Transverse oscillations in spatial and velocity space observed in coronal rain with IRIS

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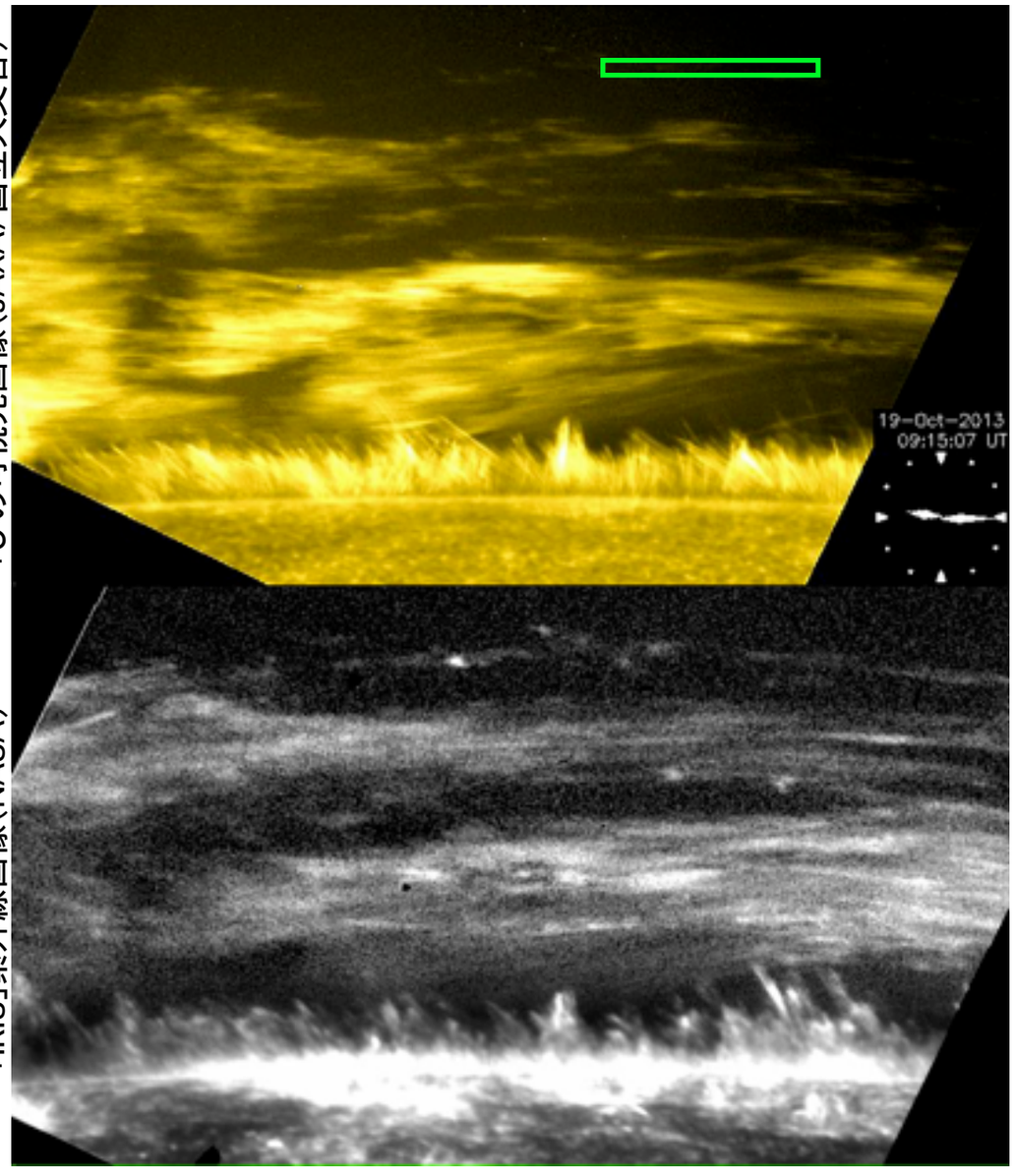
Introduction

- Coronal rain is composed of cool and dense blobs of plasma observed at coronal heights in cool chromospheric lines (Kawaguchi 1970).
- Associated with active region loops and fall along curved loop-like paths with speeds less than free-fall speed
- Multi thermal in nature and appear in hot dense coronal loops in few minutes (catastrophic cooling)
- Observed with high spatial and temporal resolution using CRISP (Antolin, 2012)
- Average width -> 310 km
- Average length -> 710 km
- Transverse oscillations have been shown to be associated with coronal rains using SOT/Hinode (Antolin & Verwichte, 2011)

Transverse MHD waves in prominences

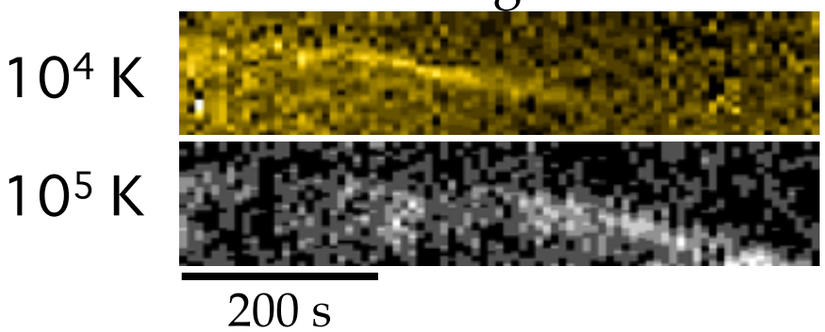
Hinode/SOT （Ca II, 10,000 K)



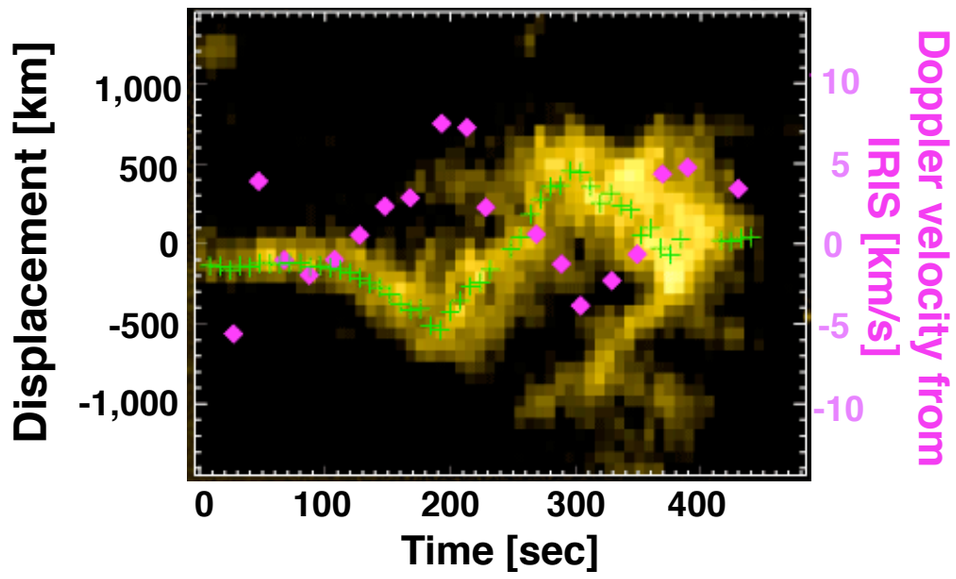
IRIS/SJI (Si IV, 100,000)

(Okamoto+2015, Antolin+2015)

x-t diagram



Motion of prominence plasma crossing the slit



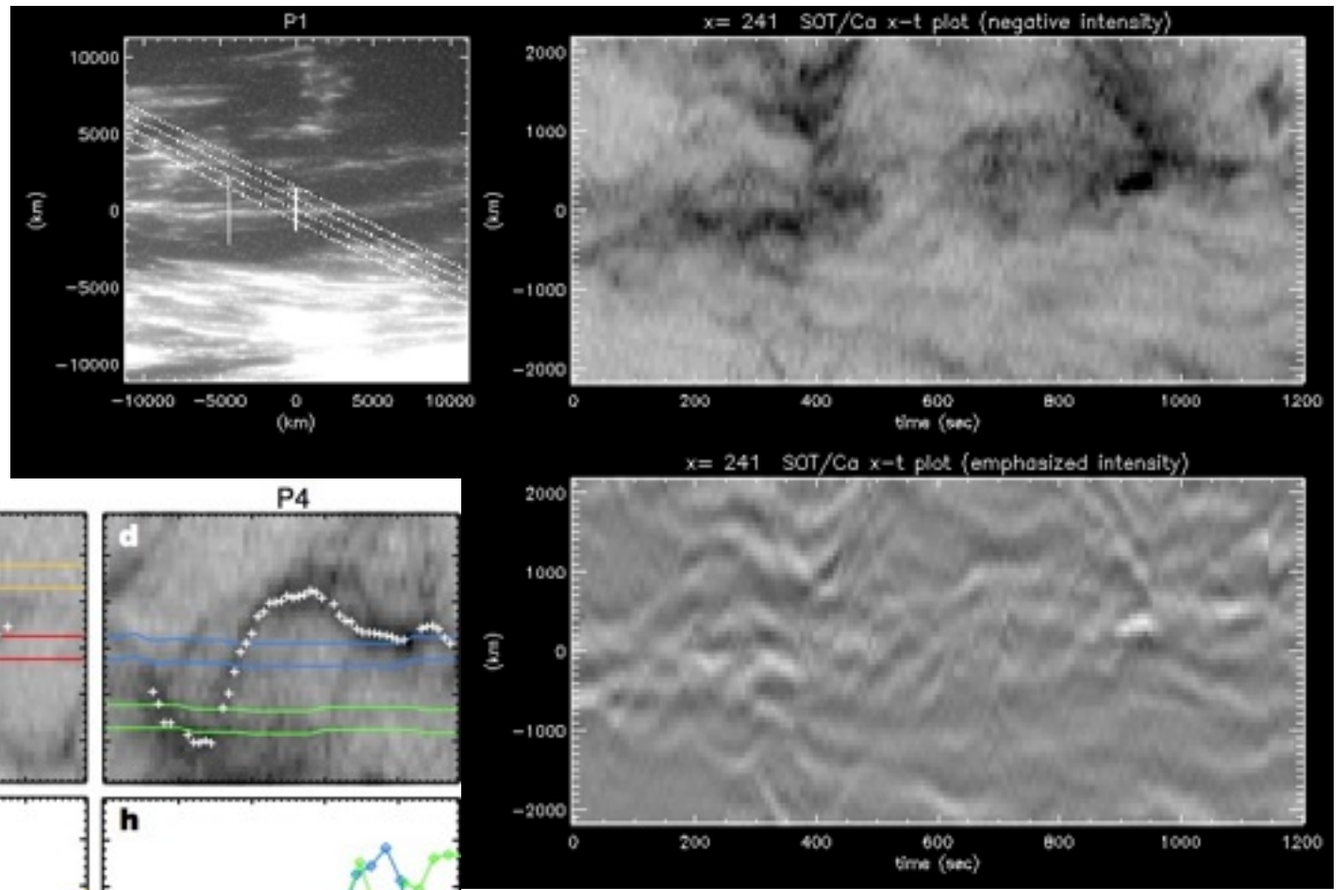
- Heating: Fading in cool line (10^4 K), subsequent appearance in hot line (10^5 K)
- POS motion out-of-phase with LOS velocity
- Thread-like structure

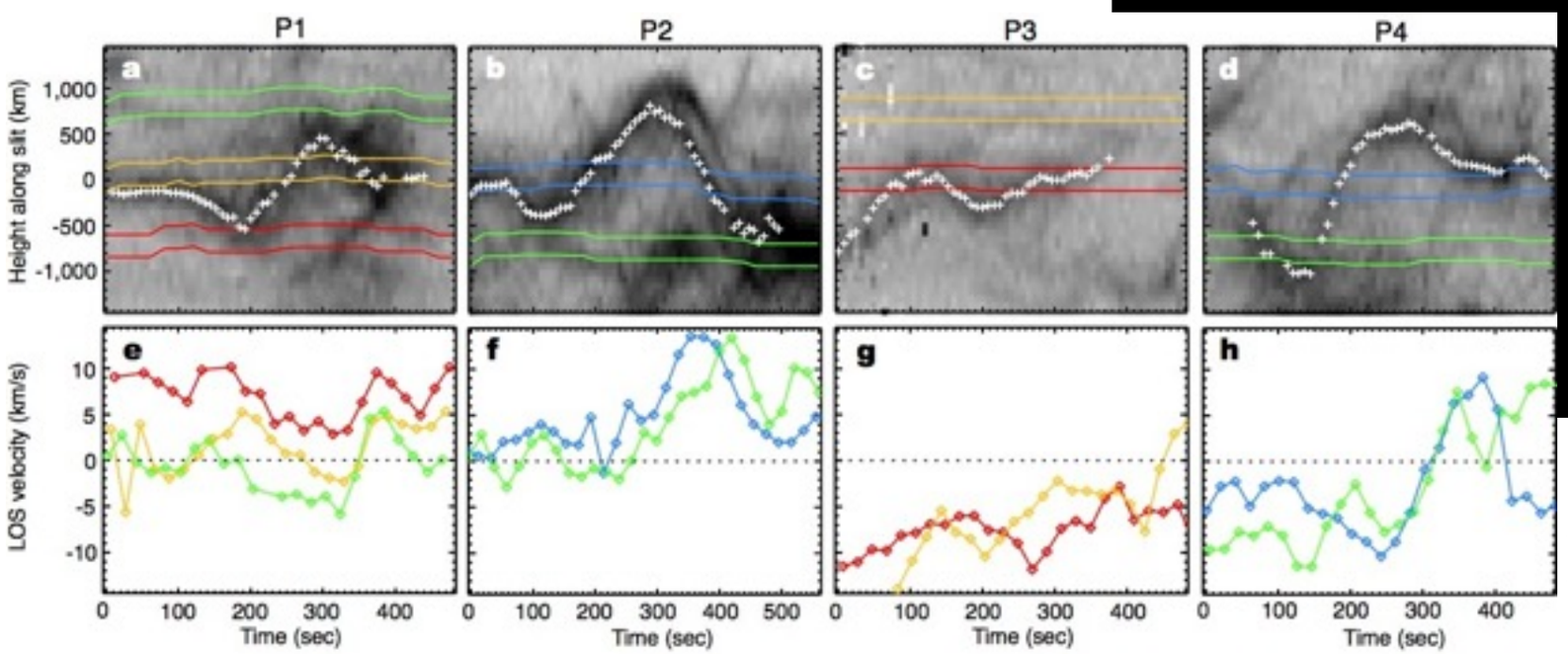
➡ Explained with 3D MHD transverse wave model: KHI + resonant absorption (current model)

IRIS/Hinode observations

- Thread-like structure
- Transverse oscillations
- Signatures of damping
- Strong transverse coherence in the plane-of-the-sky (POS) motion and the line-of-sight (LOS) velocity

