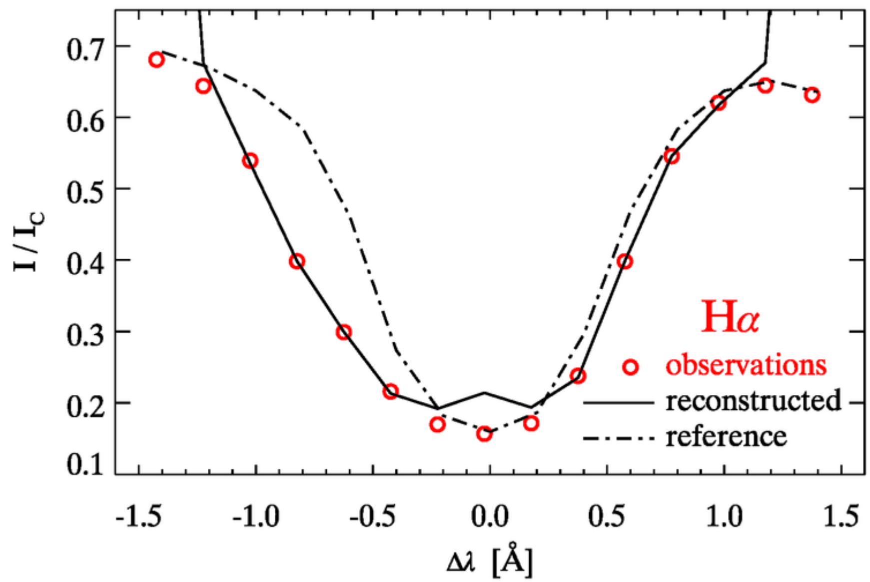


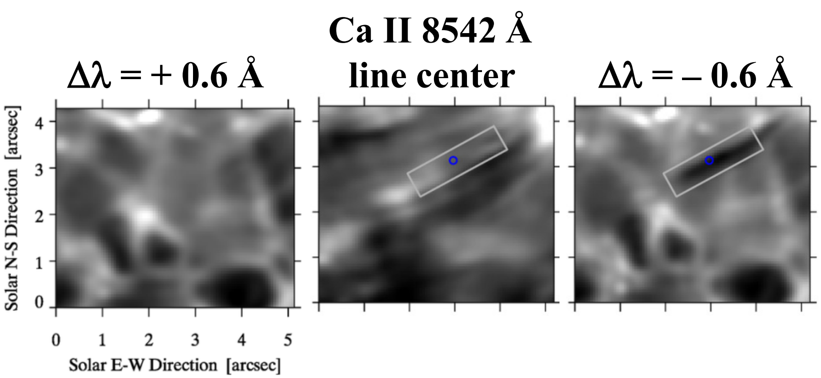


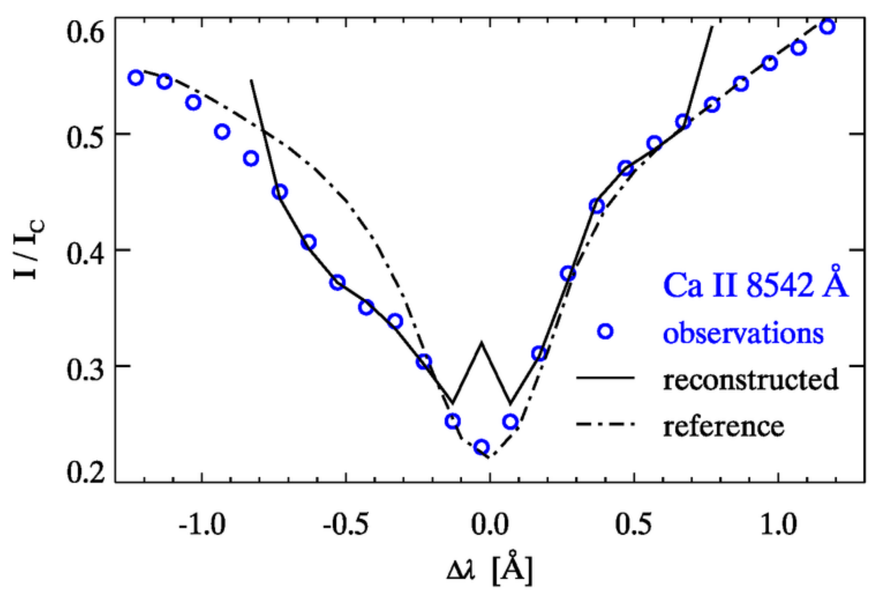
fit = cloud model fit
reference = asymmetry of reference profile
(spatial average over full FoV)

