Coronal Plasma Motions in Active Region Loops Observed with *Hinode* EIS

- a clue to understand coronal heating -

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2nd Hinode Science Meeting, Boulder, US

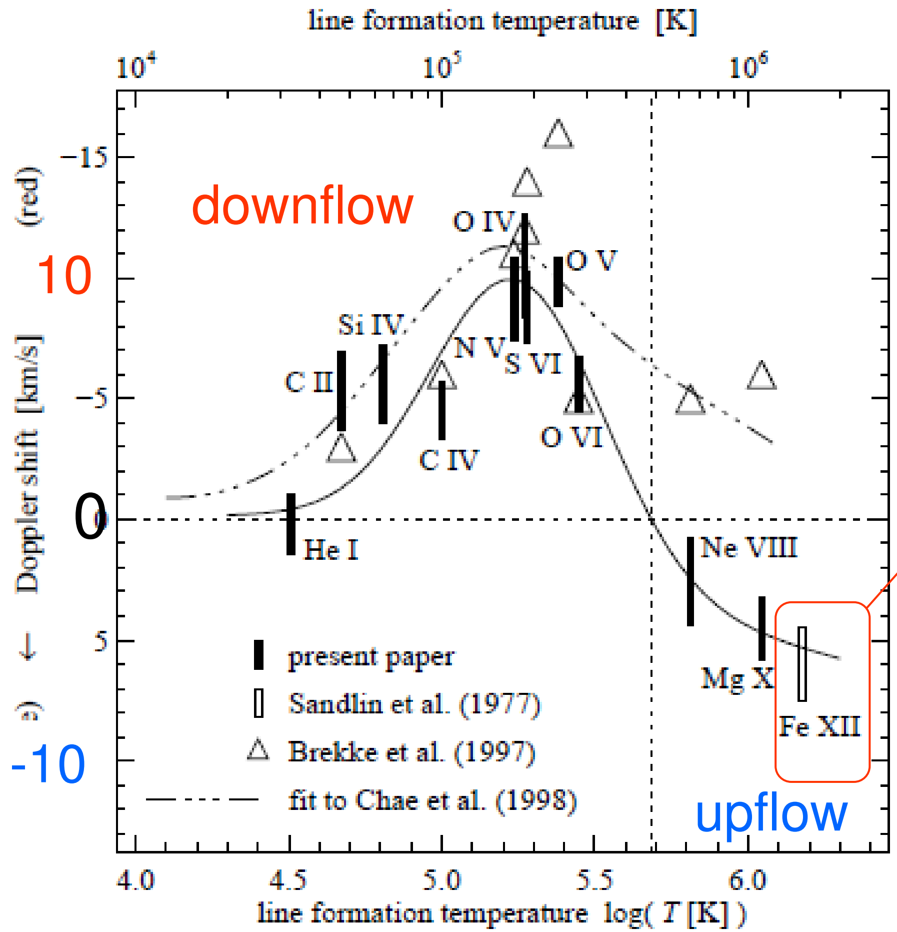
Coronal Heating Problem
- approach with *Hinode* EIS -

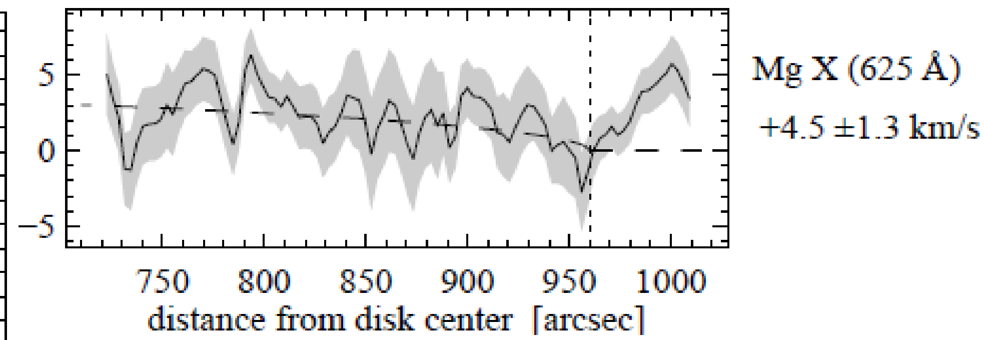
- Solar corona is heated to 10^6 K. How heated?
- ***Hinode* needs to answer:**
  DC type (**reconnection**) or AC type heating (**wave**), which predominates?
- An approach with *Hinode* EIS :
  - Investigation of upflows by Doppler velocity:
    Coronal upflows are expected when heated.
  - Investigation of a type of motion by line width:
    Search of hidden specific coronal motions
- These are investigated for an active region (AR).

Hara et al. 2008, ApJ, 678, L67

Doppler Motion in QS corona

- ~5 km/s upflows in the quiet-sun corona have been reported in SUMER observation.





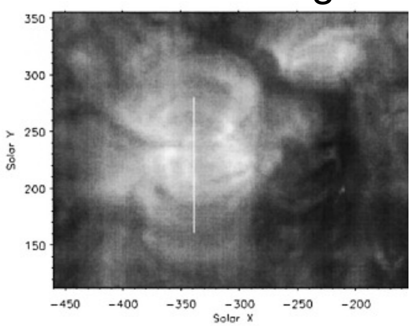
Skylab observation (Sandlin et al. 1977)

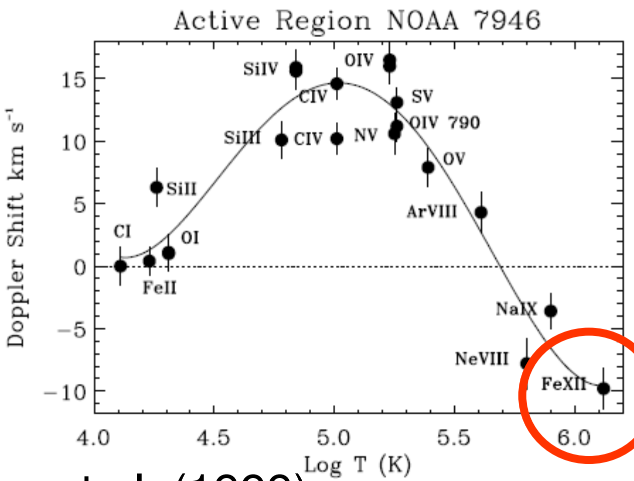
Peter and Judge (1999)

Doppler Motion in AR Corona

- 10 km/s upflows in the active region corona have been reported in a SUMER observation (Teriaca et al. 1999).
- 5-20 km/s projected upflow speed has been reported in a TRACE imaging observation (Winebarger et al. 2001).
- High-precision 2D Doppler measurements over AR in the corona with EIS are new.