Hinode/SOT



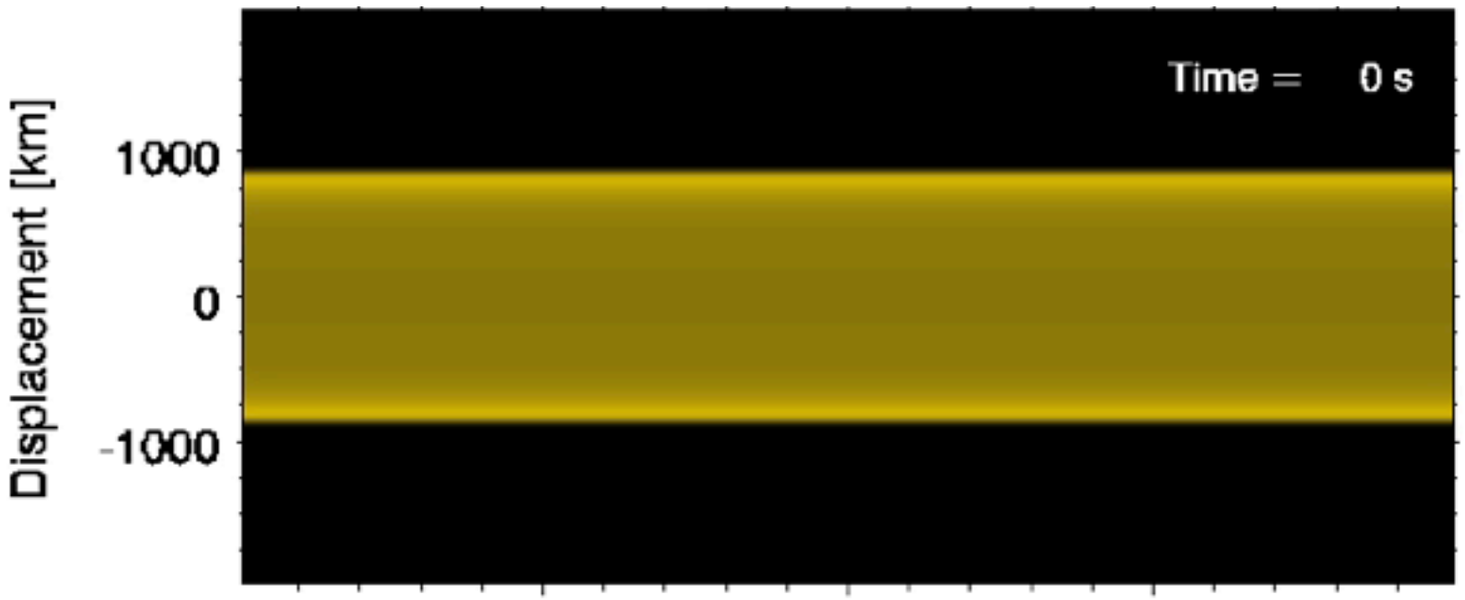


IRIS/SG

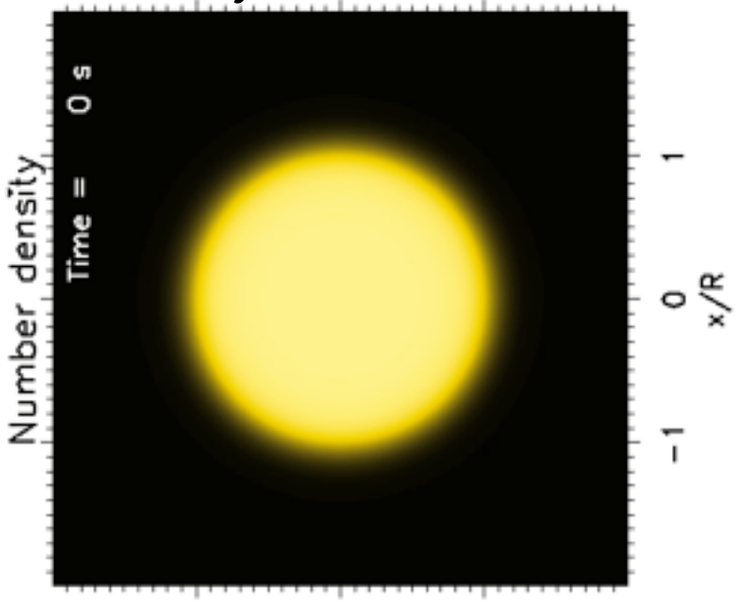
Numerical simulation

Velocity shear amplified by resonant absorption -> Kelvin-Helmholtz instability significantly deforms the flux tube

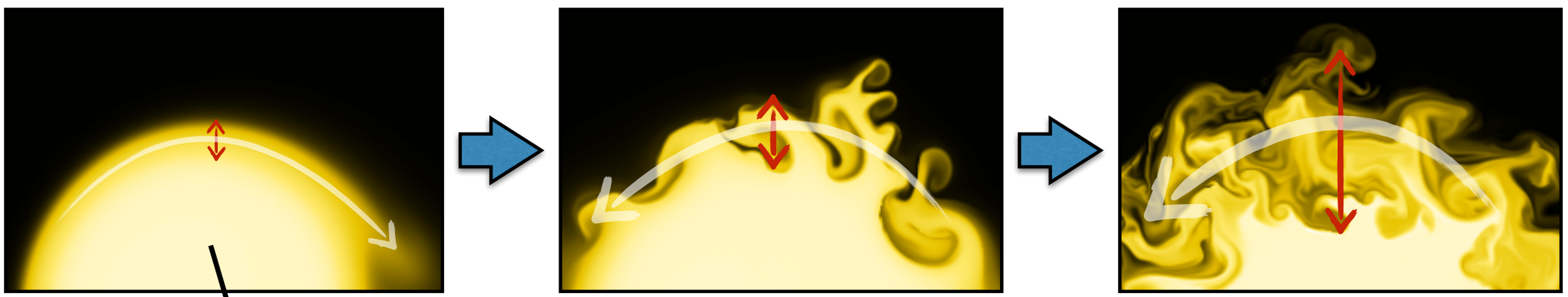
Prominence thread - Mg II k intensity



Density cross-section



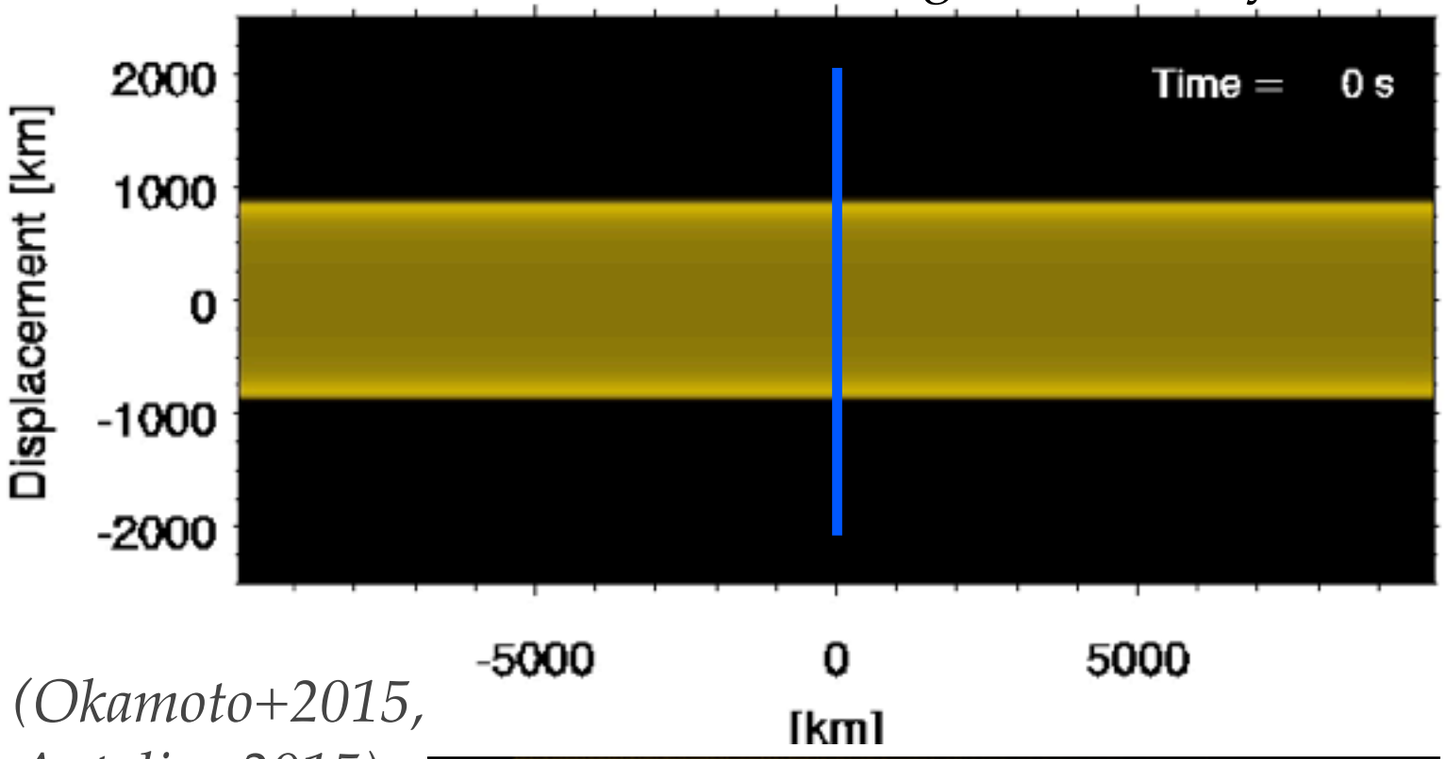
KHI takes up the resonant (azimuthal) dynamics to the observable scale



Density cross-section of prominence thread

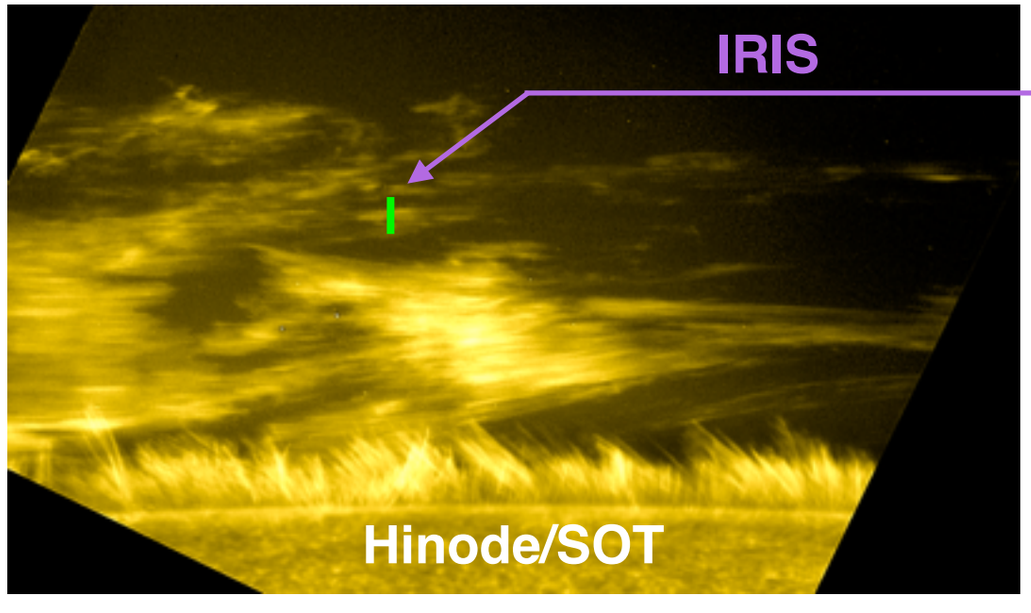
Comparing with Hinode & IRIS observations

Prominence thread - Mg II k intensity



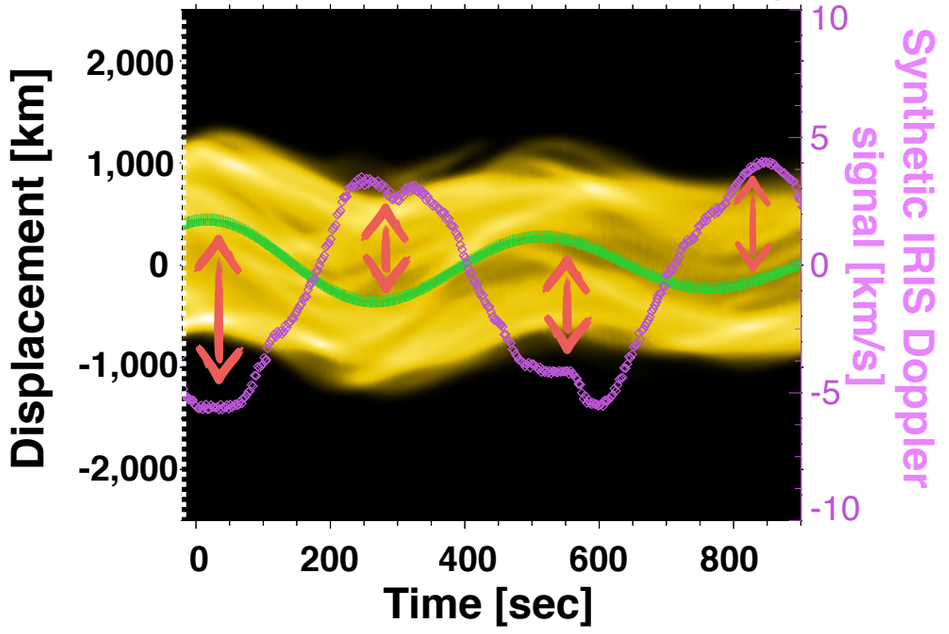
(Okamoto+2015, Antolin+2015)