Example of the Hα and Ca II 8542 Å line profiles





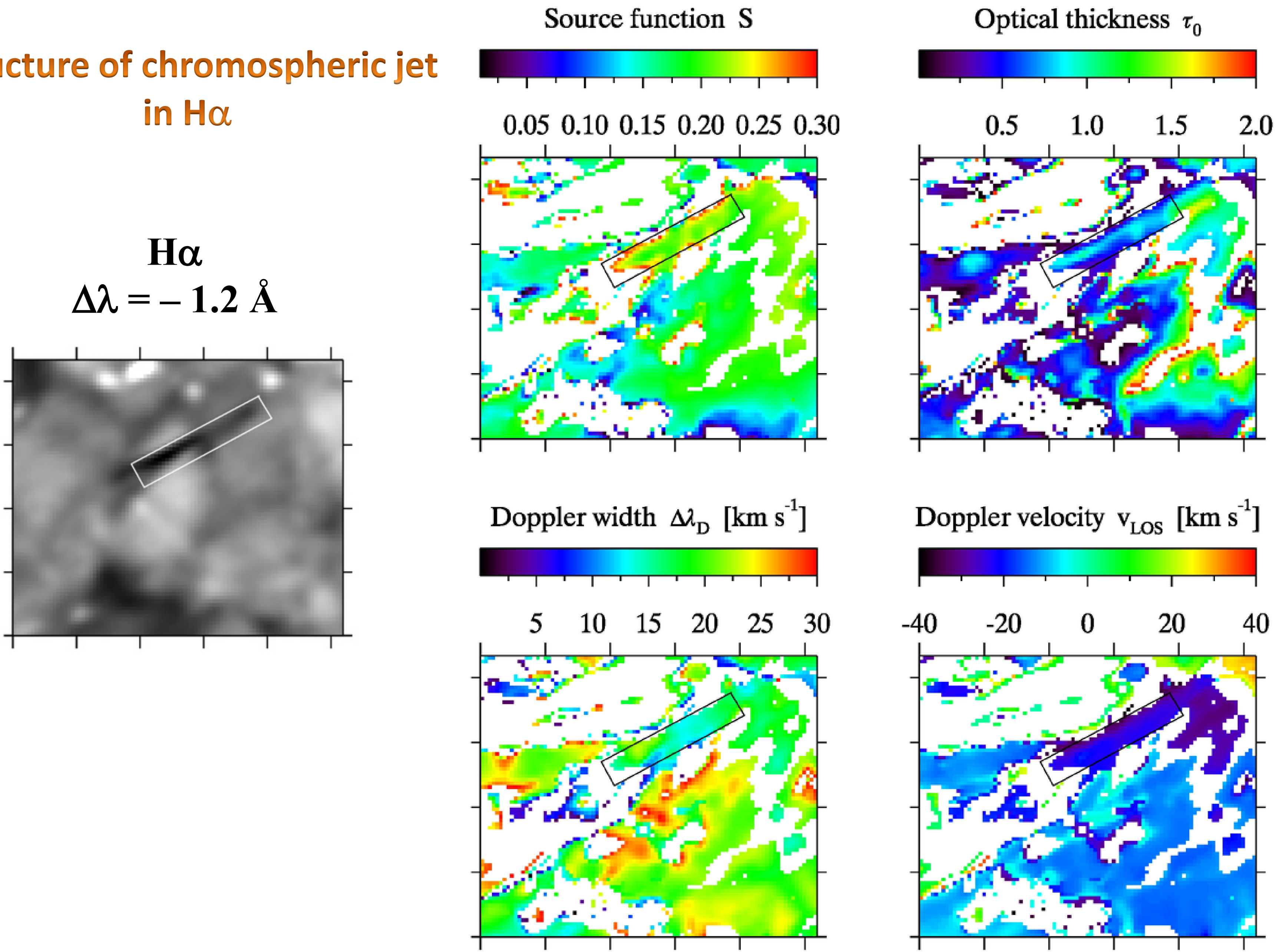




reconstructed = profile computed from cloud model parameters

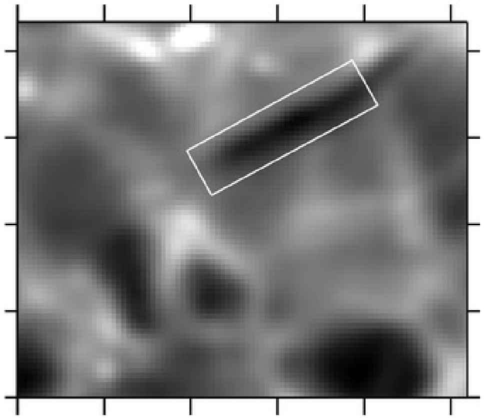
reference = spatial average over full FoV