SUMER Slit pos. on EIT image

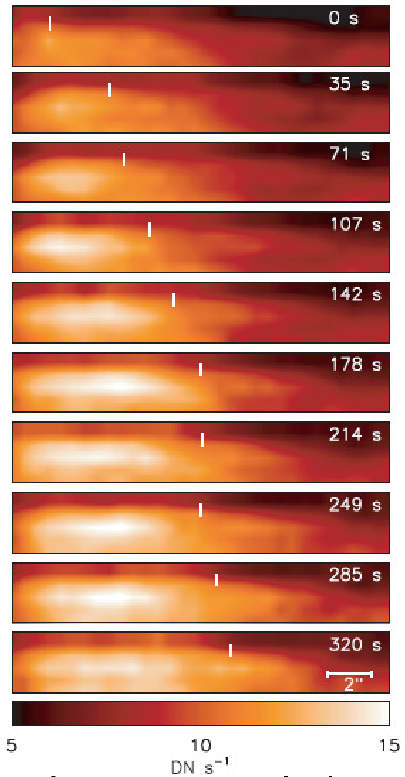




red

blue

Teriaca et al. (1999)



Winebarger et al. (2001)

Conclusions

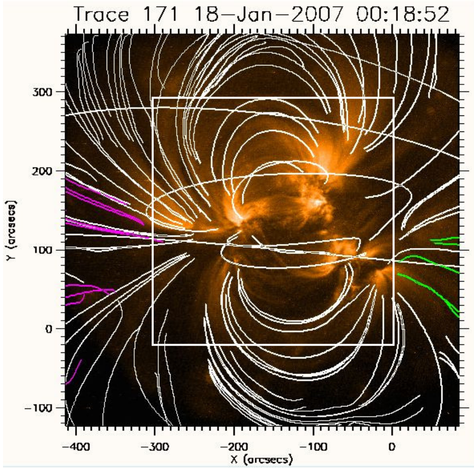
◆ We found from AR observations with Hinode EIS:

- Dynamical motions generally found near footpoints of active region loops
- Broad coronal emission lines found when multiple small-scale Doppler motions along coronal loops, mostly upflows, exist near loop-footpoint regions.
- High-speed ($V\cos\theta = V_D > 100$ km/s, $V \sim V_s$) upflow motions are detected at the footpoints, generally in low emission, as a blue-side enhancement in the emission line profile.

➢ These characteristics are direct evidence for heating by nanoflares, which are intrinsically small-scale events that <u>predominantly occur near footpoints</u>.