very good match with observations



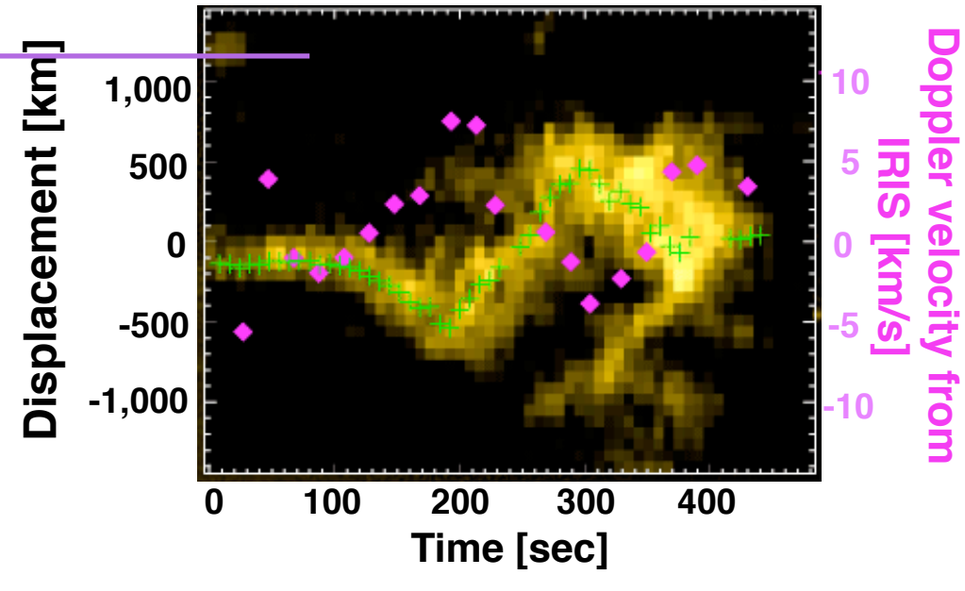
Numerical results

Motion of prominence plasma crossing the slit

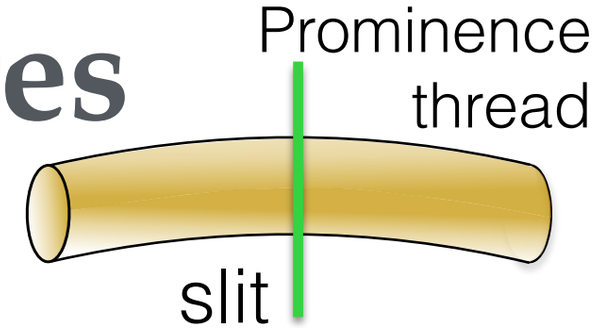


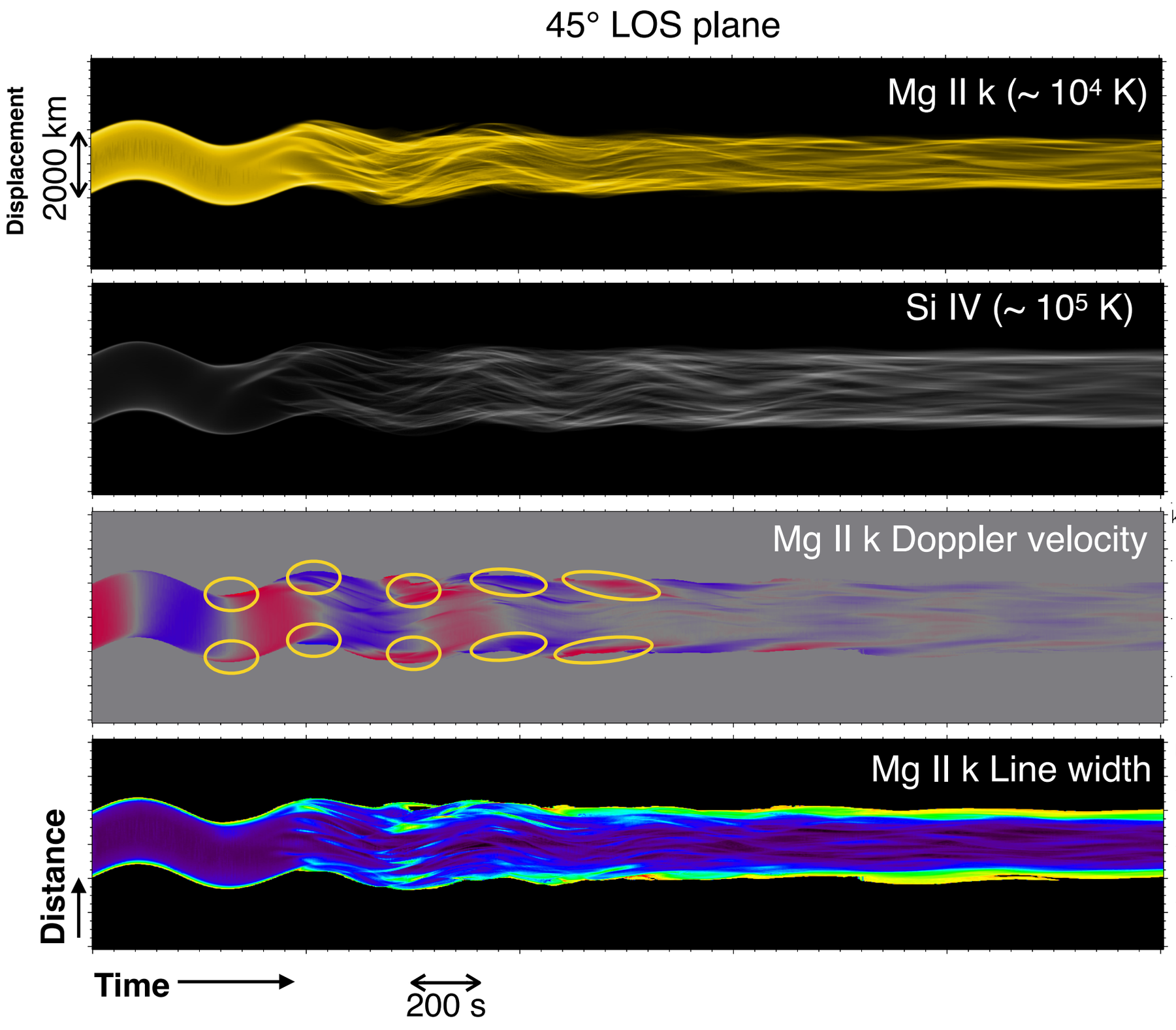
Observational results

Motion of prominence plasma crossing the slit



Observational signatures





fading & thinning in chromospheric lines

appears in TR lines, broadened

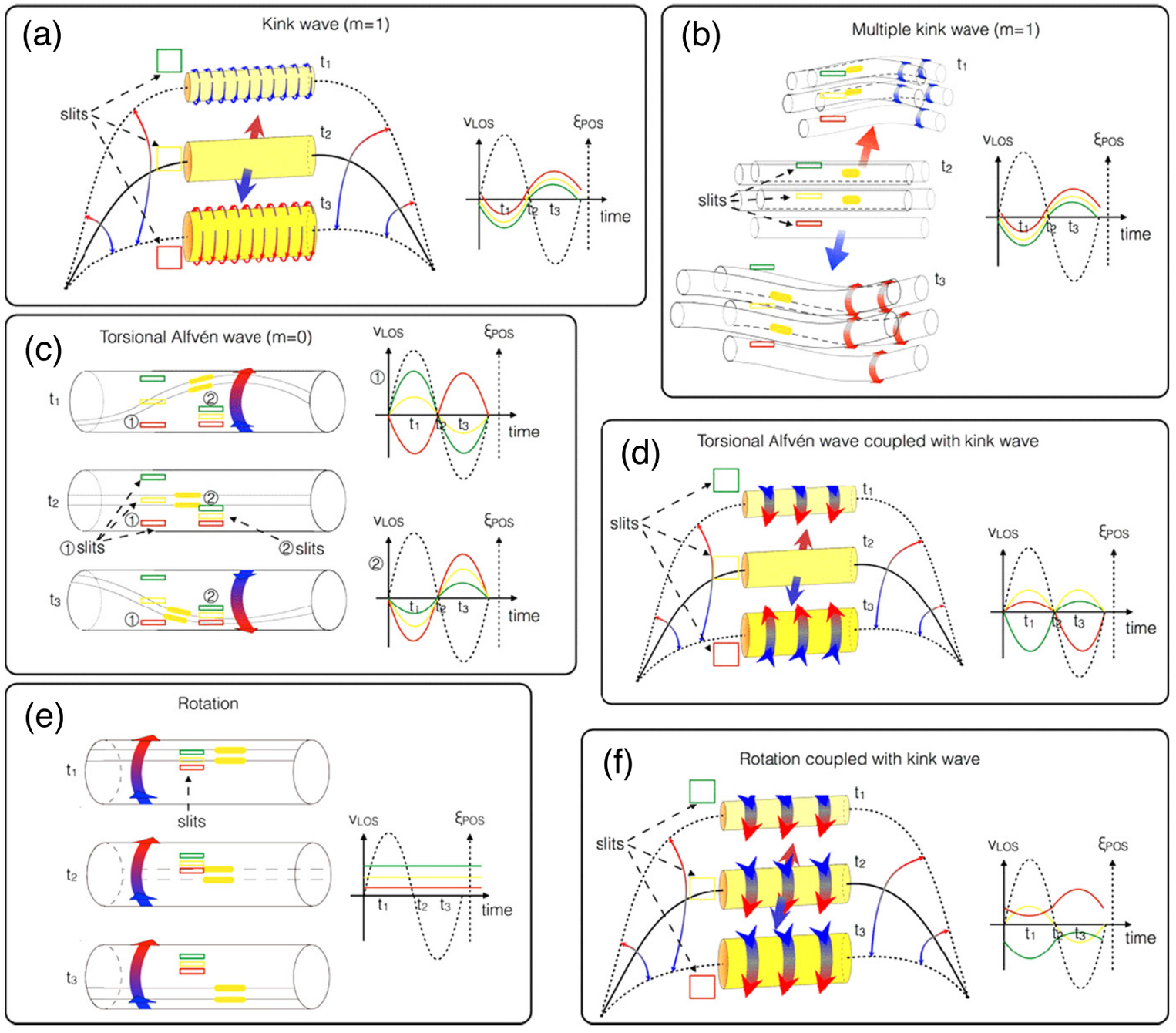
➜ mixing & heating

LOS velocity out-of-phase with POS motion

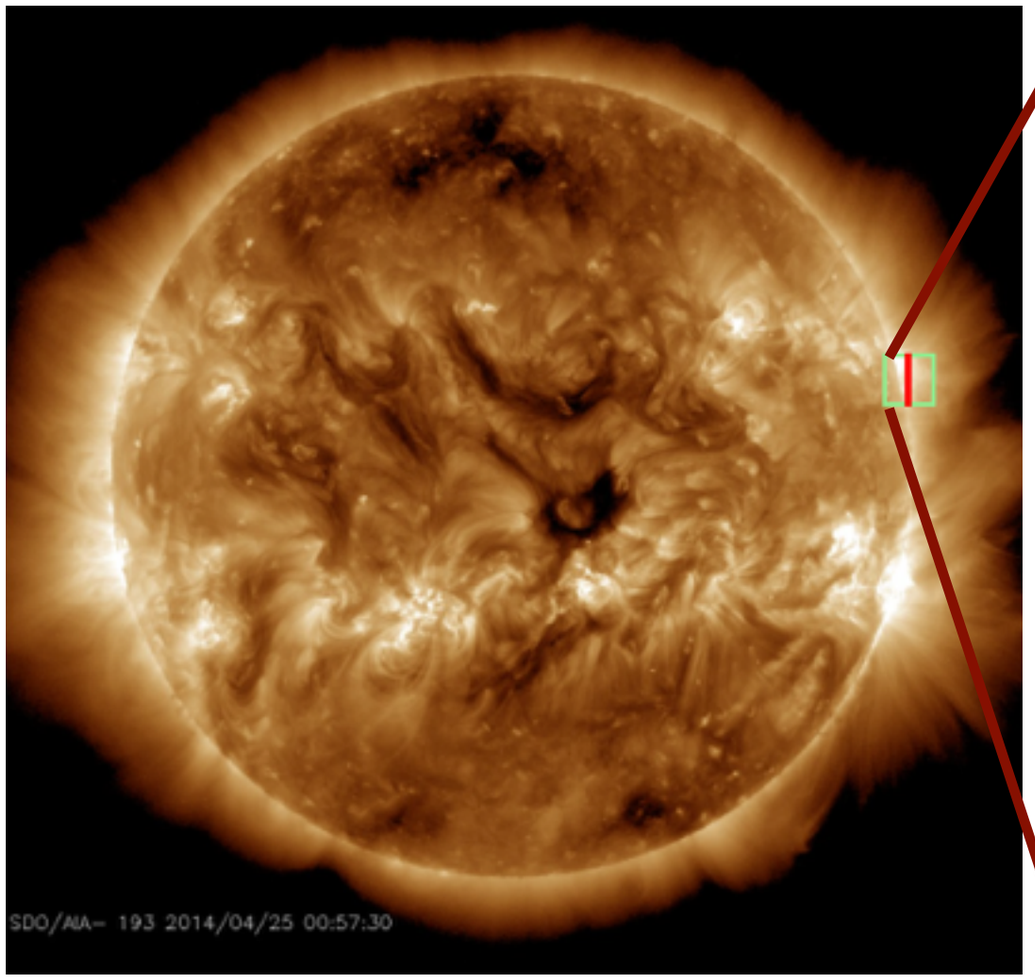
➜ RA+phase mixing

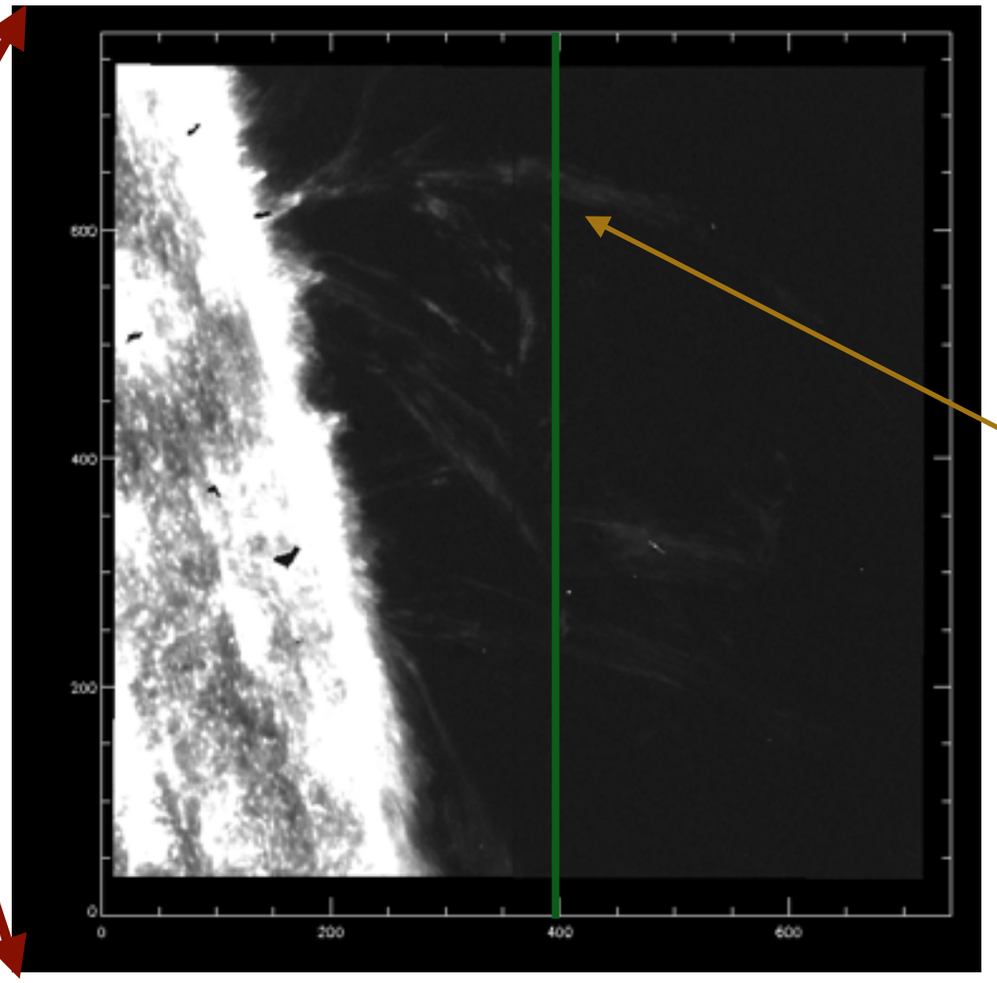
Line broadening at edges

Other considered interpretations



Observations





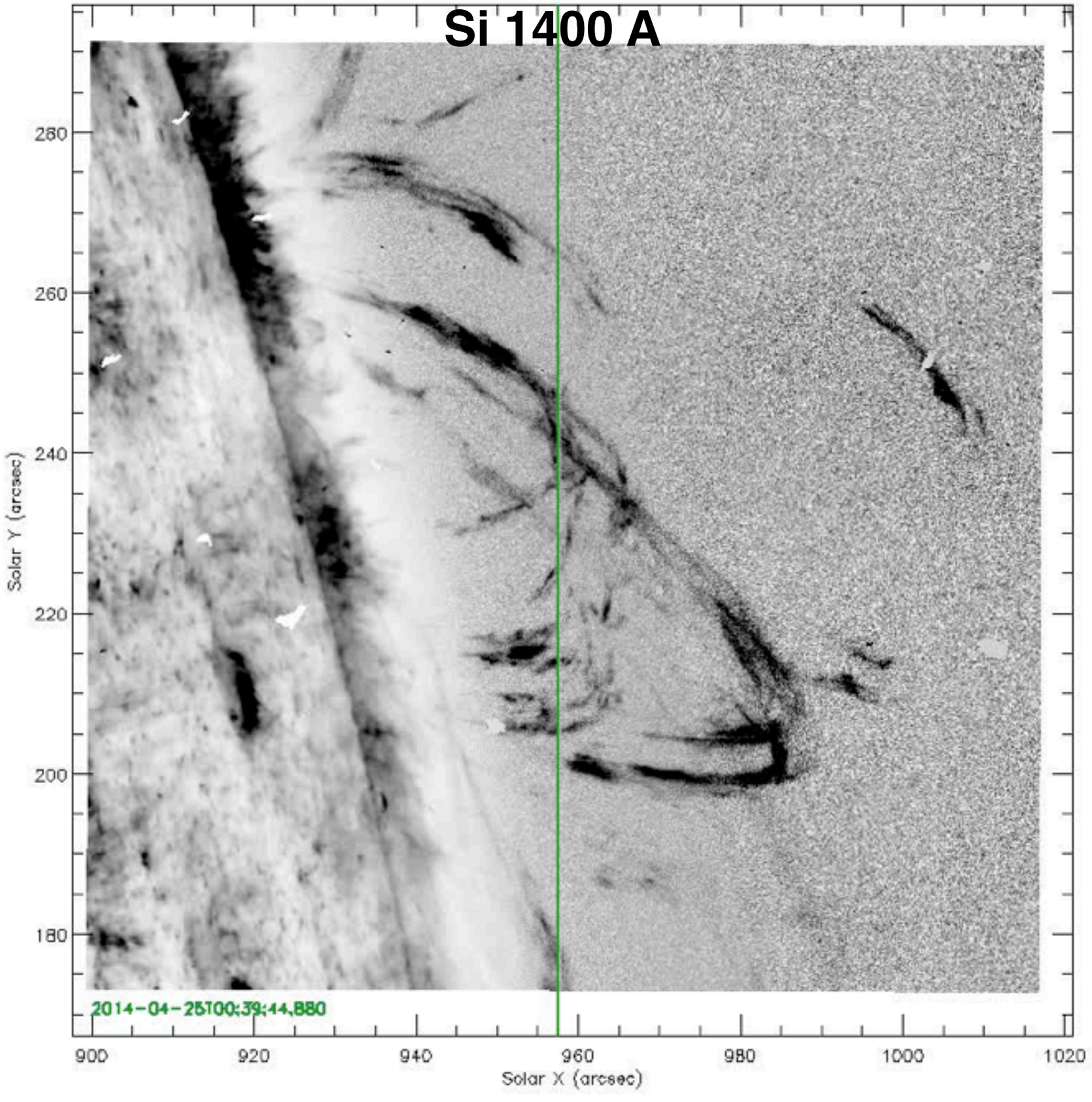
IRIS Sg slit

AIA 193 A

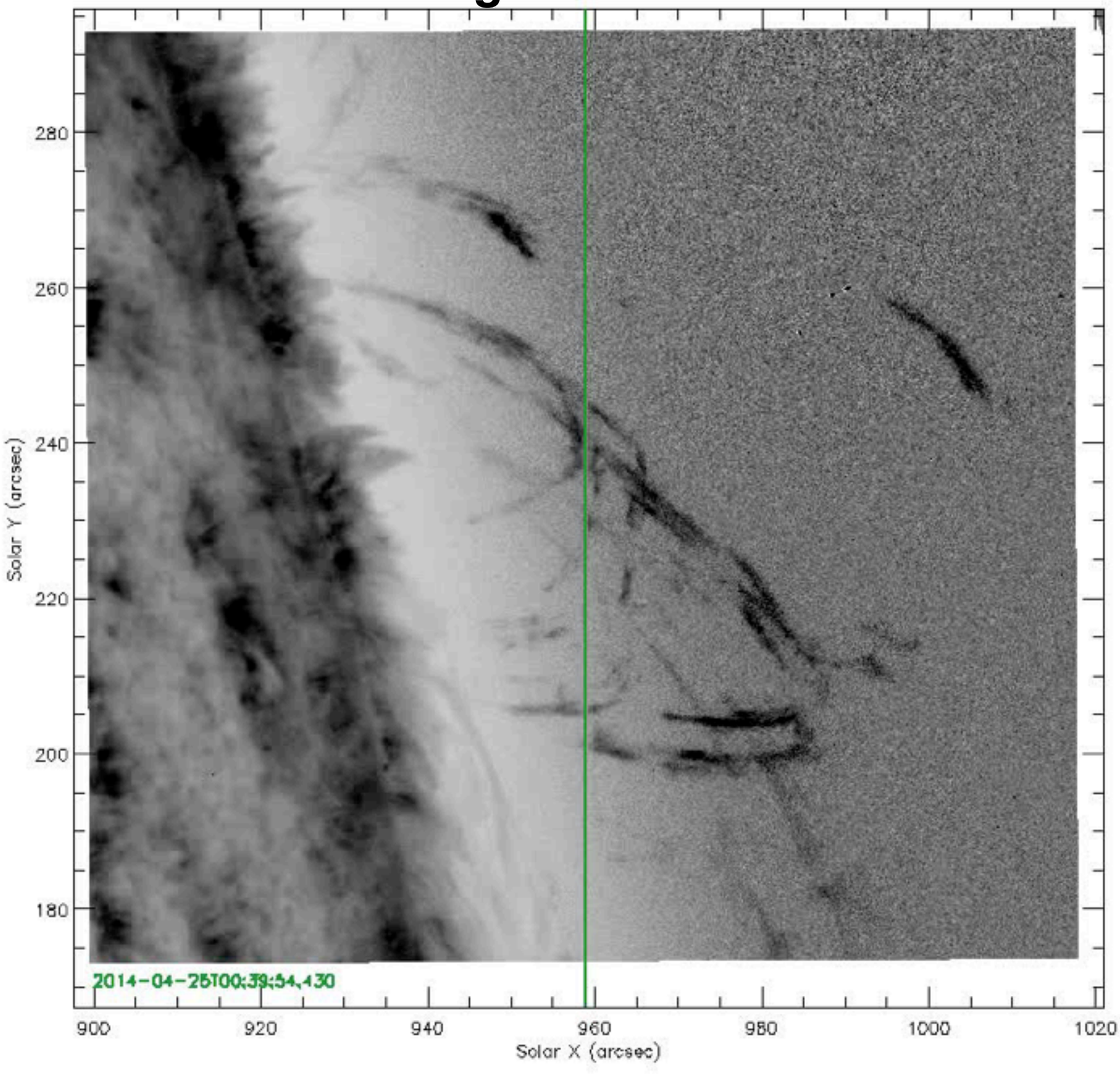
IRIS 1400 A

- High spatial (0.166”/pixel) resolution