Structure of chromospheric jet in Hα

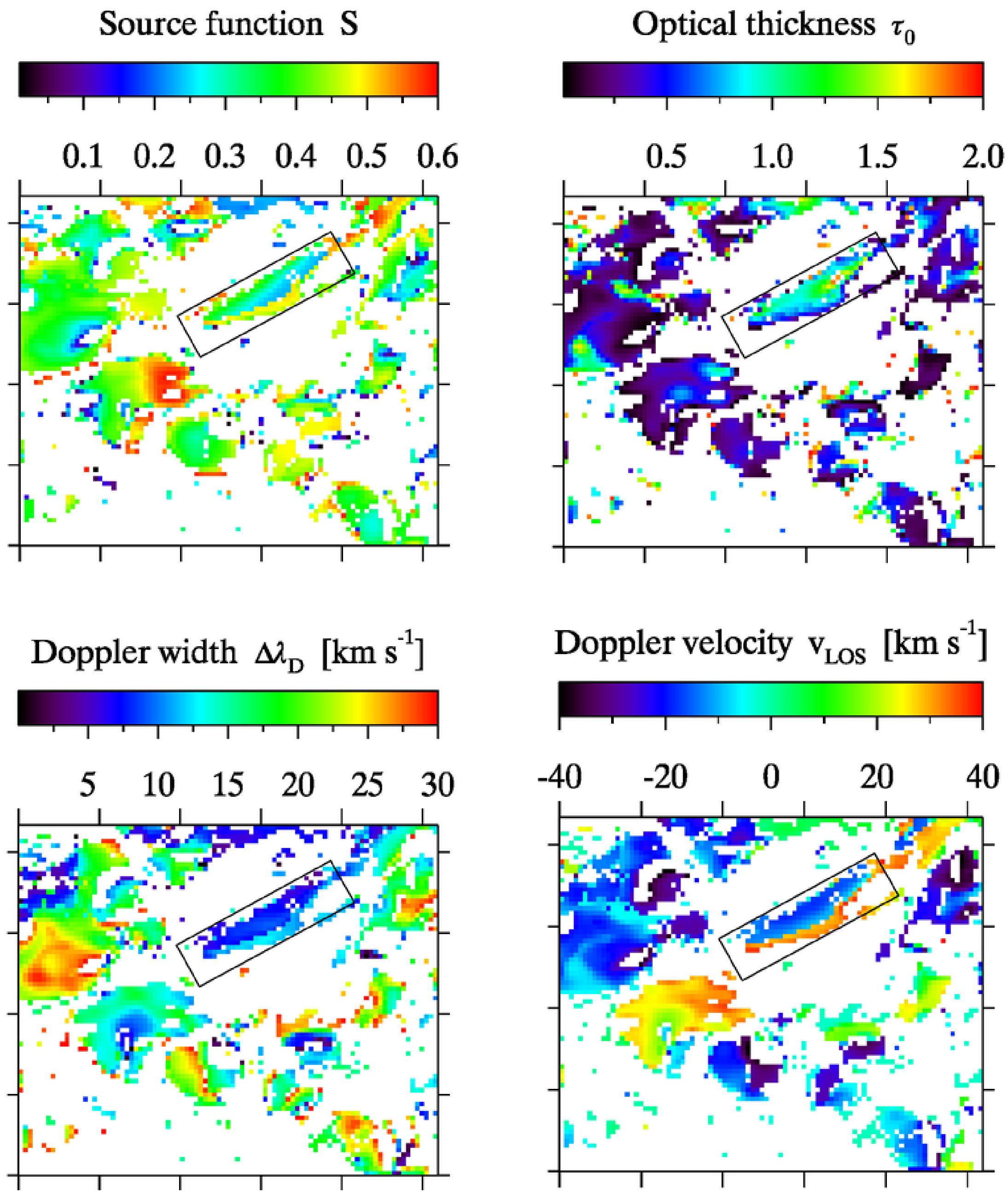


Structure of chromospheric jet in Ca II 8542 Å

Ca II 8542 Å