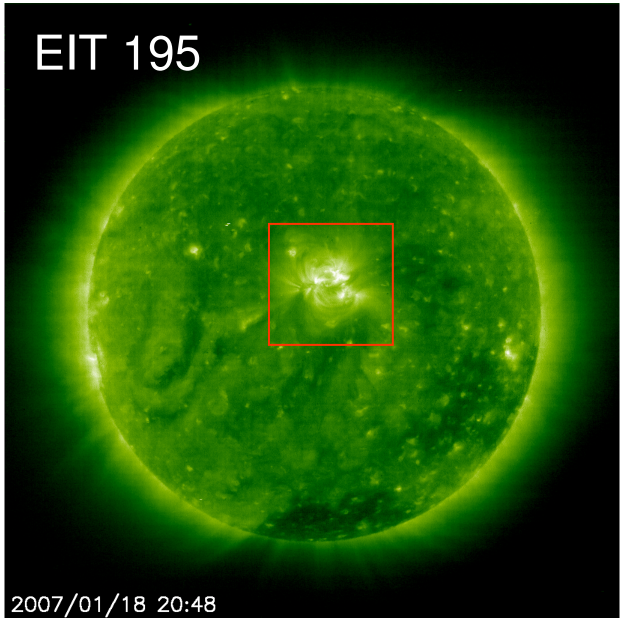
Data

- Several *Hinode* EIS raster scan data set:
  2007 Jan 18 – 25
- AR 10938

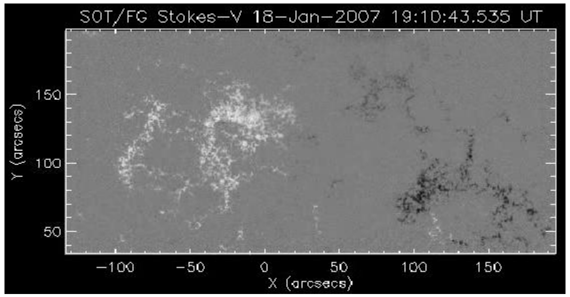


TRACE + potential field lines

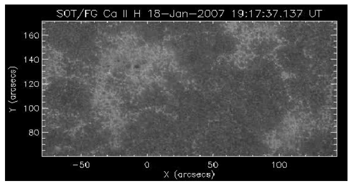
Solar features in other observations

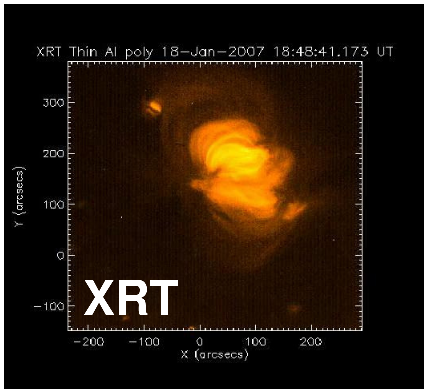


SOT Stokes-V

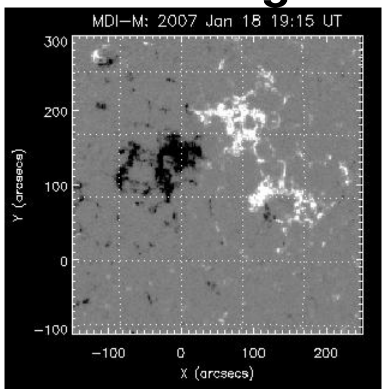


SOT Ca H

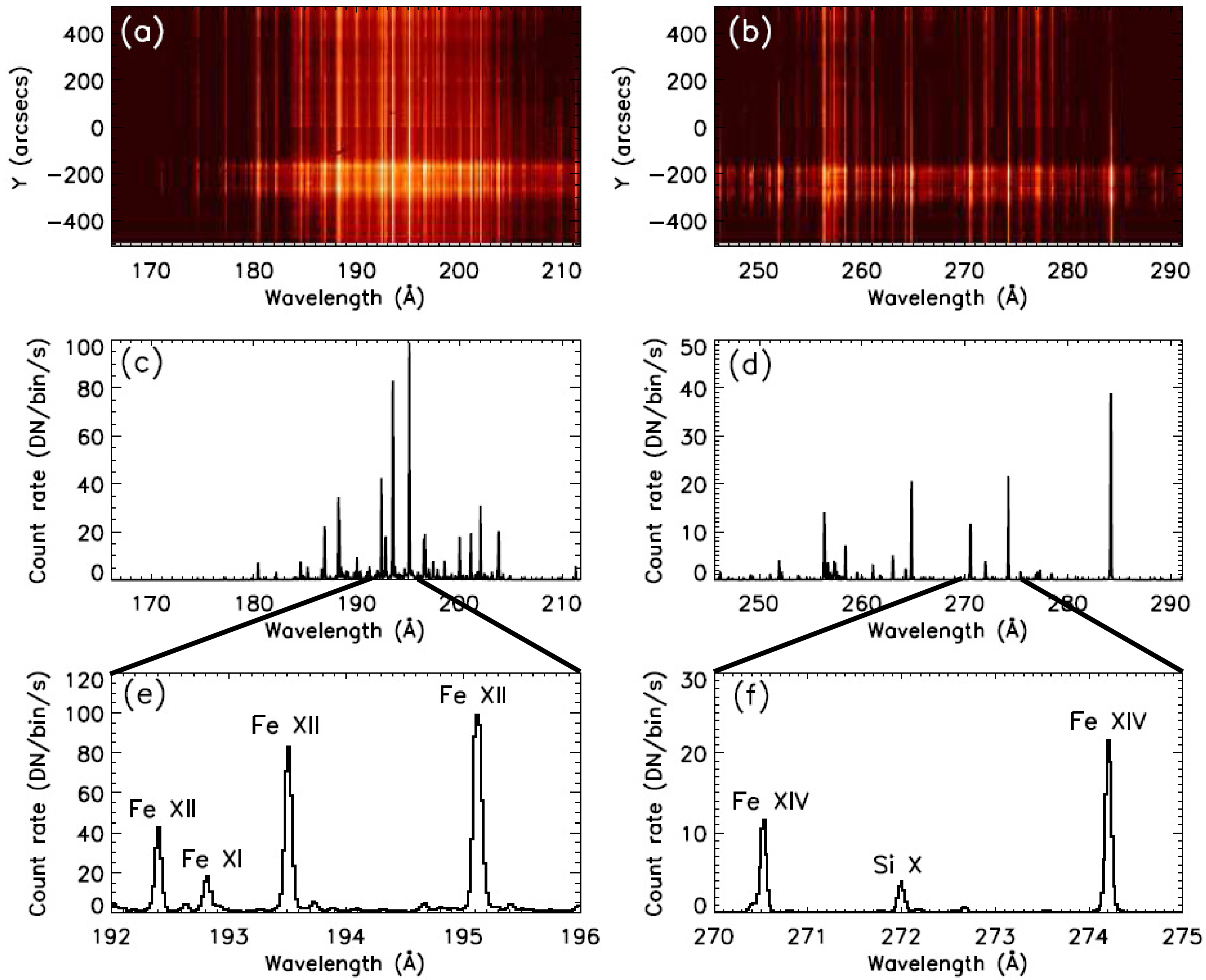




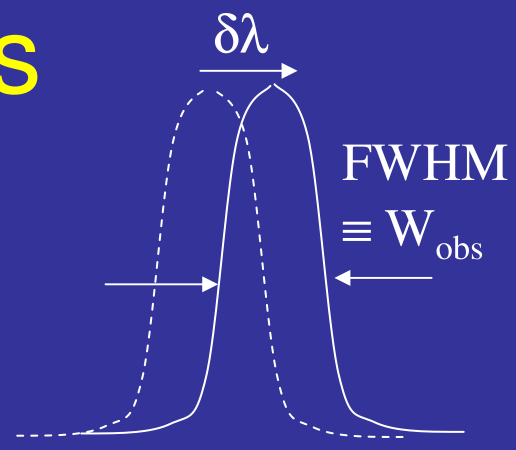
MDI Mag.