- 4 step raster with step cadence ~ 9 sec.
- SJI 1400 A cadence -> 18 sec
- Sg slit 1 and 3 are seen in consecutive IRIS 1400 A SJI
- Sg slit 2 and 4 are seen in consecutive IRIS 2796 A SJI

Transverse Oscillations

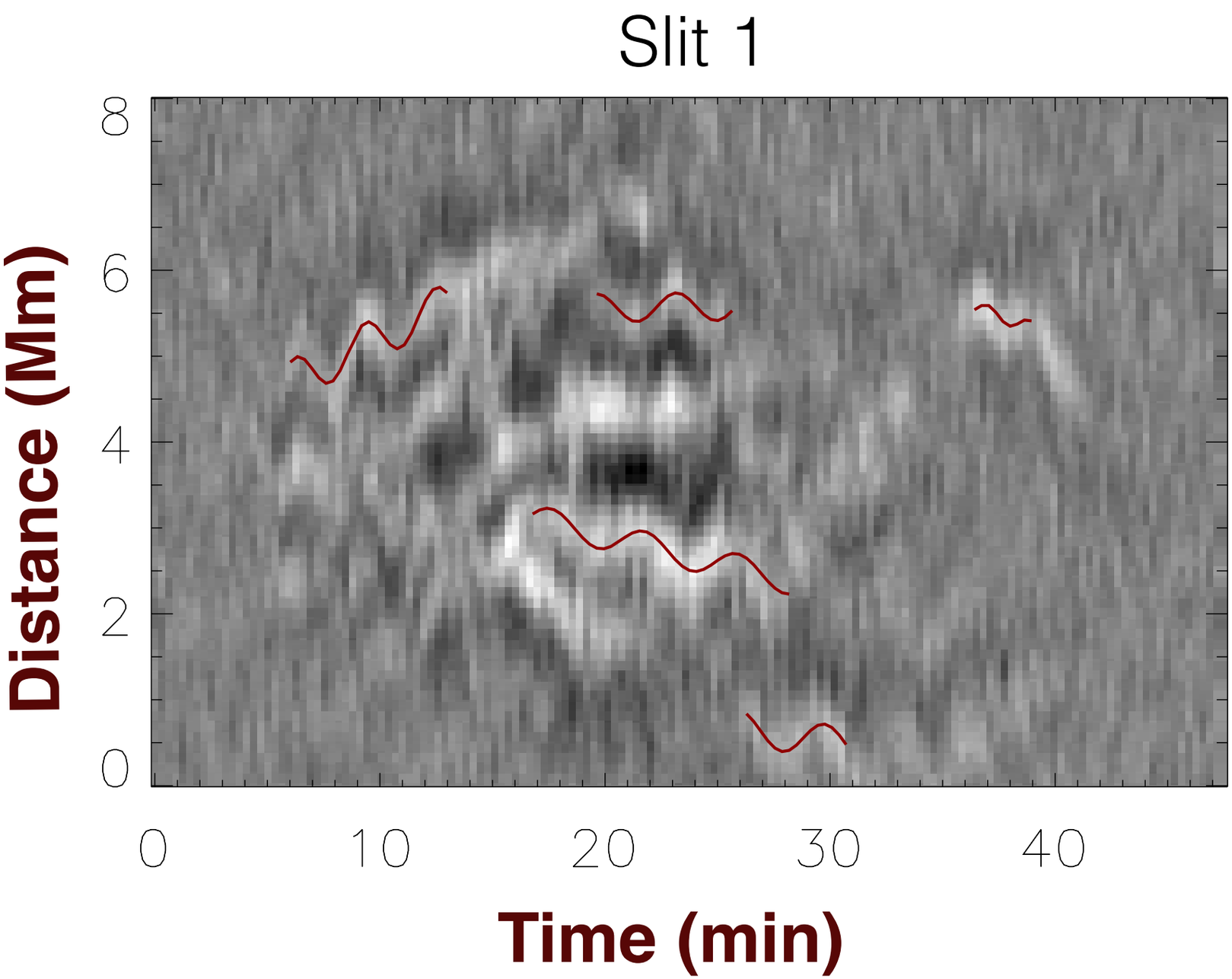


- Radial gradient filter is applied
- Several transverse oscillations are seen
- Nine different artificial slices are placed

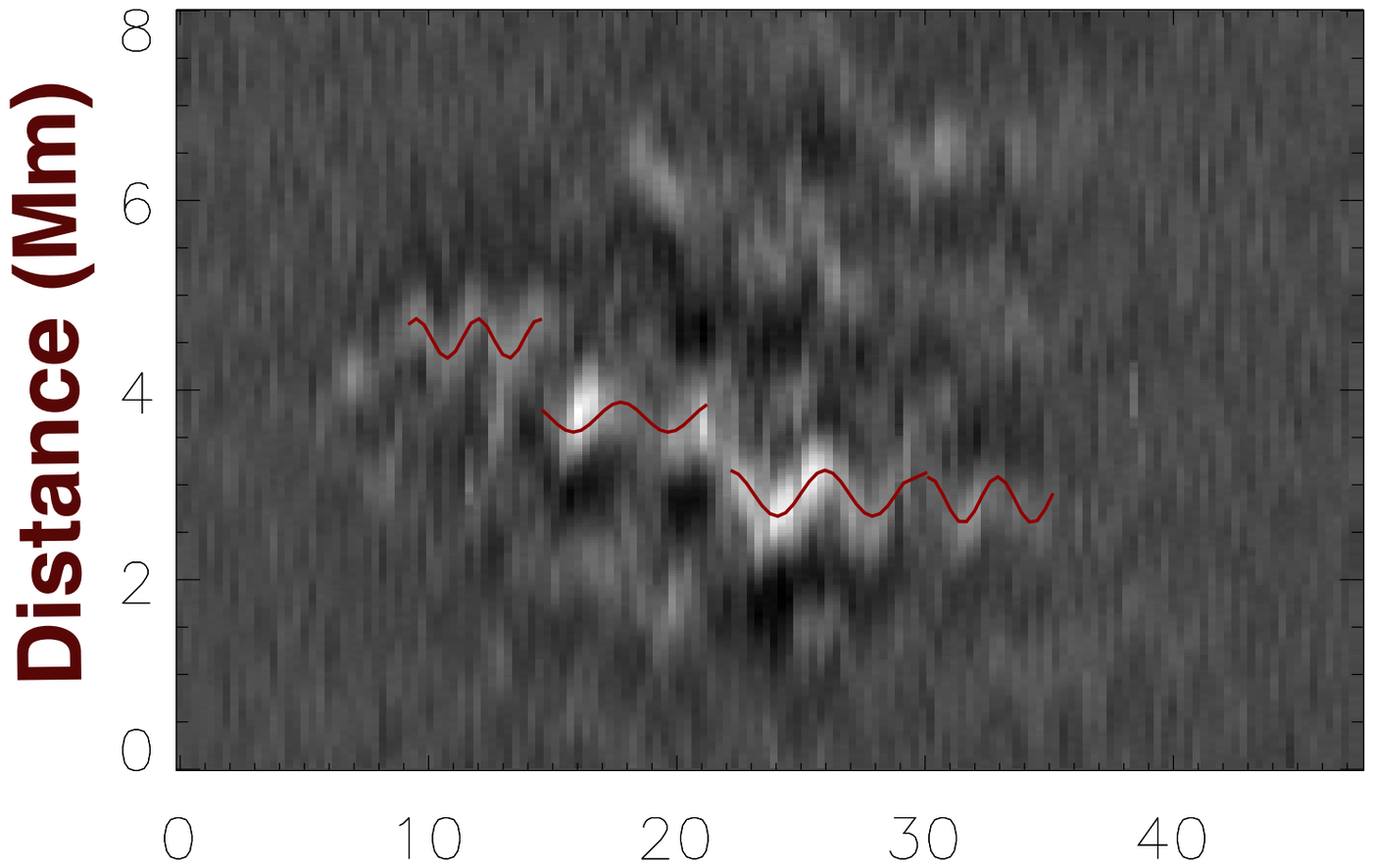


- Radial gradient filter is applied
- Several transverse oscillations are seen
- Slit 8 is placed which is co-spatial with 1400 A SJI

Time distance maps



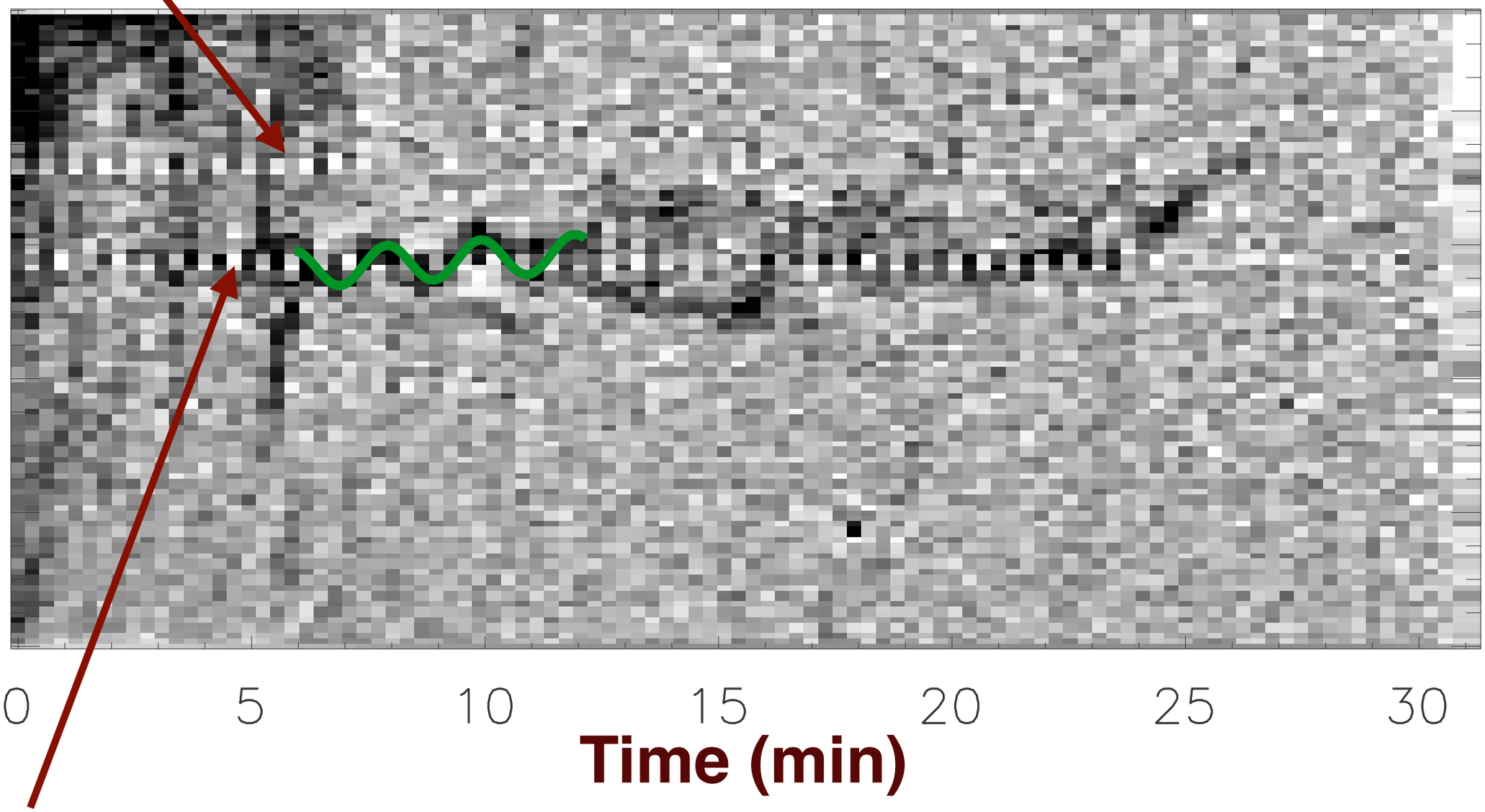
Sinusoidal fitting is performed using the algorithm as described in Morton et al (2012)



Blobs move along the coronal loop -> Intensity enhancement not seen all the time at a fixed position

Spectrograph slit position 1

Slit 8 (Si 1400 A)