$\Delta\lambda = -0.6$ Å

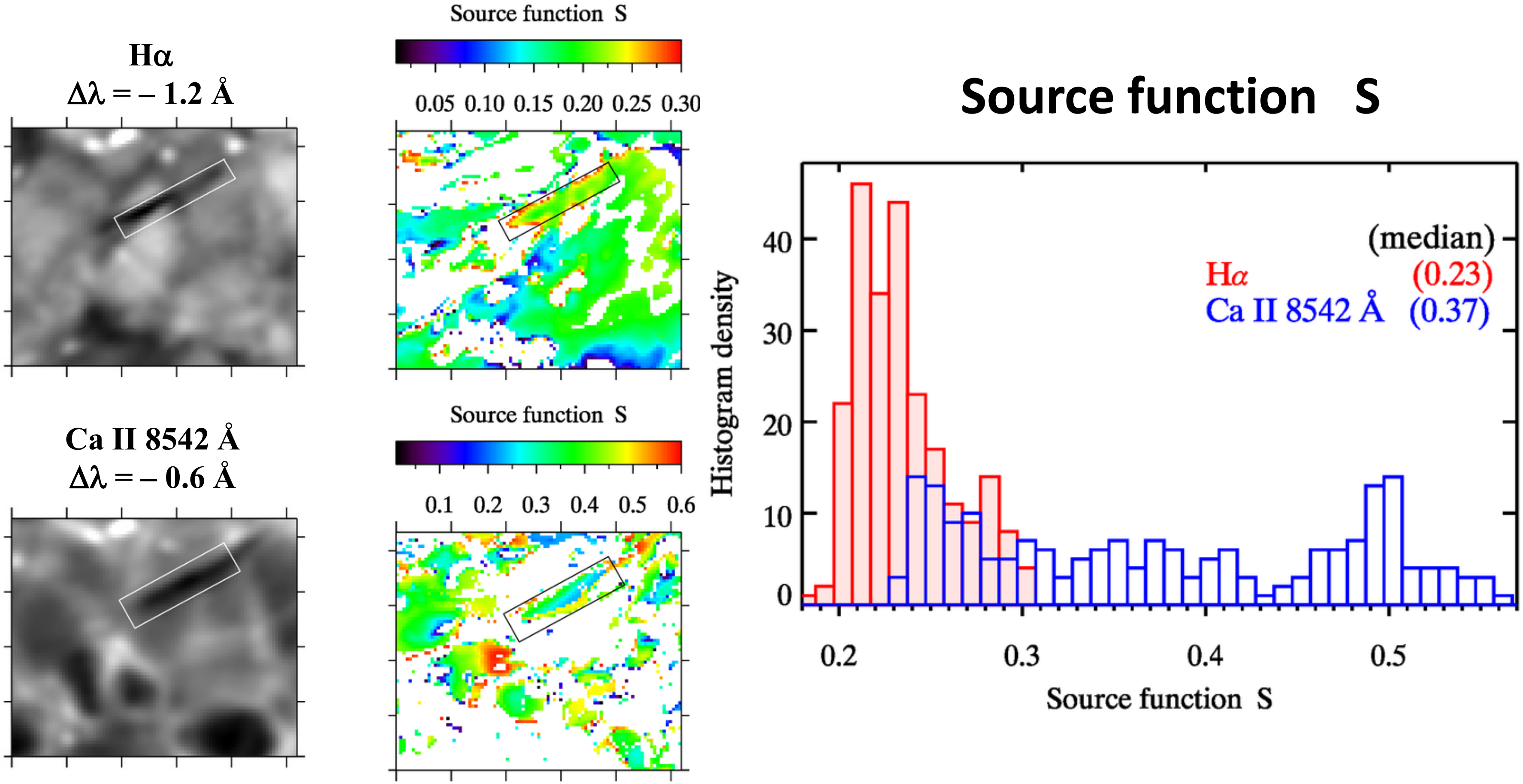


Correlations of the parameters
$S \quad \tau_0 \quad \Delta\lambda_D \quad v_{LOS}$