EUV Spectra from EIS



Basic Observables



Information from a single emission line

- Line intensity
- Line shift by Doppler motion
  Doppler velocity = (δλ/λ) c
- Line width: temperature, non-thermal motion

thermal Doppler velocity

Instrumental width

nonthermal velocity

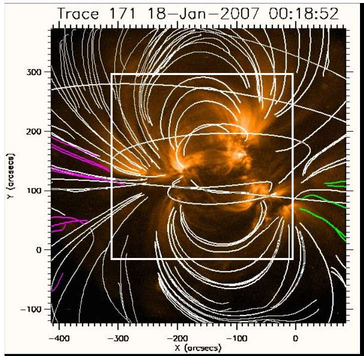
$$W_{\rm obs} = \sqrt{{W_{\rm I}}^2 + 4\ln 2\left(\frac{2kT_i}{M_i} + {V_{\rm NT}}^2\right)} \equiv \sqrt{{W_{\rm I}}^2 + W^2}$$

In velocity unit

$V_{\rm NT}$: nearly isotropic. QS: Chae et al. 1998, AR: Hara & Ichimoto 1999

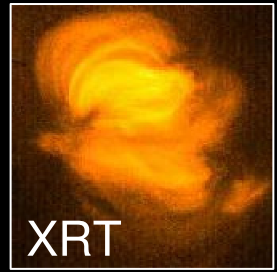
Information from selected two line ratio

- Temperature
- Density



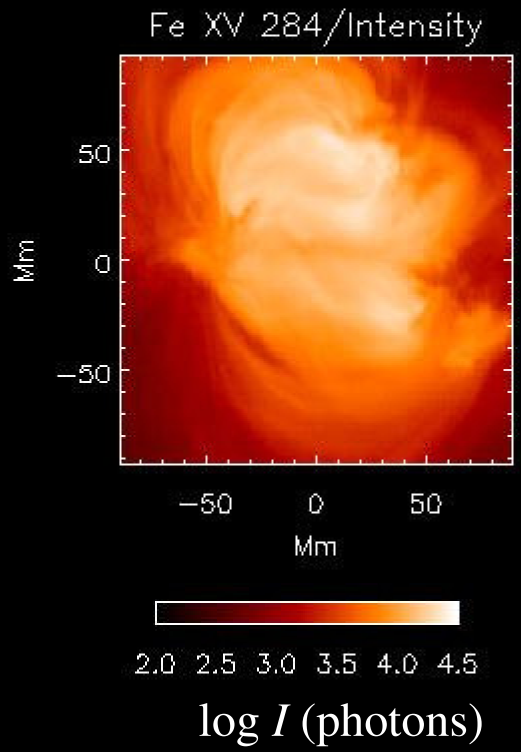
Maps from a Gaussian Fitting

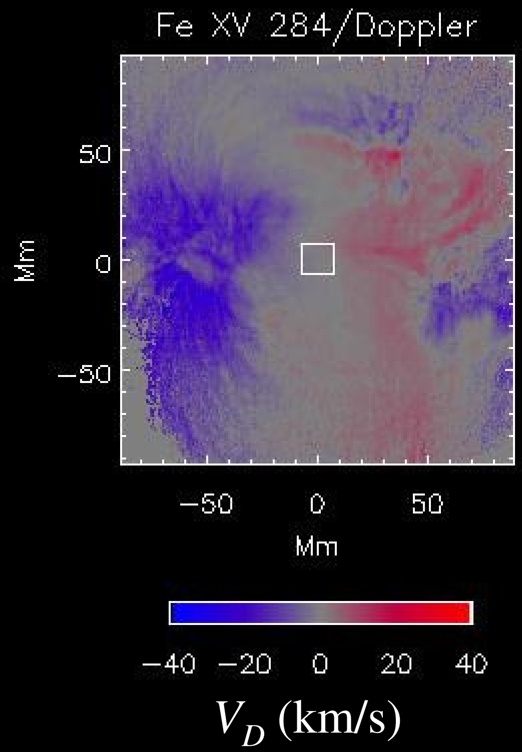
$I, V_D, FWHM$

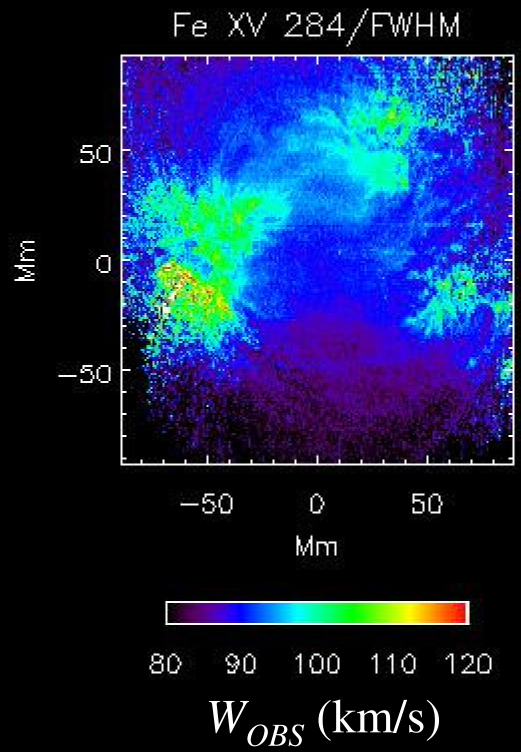


Fe XV 284 (log T = 6.3)

Scanning direction (= time)