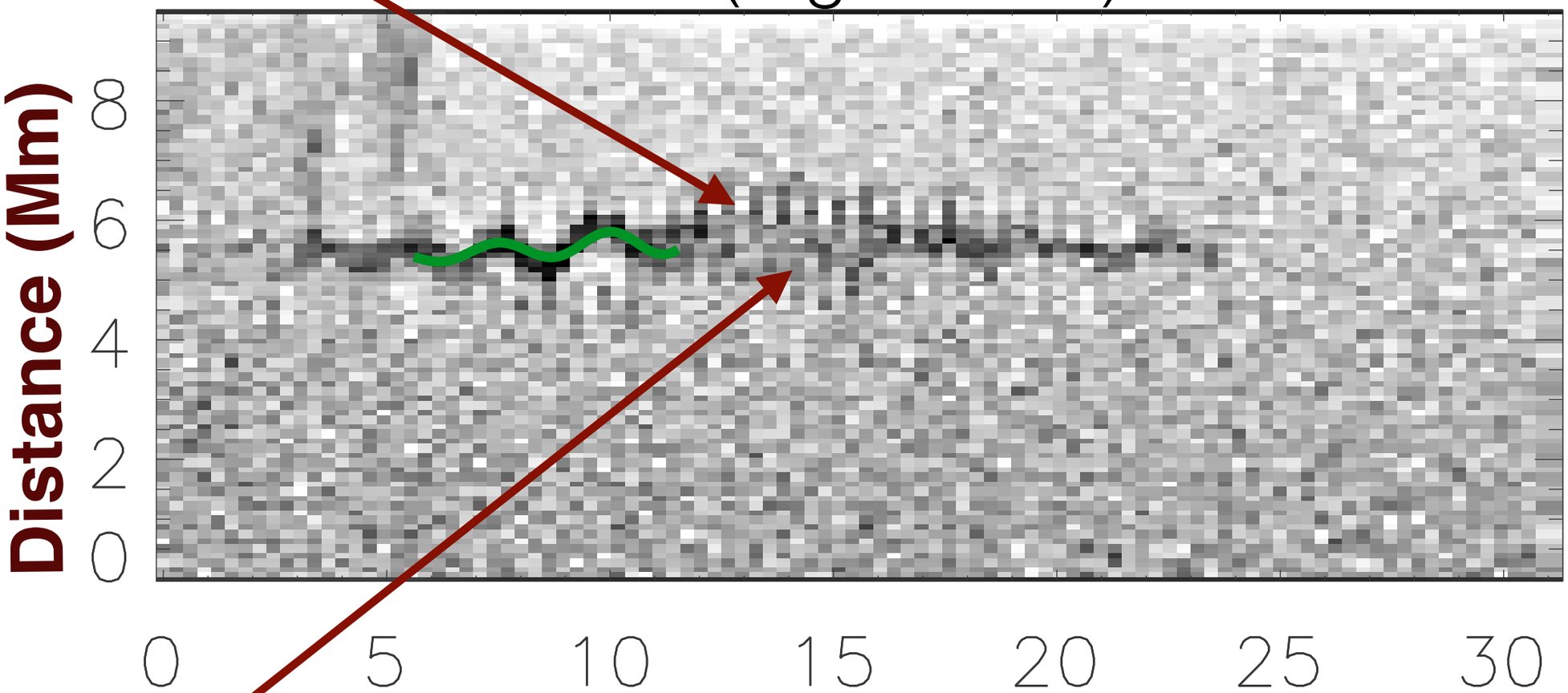


Spectrograph slit position 3

Loop is passing through the Sg slit 3 while oscillating

Spectrograph slit
position 2

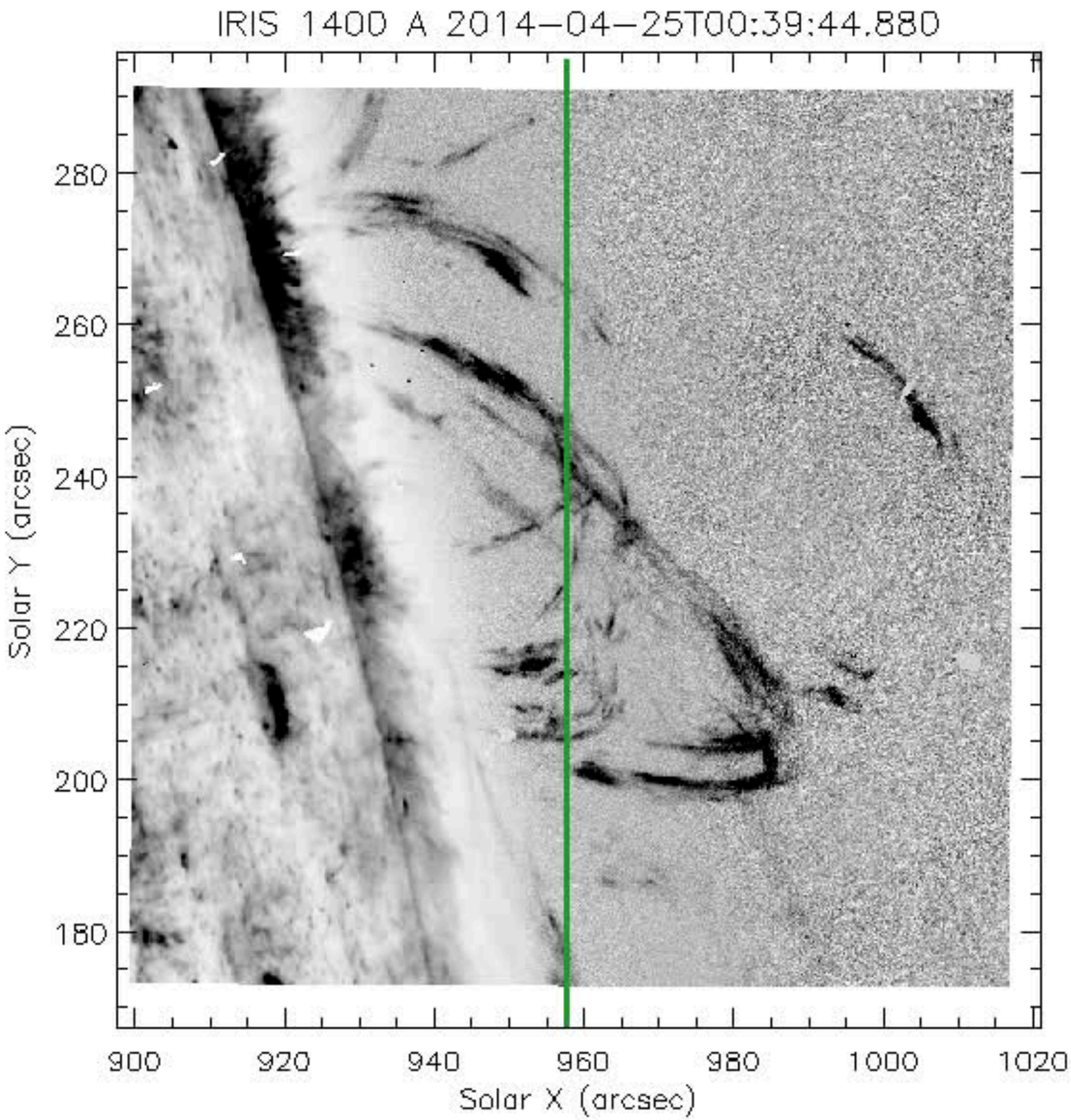
Slit 8 (Mg 2796 A)

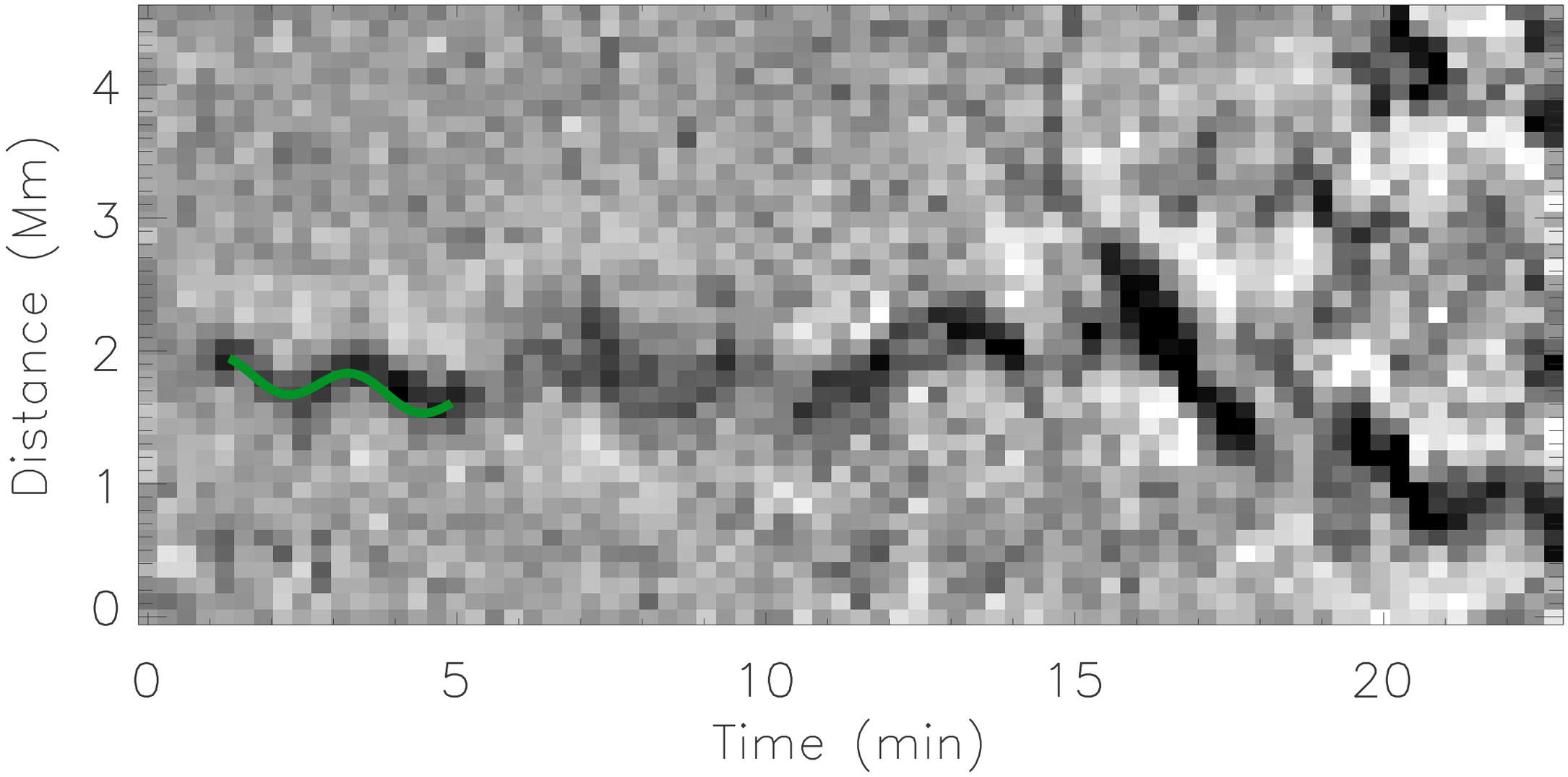


Spectrograph slit
position 4

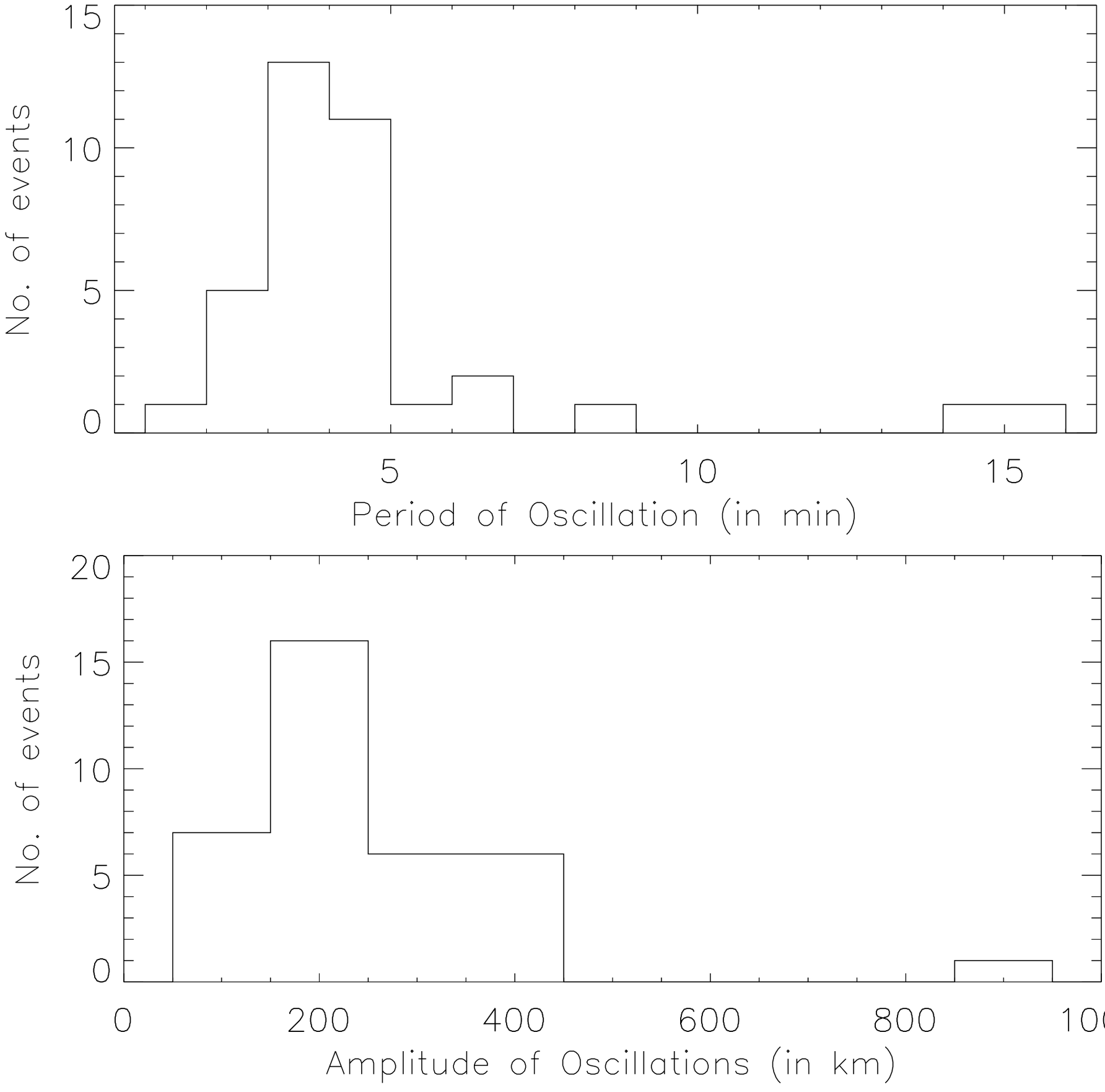
Loop is passing through the Sg slit 3 and
Sg slits 2 and 4 surround the loop

Slits co-moving with blobs

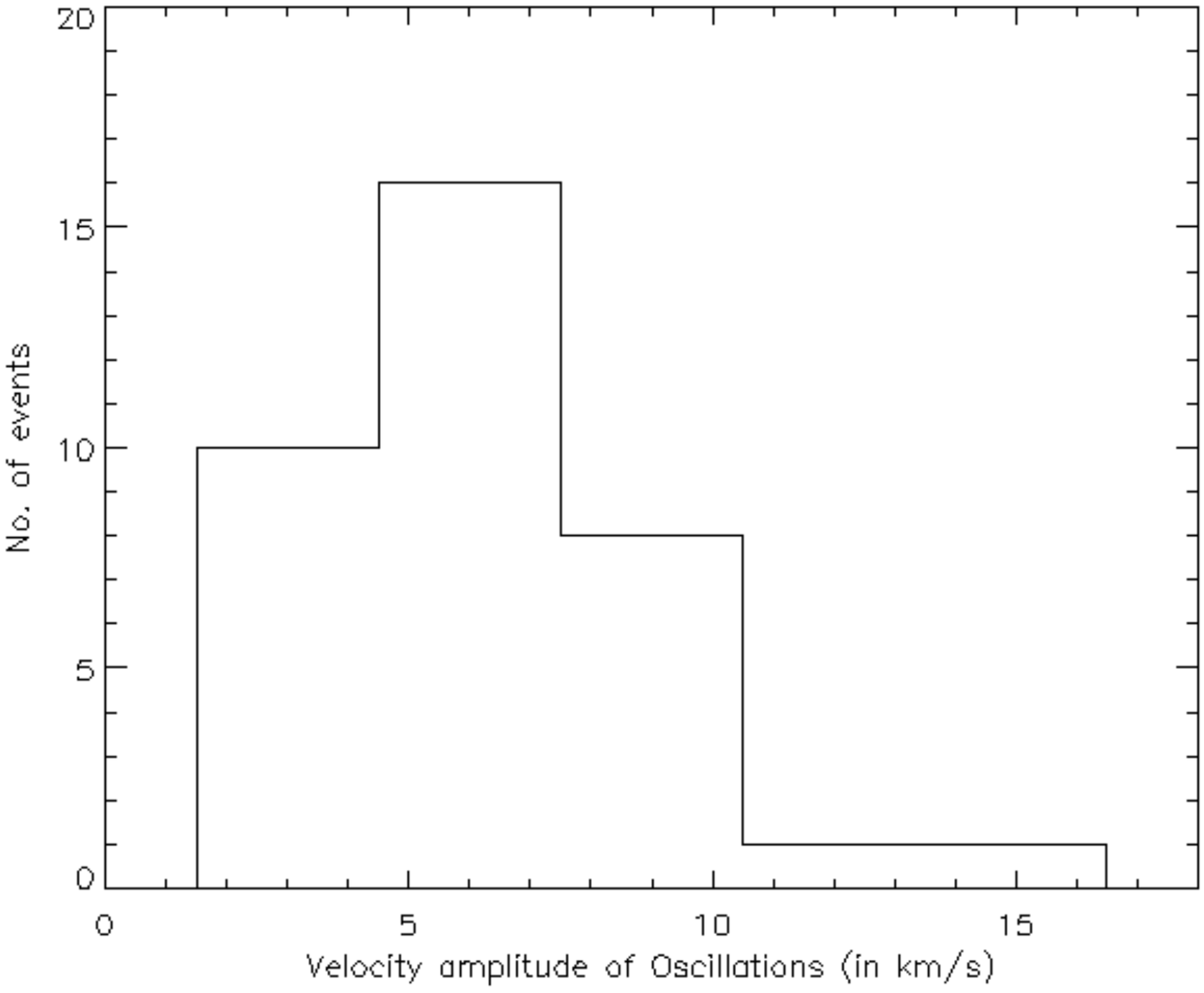




- Blobs accrete material while moving.
- Expand, stretch and breaks into several small blobs
- Difficult to follow a single blob -> extremely subjective