bi-directional flow?

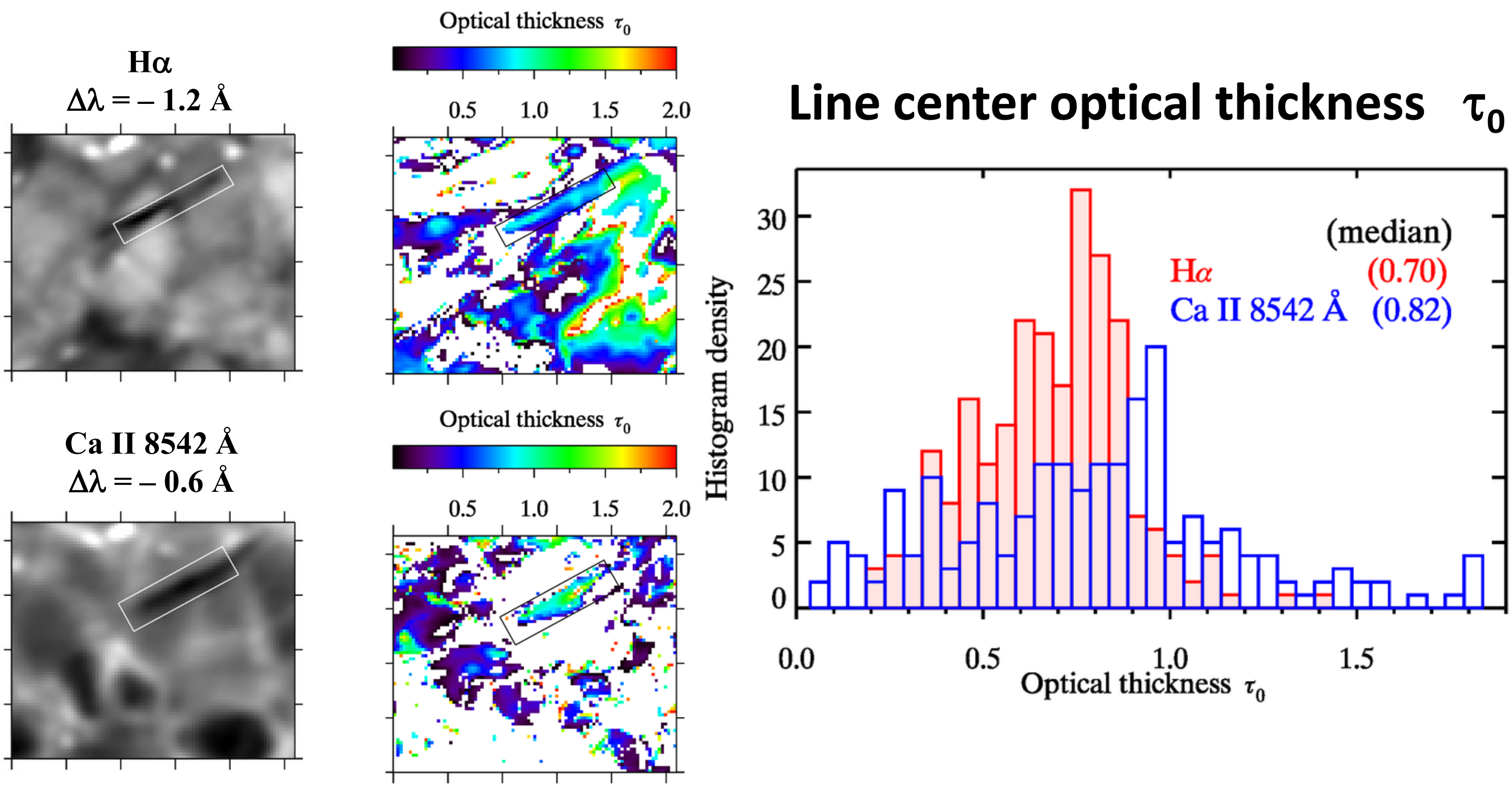
Structure of chromospheric jet in Hα and Ca II 8542 Å