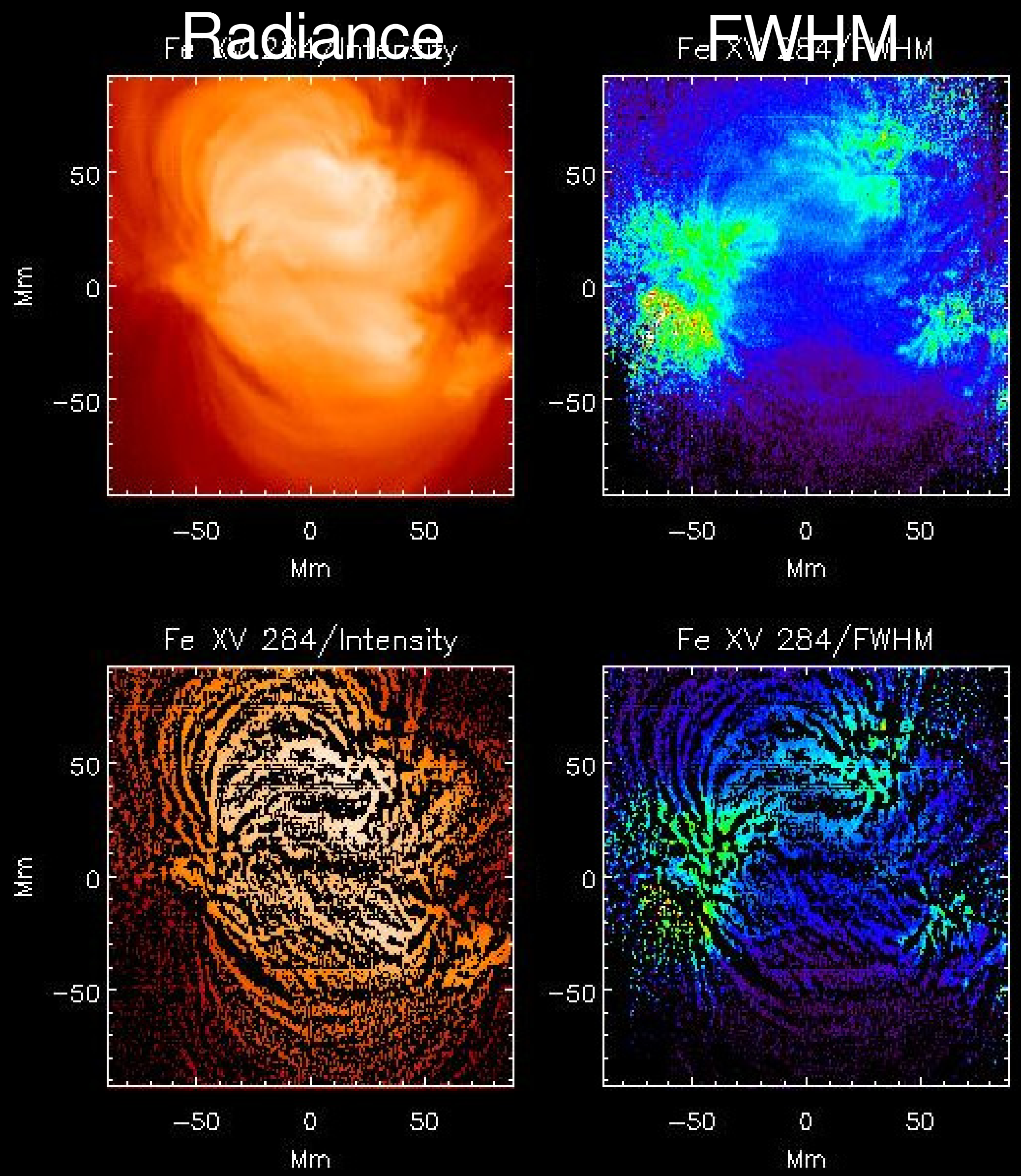


See Doschek et al. (2007) for the 1st published EIS *I, V, W* maps.

Square at the center is set to be zero velocity point in showing Doppler map.

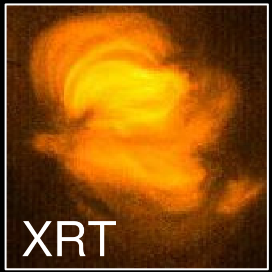
Containing line broadening of instrumental origin

Height of FWHM enhancement



- A filter to find coronal loops is applied.
- Apparently FWHM decreases from the bottom to top in coronal loops.
- The scale length in the FWHM change ~ 10-20 Mm ?