No. of events
15
10
5
0
5
10
15
Period of Oscillation (in min)
No. of events
20
15
10
5
0
0
200
400
600
800
1000
Amplitude of Oscillations (in km)

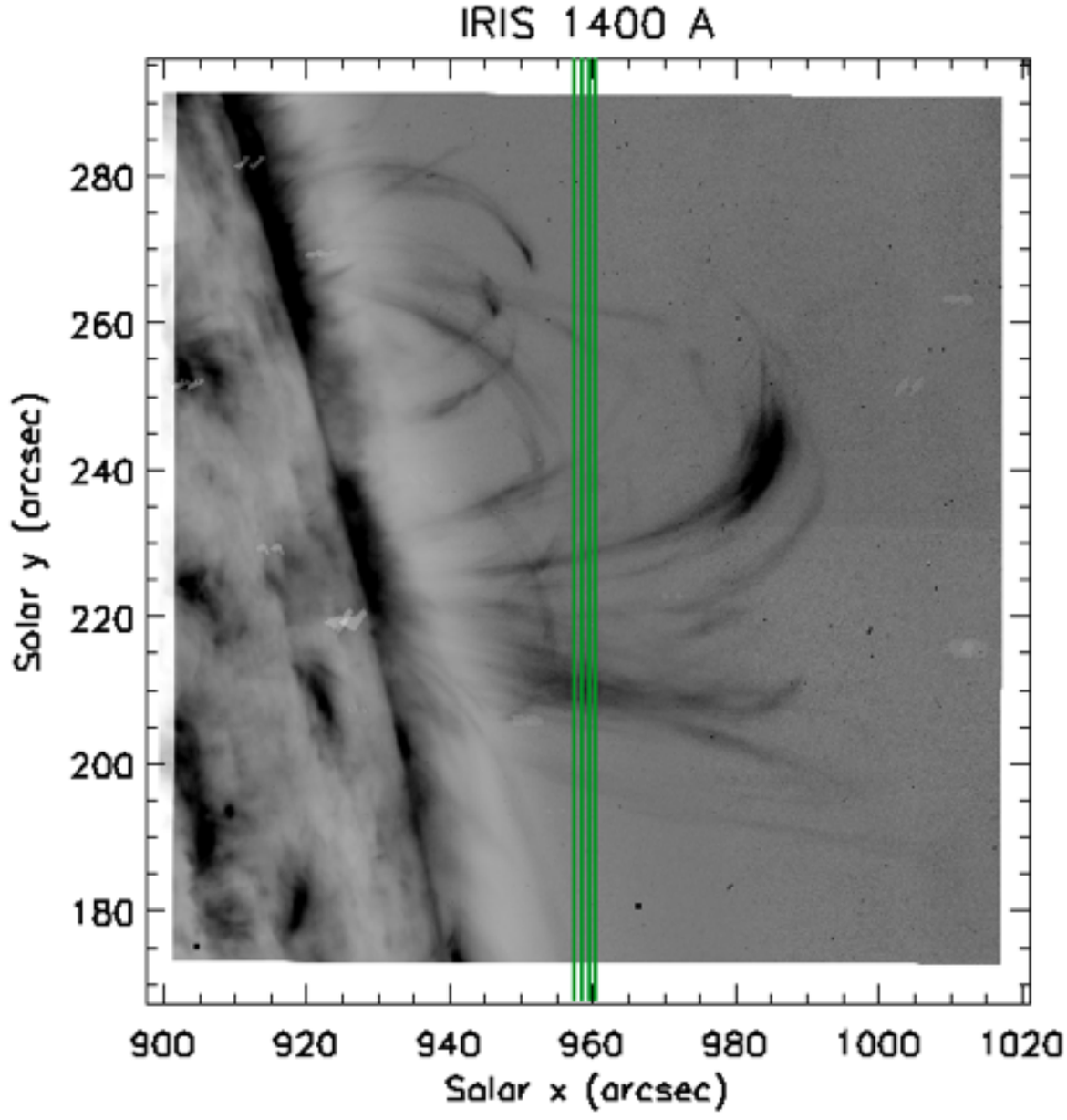
Velocity amplitude



Spectroscopic Analysis

- 4 step sparse raster was taken
- Step cadence -> 9 sec and step distance -> 1”
- Analogous -> 4 sit and stare with cadence of 36 sec

- Si IV 1394 A, 1402 A and Mg II K line spectra are present
- Used Si IV 1394 A and Mg II K with single Gaussian fitting
- Absolute wavelength calibration is not performed
- Mg II k 2796 A and Si IV 1394 A datasets are aligned choosing small coronal rain blobs which are seen in both wavelengths
- No offset is noted in the datasets of both wavelengths



si 1394 A Intensity

Line of sight velocity

line width

Solar x (arcsec)

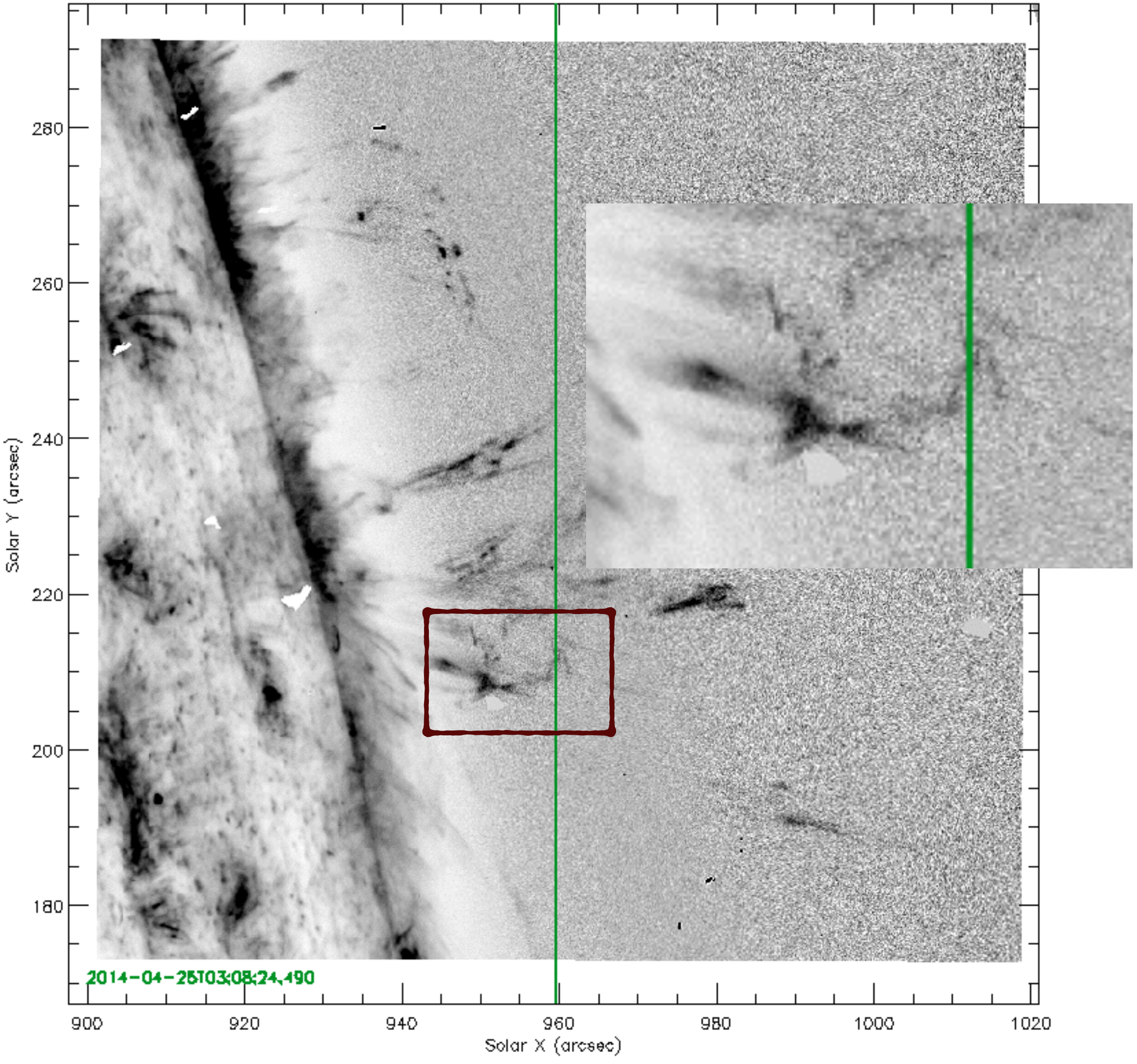
280
260
240
220
200
180

15
12
10
7
5
2
0

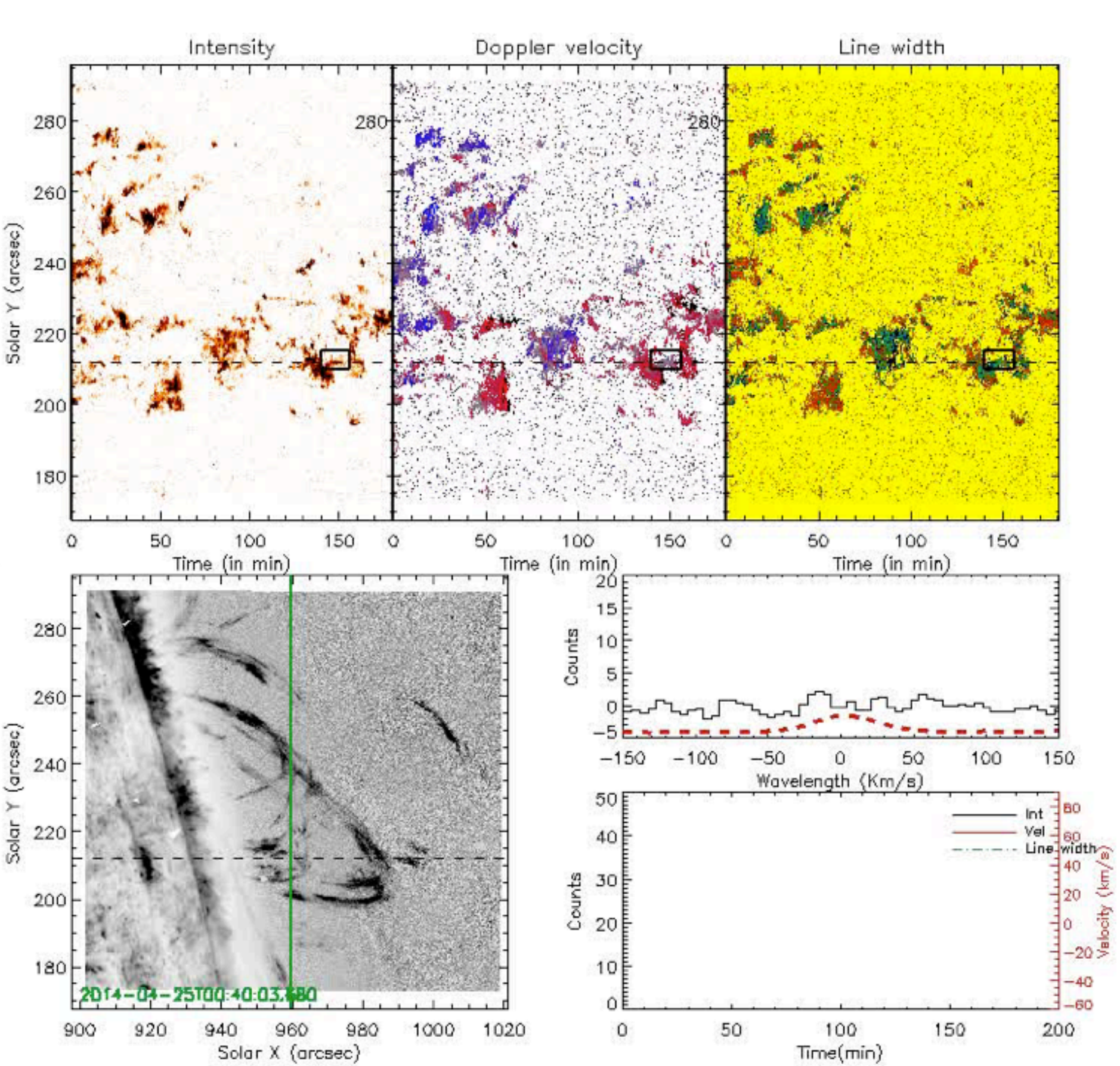
40
26
13
0
−13
−26
−40
km/s

75
62
50
37
25
12
0
km/s

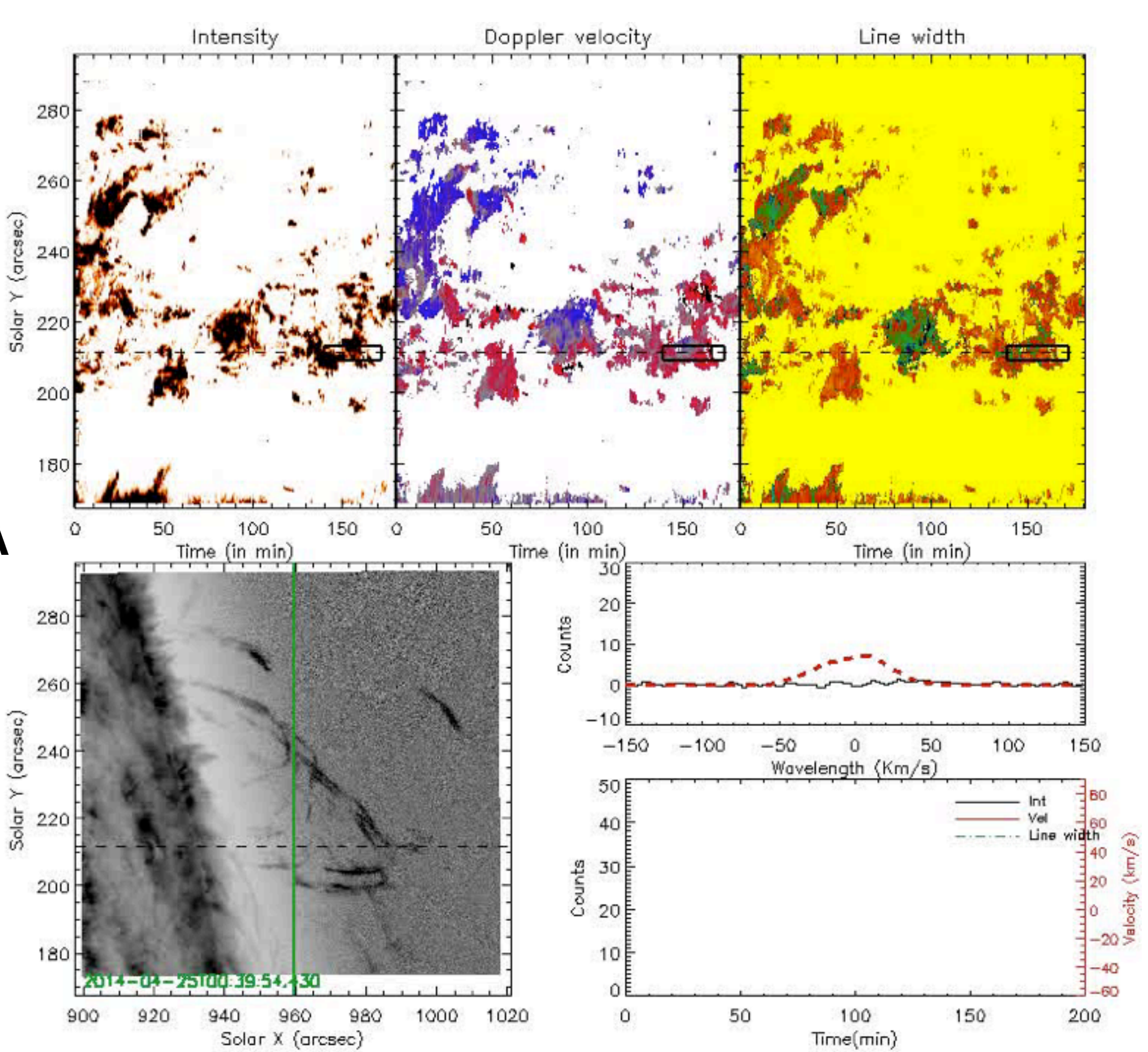
0
50
100
150
Time (min)