Hα
- S increases from the jet core towards its outer limits from S ≈ 0.2 to S ≥ 0.3
- prominent peak in the histogram at S ≈ 0.23

Ca II 8542 Å
- S increases from the jet core towards its outer limits from S ≈ 0.25 to 0.45
- the histogram suggests flat distribution of S

Structure of chromospheric jet in Hα and Ca II 8542 Å

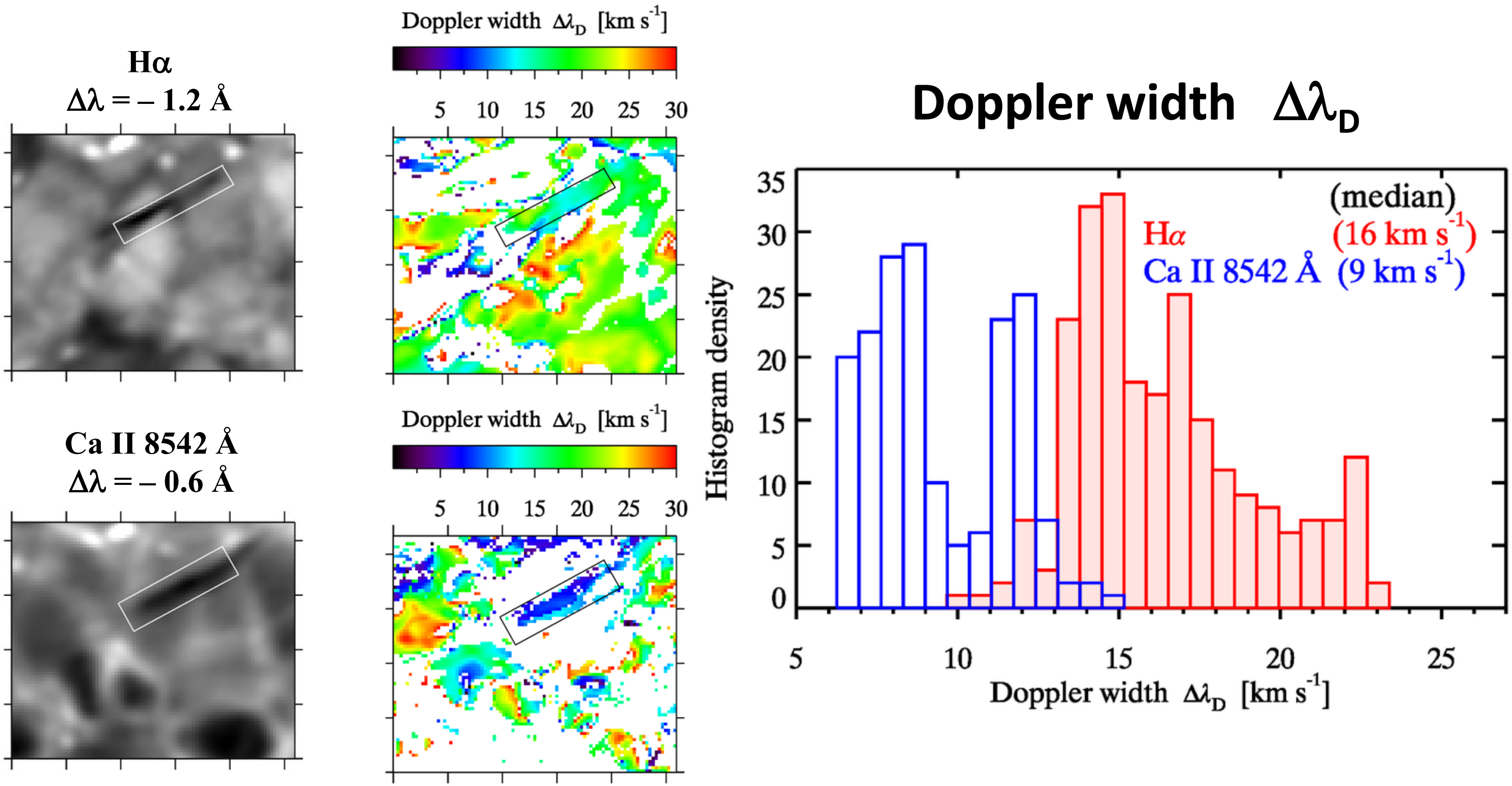


Hα - τ_0 decreases from the jet core towards its outer limits from $\tau_0 \approx 0.8$ to 0.5

Ca II 8542 Å - τ_0 decreases from the jet core towards its outer limits from $\tau_0 \approx 1.2$ to 0.5

Can be the jet considered as optically thin?