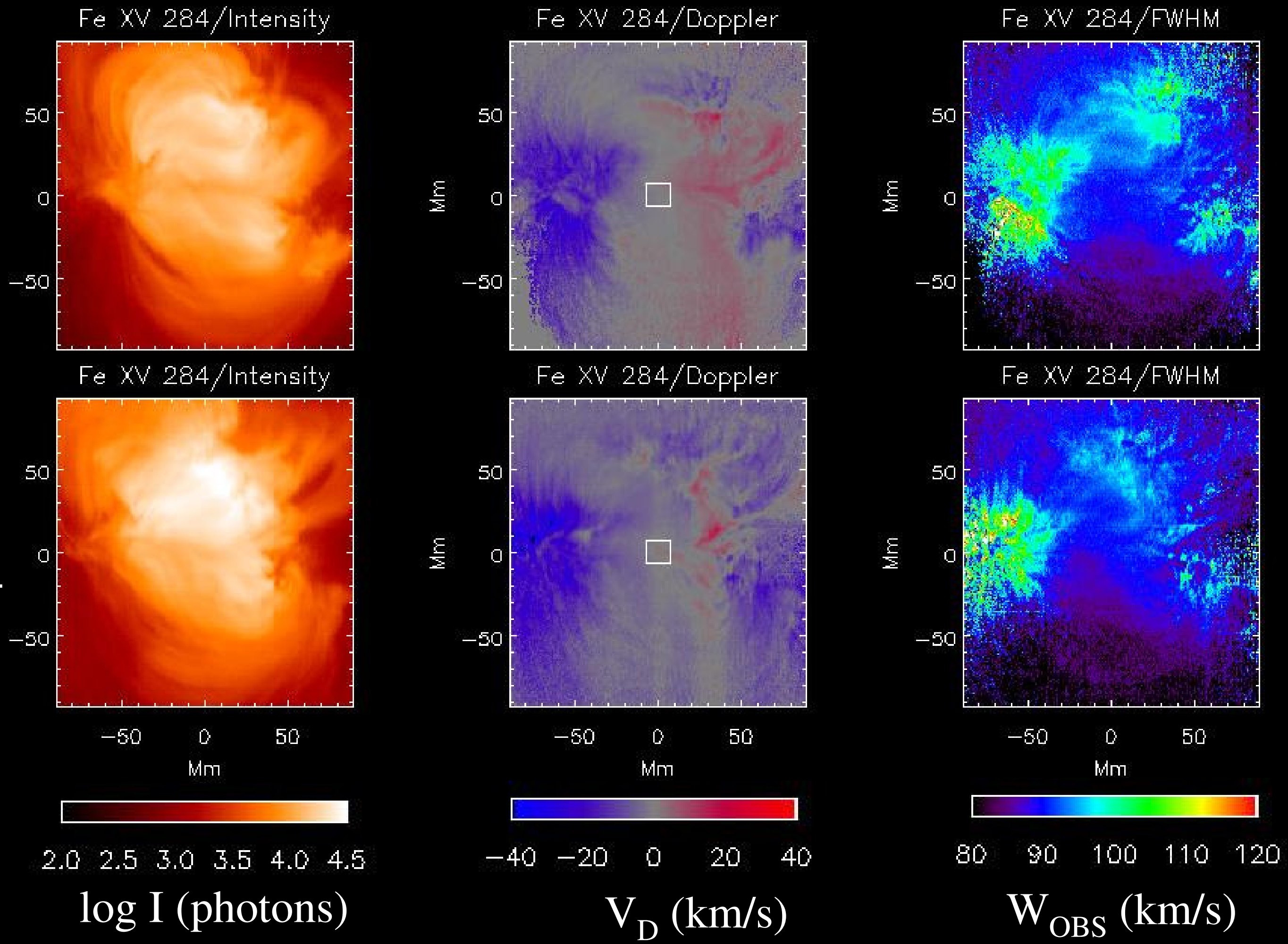
Stability of the Structure

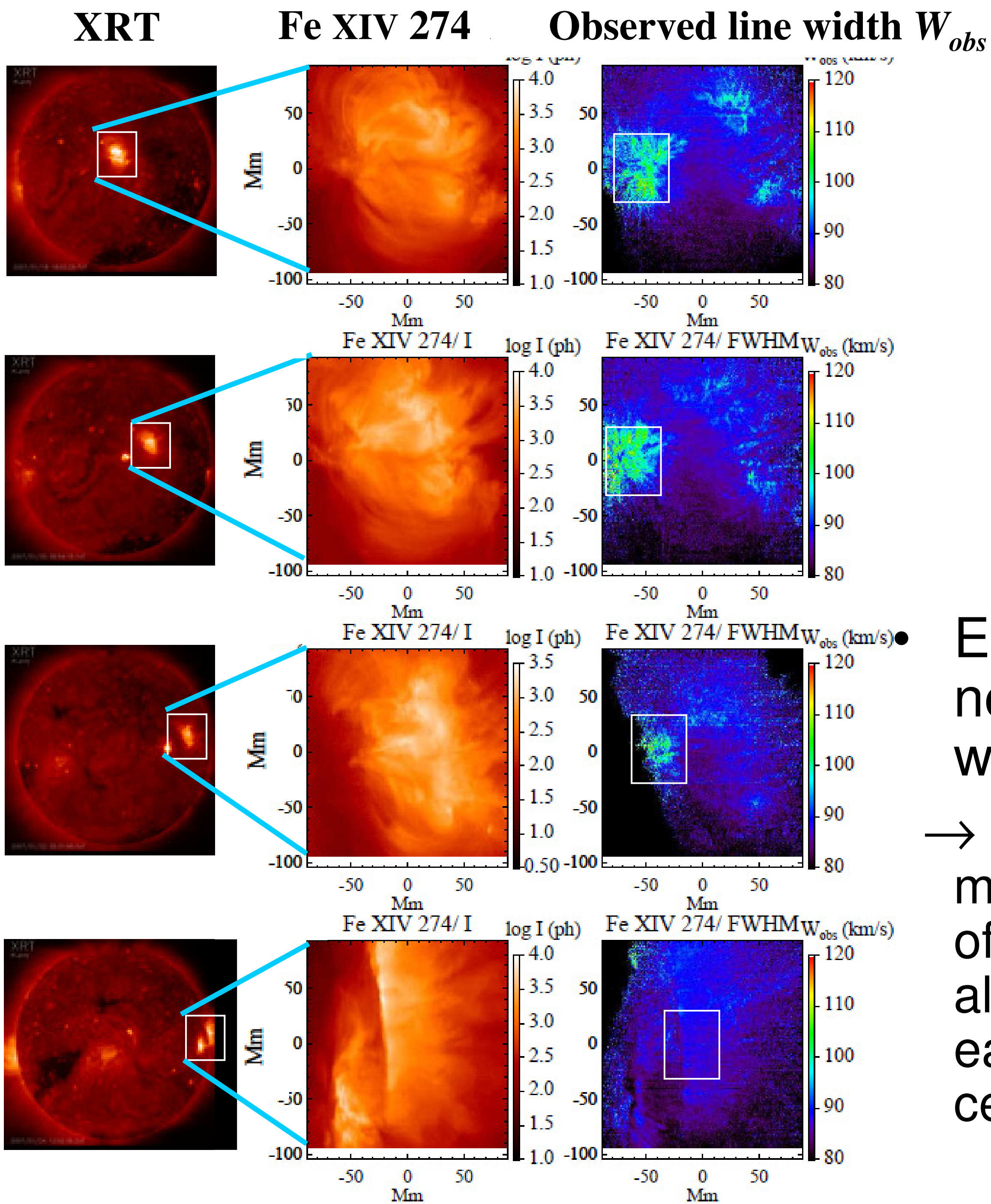


Fe XV 284 (log T = 6.3)