280
260
240
220
200
180
Solar Y (arcsec)
2014-04-25T03:08:24.490
900
920
940
960
980
1000
1020
Solar X (arcsec)

Si 1394 A

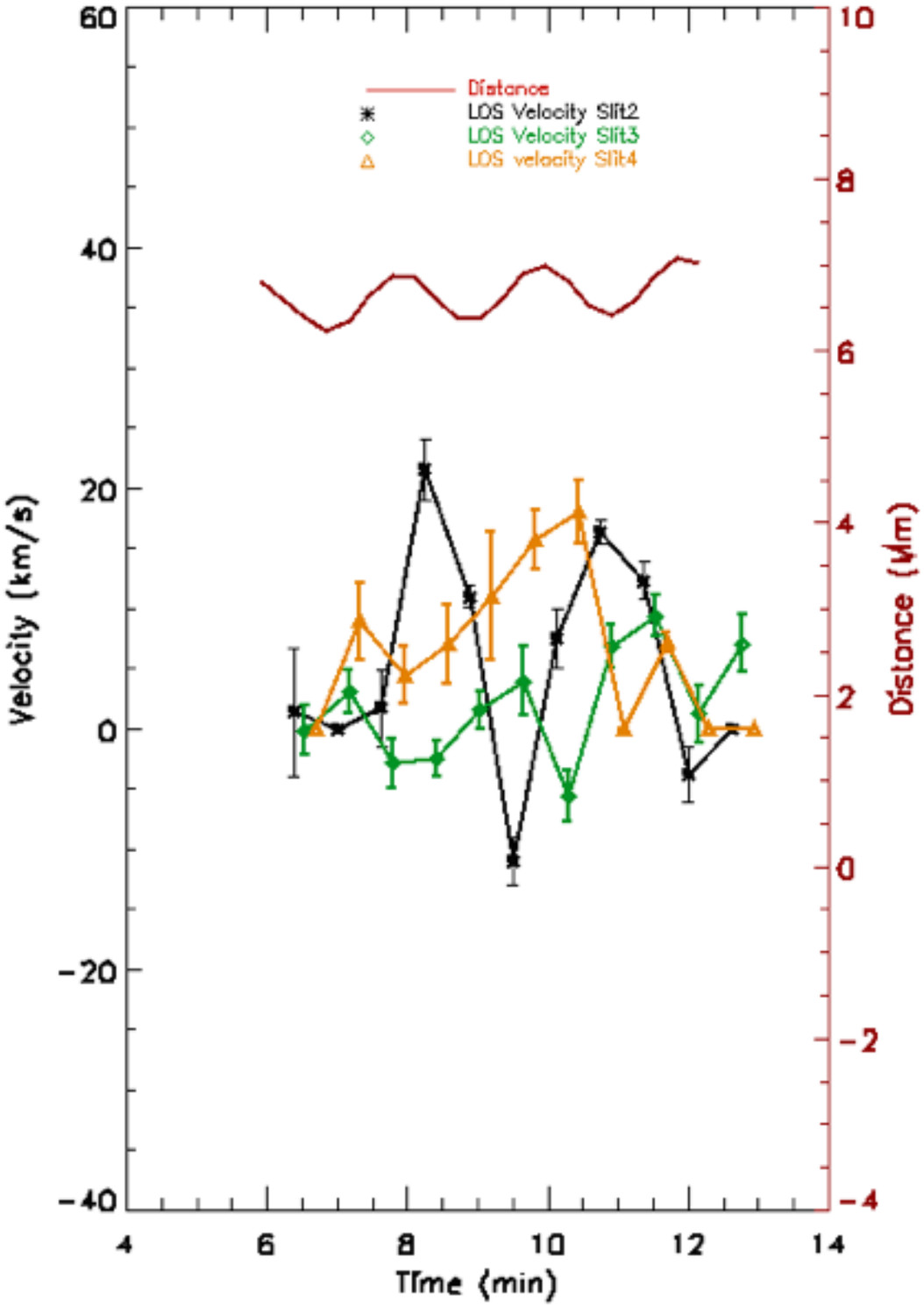

Intensity
Doppler velocity
Line width
Solar Y (arcsec)
Time (in min)
Solar X (arcsec)
2014-04-25T00:40:03.680
Counts
Wavelength (Km/s)
Int
Vel
Line width
Velocity (km/s)
Time(min)

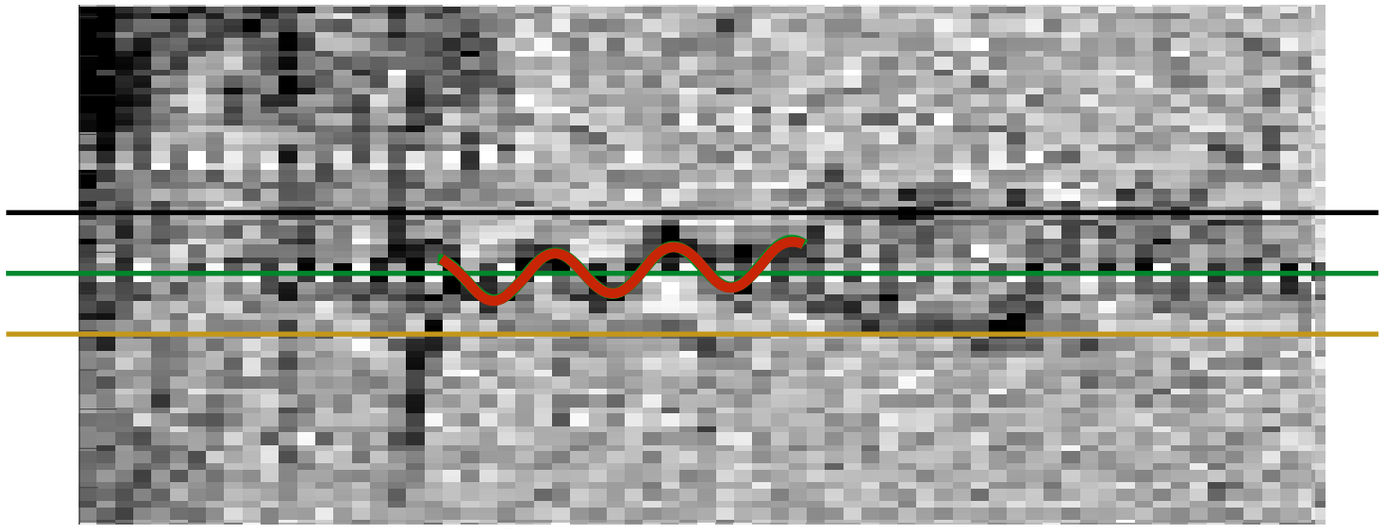
Mg 2796 A


Intensity
Doppler velocity
Line width
Solar Y (arcsec)
Time (in min)
Solar X (arcsec)
Counts
Wavelength (Km/s)
Int
Vel
Line width
Velocity (km/s)
Time(min)