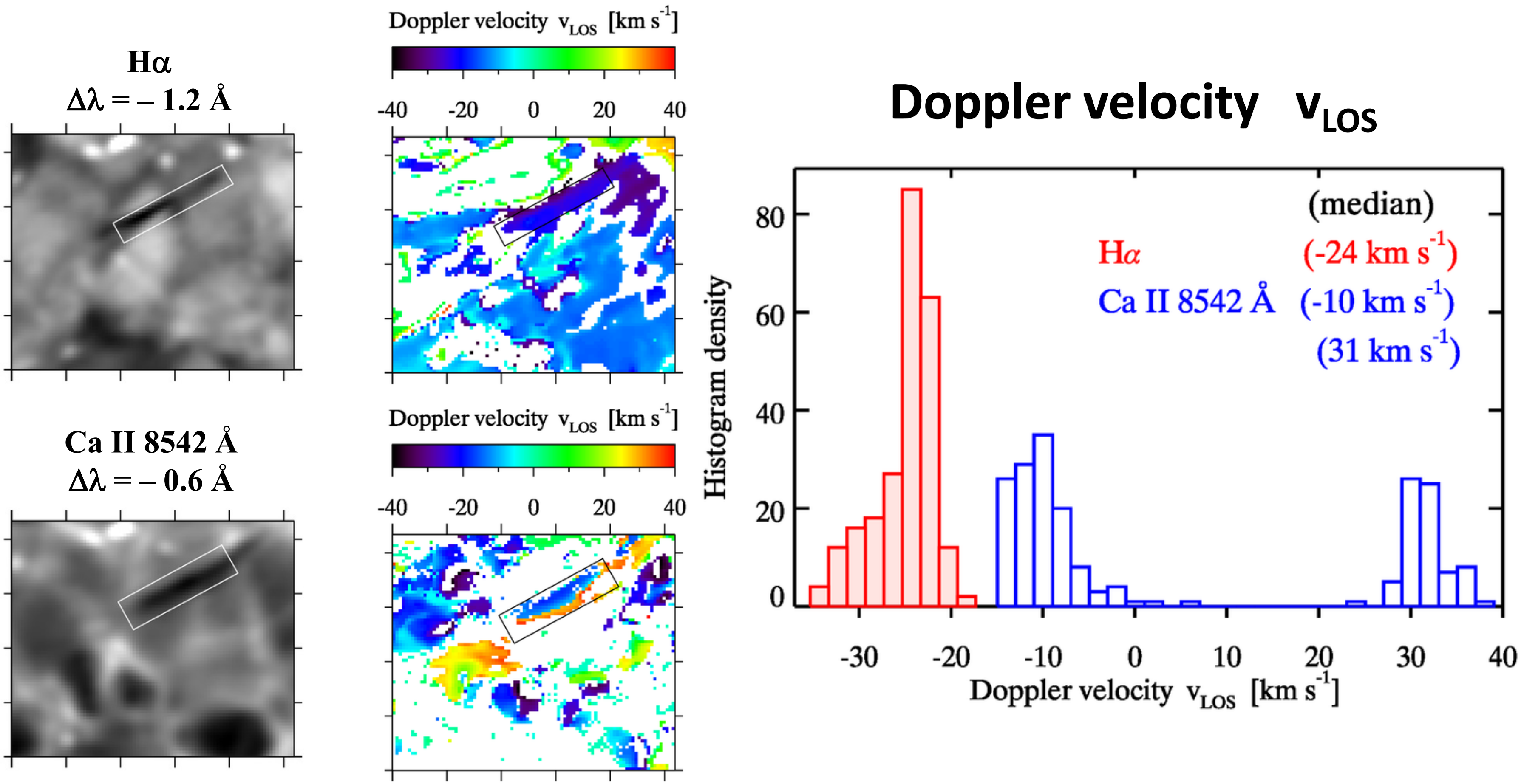
Structure of chromospheric jet in Hα and Ca II 8542 Å



Single-peak distribution of $\Delta\lambda_D$ for Hα but double-peak distribution for Ca II 8542 Å.

The first peak at 8 kms^{-1} suggests very cold jet plasma and/or very small non-thermal broadening.

Structure of chromospheric jet in Hα and Ca II 8542 Å



Larger v_{LOS} measured in Hα than in Ca II 8542 Å.

Ca II 8542 Å - signature of bi-directional flow
- sharp boundary between up- and downflows

Result summary

- the new version of the modified cloud model by Liu & Ding (2001) was applied to infer parameters of chromospheric jet observed simultaneously in the $H\alpha$ and Ca II 8542
- the source functions of $H\alpha$ and Ca II 8542 Å **increase** from the jet core towards its outer limits
- the line center optical thicknesses of $H\alpha$ and Ca II 8542 Å **decrease** from the jet core outwards
- the jet is optically thicker in Ca II 8542 Å ($\tau_0 \approx 0.82$) than in $H\alpha$ ($\tau_0 \approx 0.7$)
- the jet shows single-peak distribution of the Doppler width $\Delta\lambda_D$ for $H\alpha$ but double-peak distribution for Ca II 8542 Å.
- larger Doppler velocity v_{LOS} measured in $H\alpha$ than in Ca II 8542 Å
- signature of **bi-directional flow** in Ca II 8542 Å Doppler velocity

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SST/CRISP data processing: Luc Rouppe van der Voort

(Institute of Theoretical Astrophysics, University of Oslo)