2007 Jan 18
18:12- 20:27 UT

2007 Jan 20
02:33 - 05:31 UT





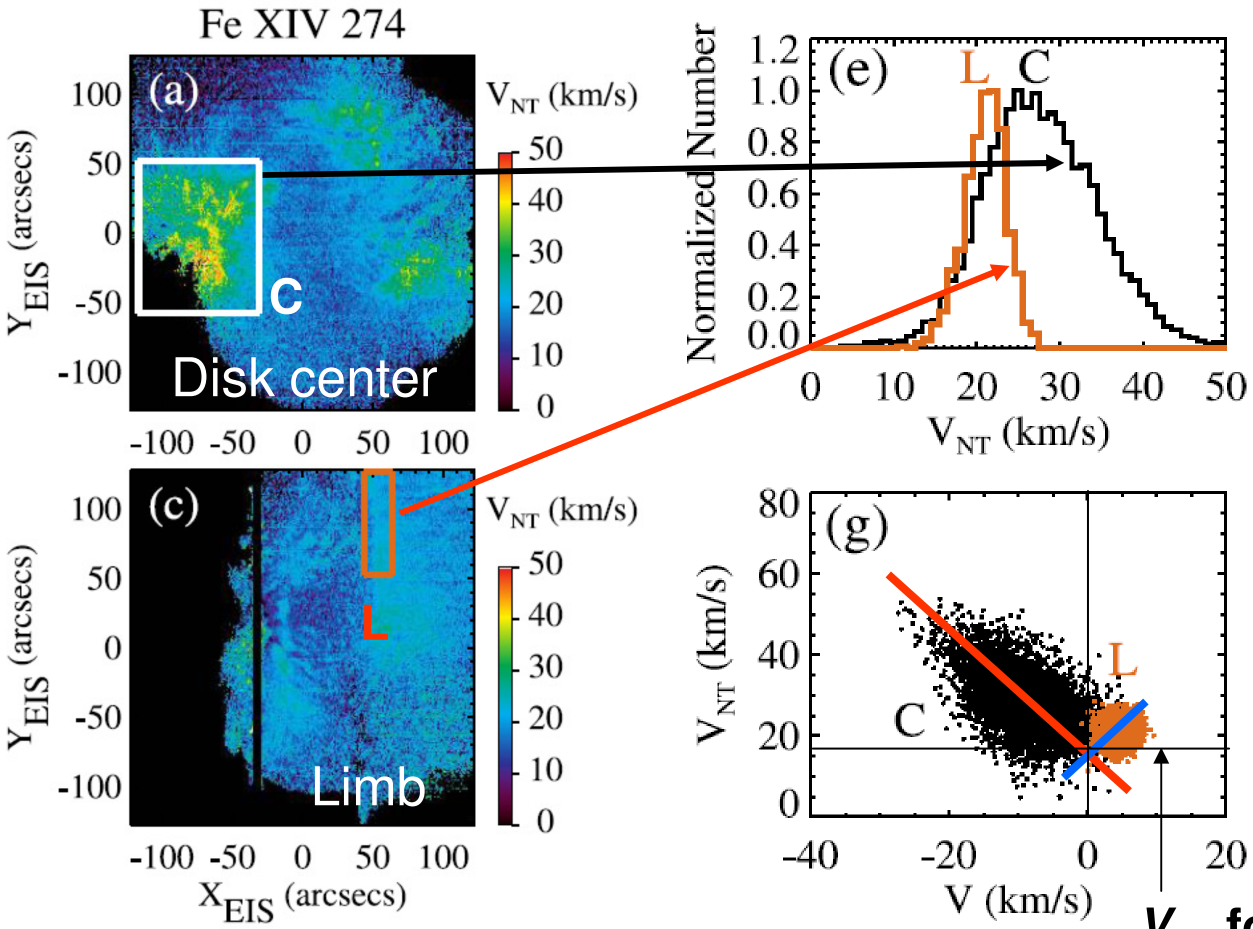
Line width change with rotation

- Enhanced line broadening near footpoints disappears with rotation.

→ Excess line broadening may be due to superposition of multiple components along magnetic field line, each with different line centers.

Unresolved Flows

hidden in line width



Histogram of V_{NT}

$V_D - V_{NT}$ Scatter plot

V_{NT} for V_D=0

There is correlation between V and V_{NT}.

→ Superposition of line-of-sight plasma motions along magnetic field lines

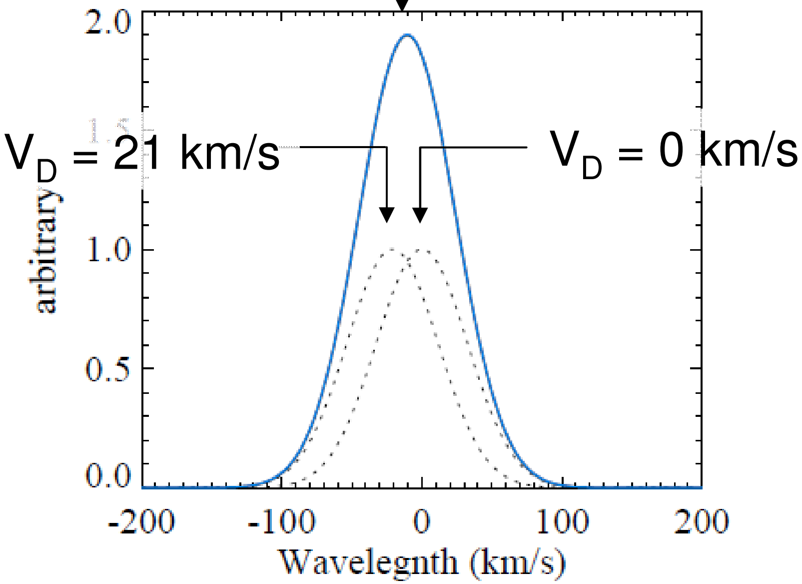
Unresolved Doppler components are hidden !