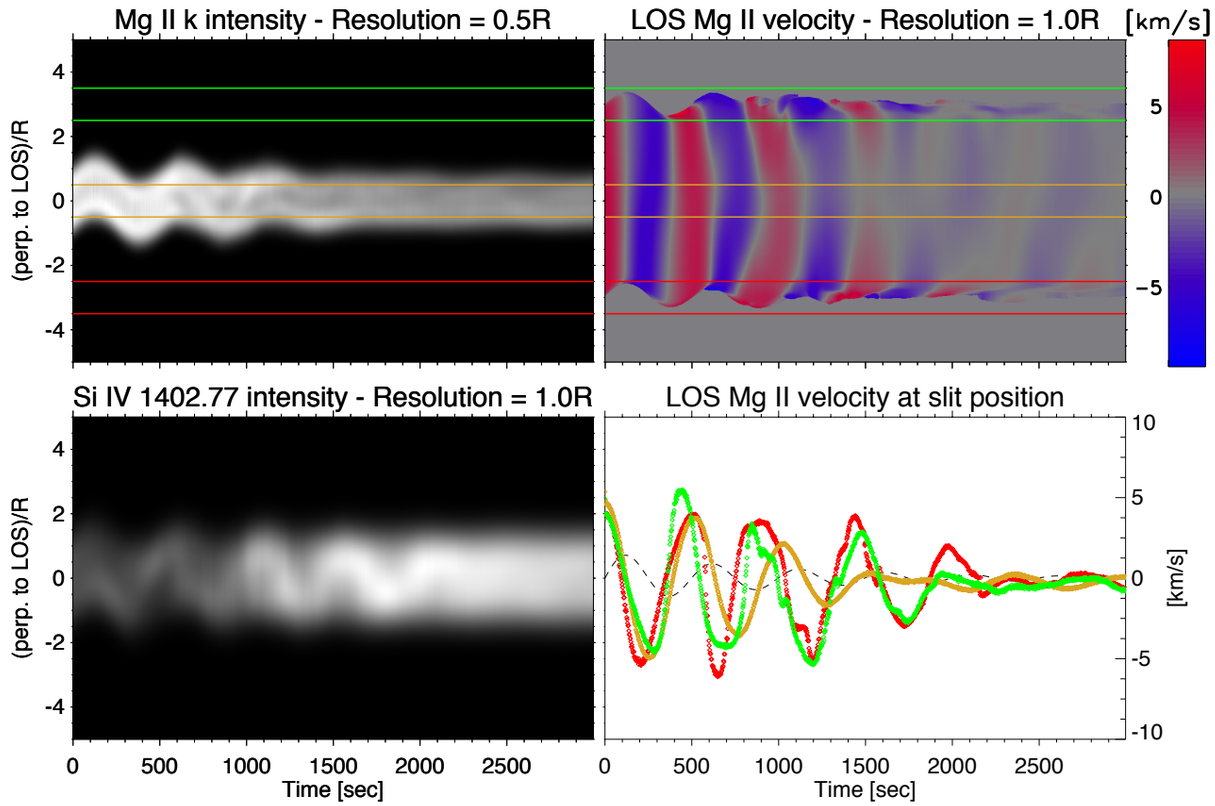
Velocity amplitudes at slit 8 position

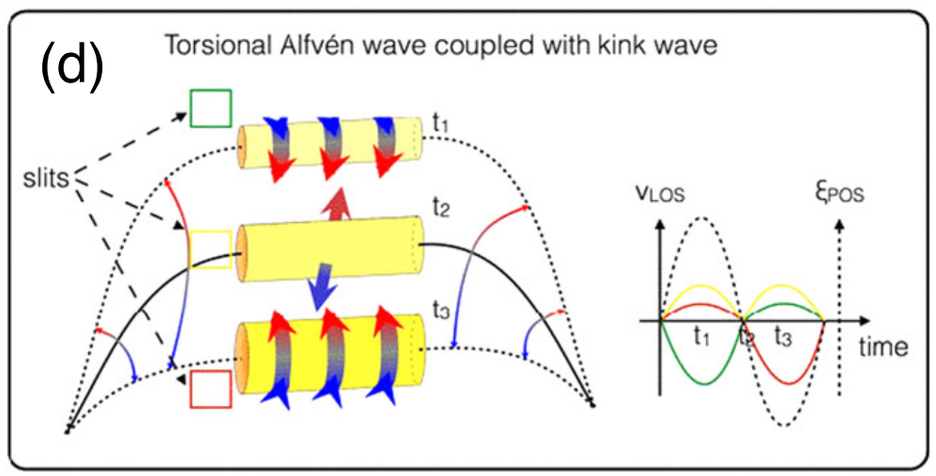
Si 1394 A





45° Line-of-sight plane

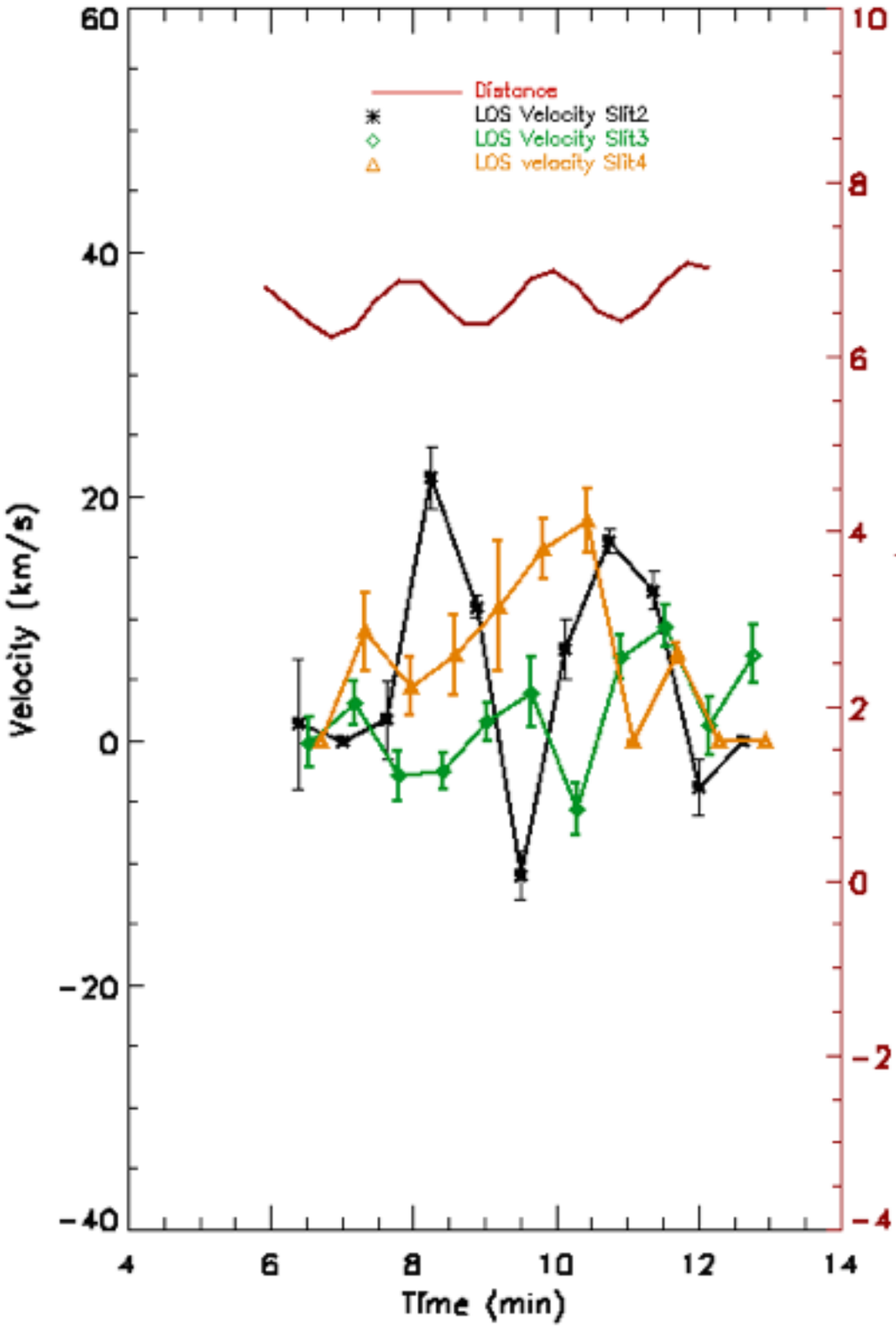




Okamoto & Antolin, 2015

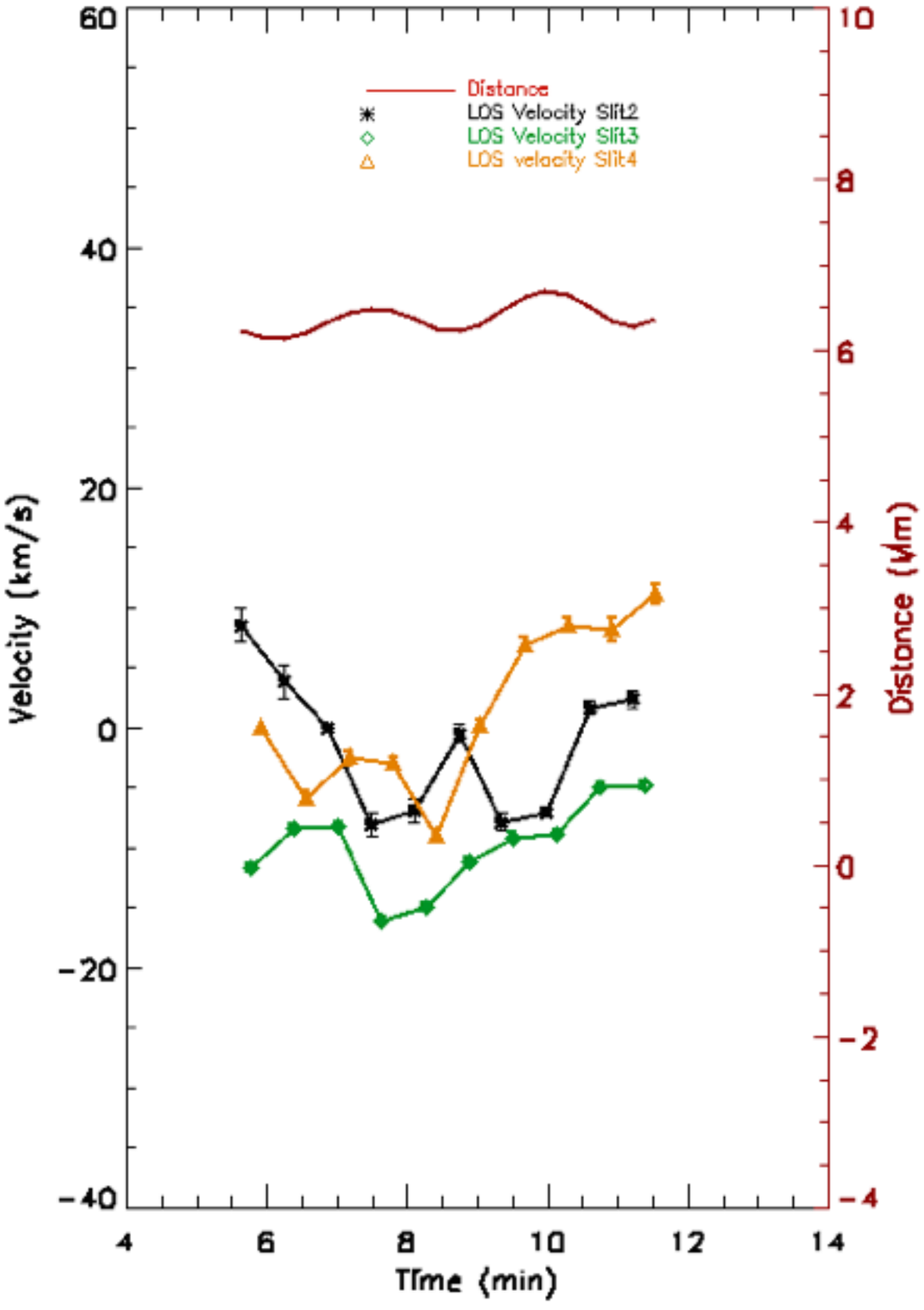
Velocity amplitudes at slit 8 position

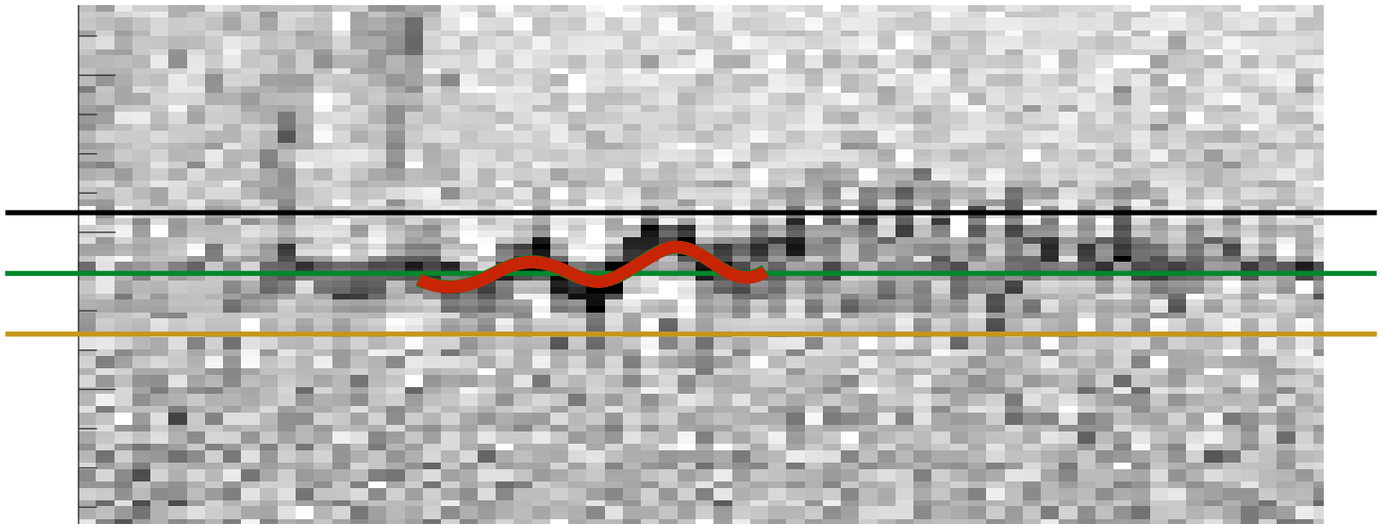
Si 1394 A



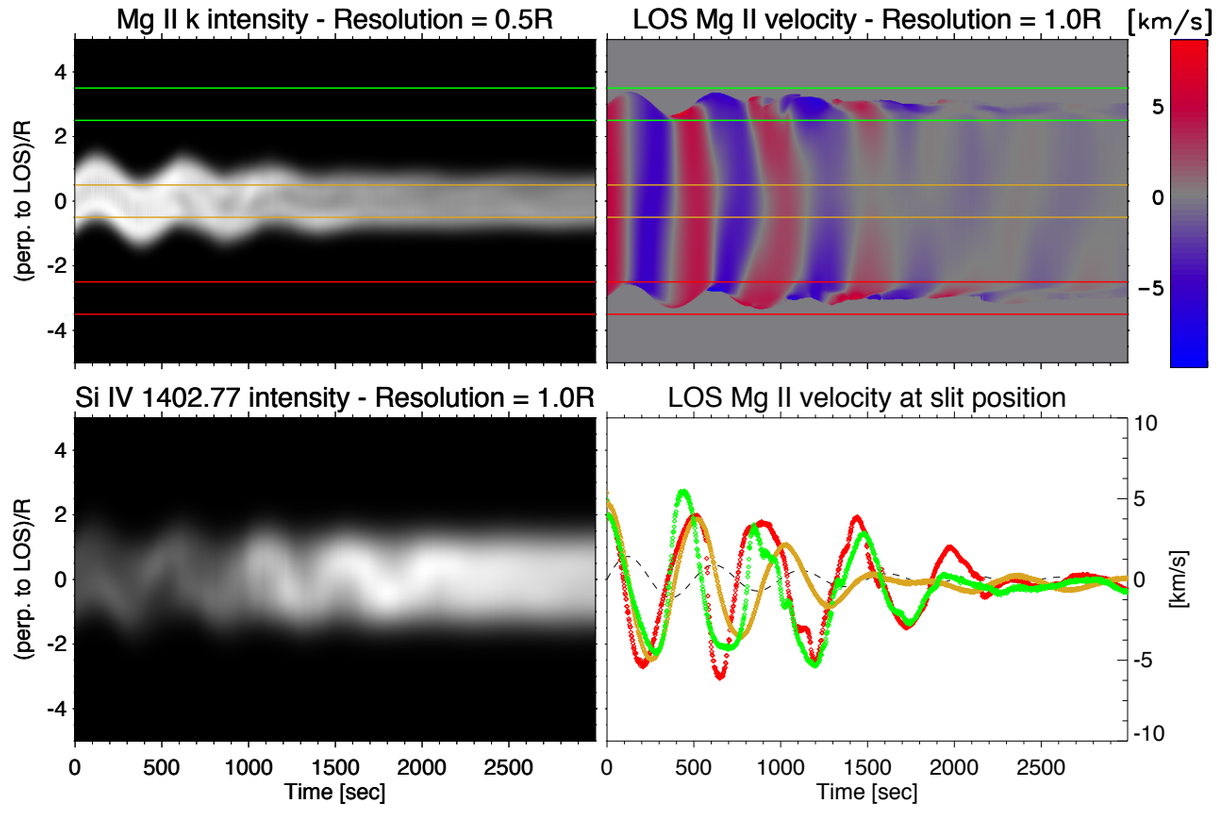
- Slit 3 passes through the loop
- Slit 2 and slit 4 surround the loop
- Slit 3 and slit 4 are almost in phase
- While slit 2 and slit 3(and 4) are almost out of phase
- The phase difference between LOS velocity as estimated from slit 2 (and 3) and POS displacement is ~ 90 -180 degrees
- Phase difference from slit 4 is hard to measure
- Could be a signature of resonance absorption as Reported in the threads of prominences by Okamoto & Antolin (2015)

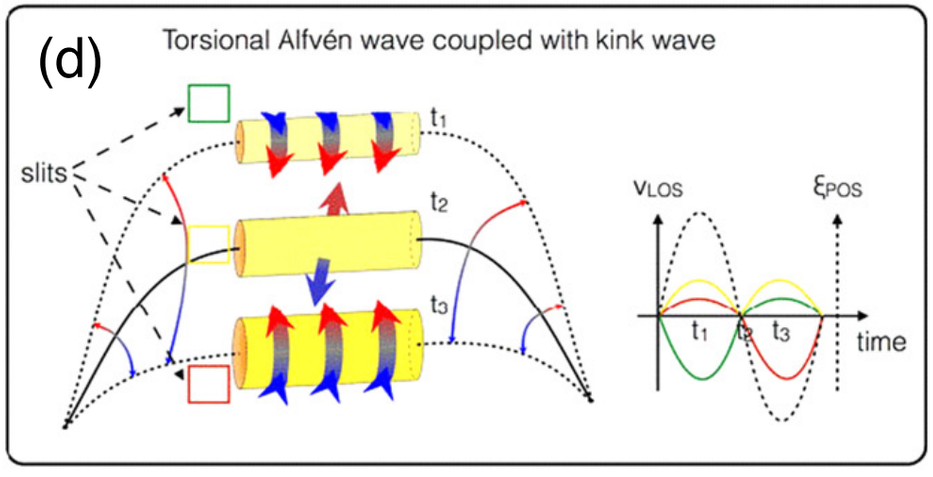
Mg 2796 A





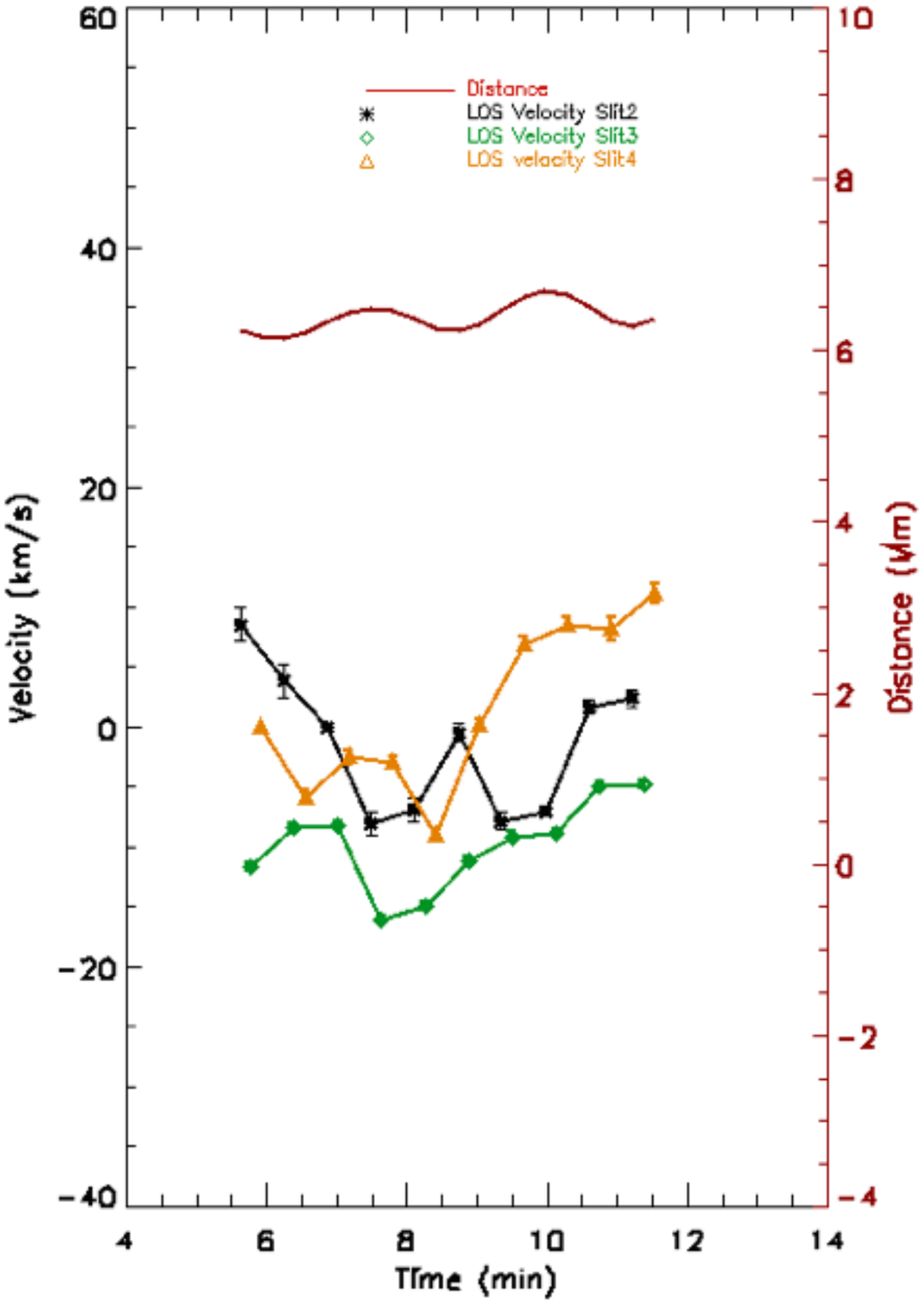
45° Line-of-sight plane



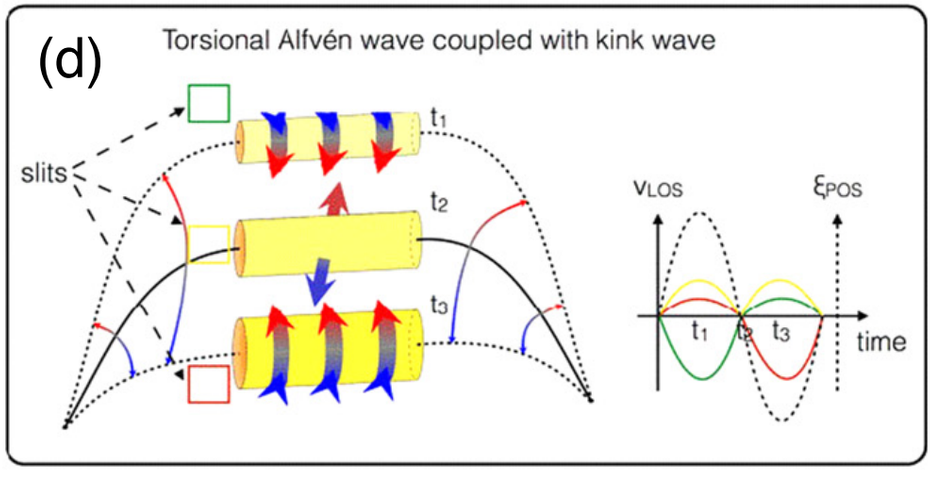


Okamoto & Antolin, 2015

Mg 2796 A



- Growing amplitude of POS displacement is seen
- Phase difference of ~180 degree between slit 2 and POS displacement
- In slit 3 and 4, the phase difference of ~180 degrees is noted for first cycle of oscillation.
- In second cycle where amplitude is growing, the phase difference vanishes
- slit 3 and slit 4 vary coherently while slit 2 is out of phase from slit 3 (and 4) at certain instances
- Combining the information from Si 1394 A and Mg 2796 A. This scenario can be explained to certain extent by the presence of torsional Alfven wave coupled with kink wave



Okamoto & Antolin, 2015

Future works

- Estimate density of coronal rains using Si IV and O IV line ratios
- Look for the signature of oscillations in different wavelengths of AIA/SDO

Thank You