Hara et al. 2008, ApJ, 678, L67

Multiple emission-line components

V_{NT} = 15.4 km/s

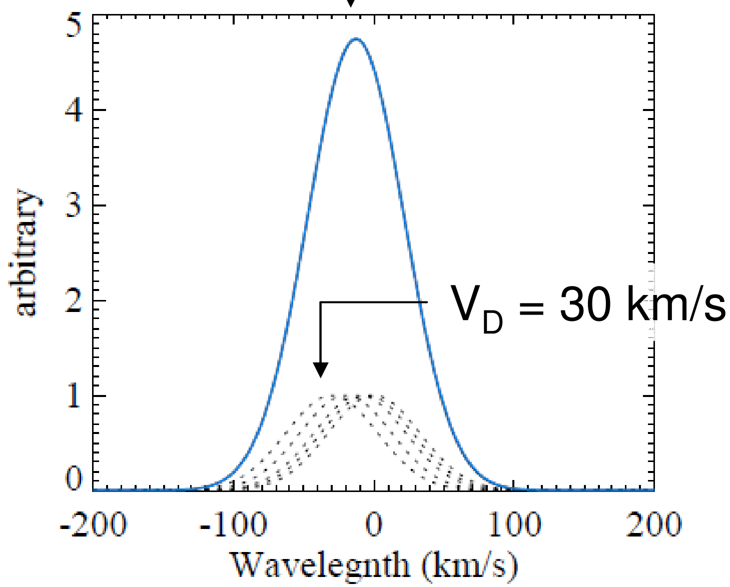
V_D = 10.5 km/s observed



Two components model
with the same profile
as the simplest case

V_{NT} = 15.6 km/s

V_D = 12.9 km/s observed

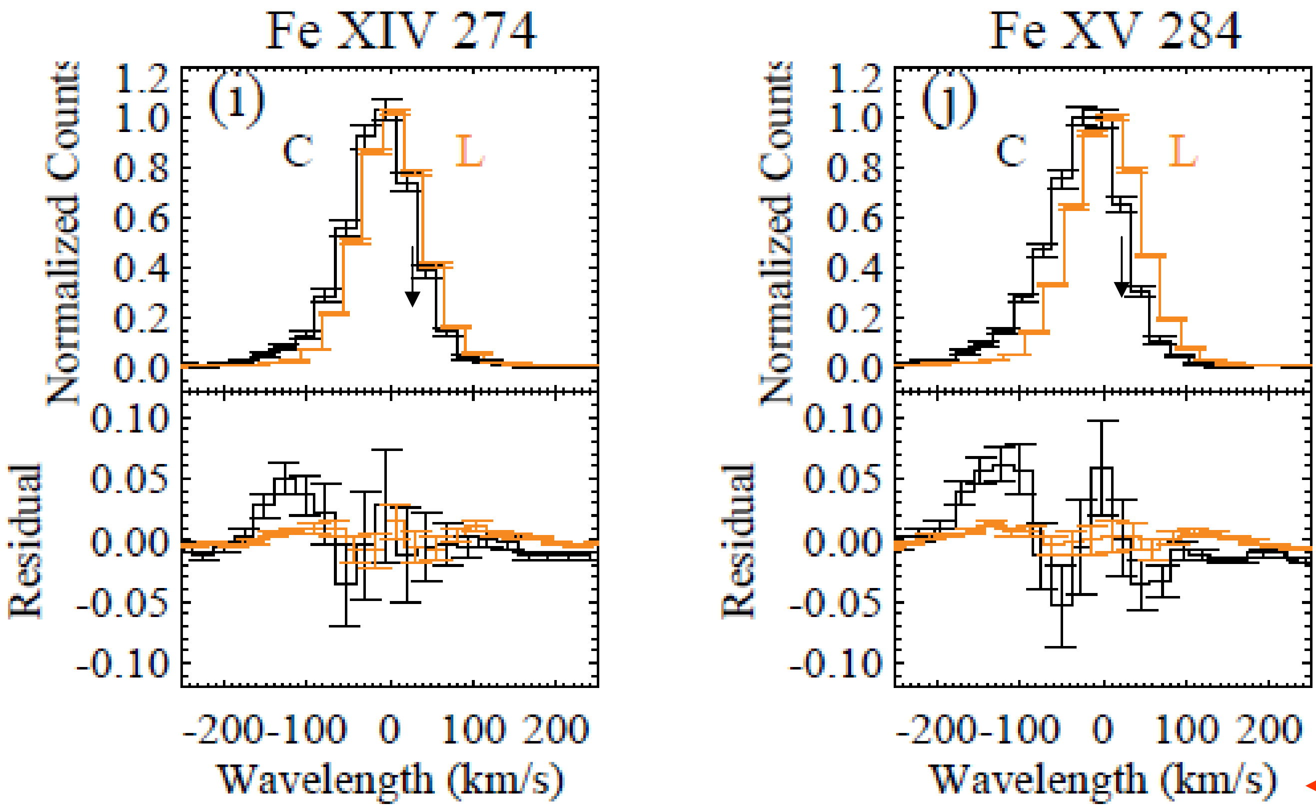


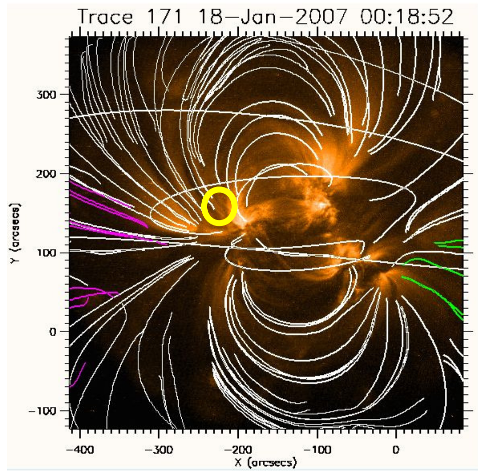
Blue lines: Gaussian-fitted line

Still a few tens of km/s

Blue-side Enhanced Line Profile

Line profiles at loop footpoints





C: disk center

L: limb

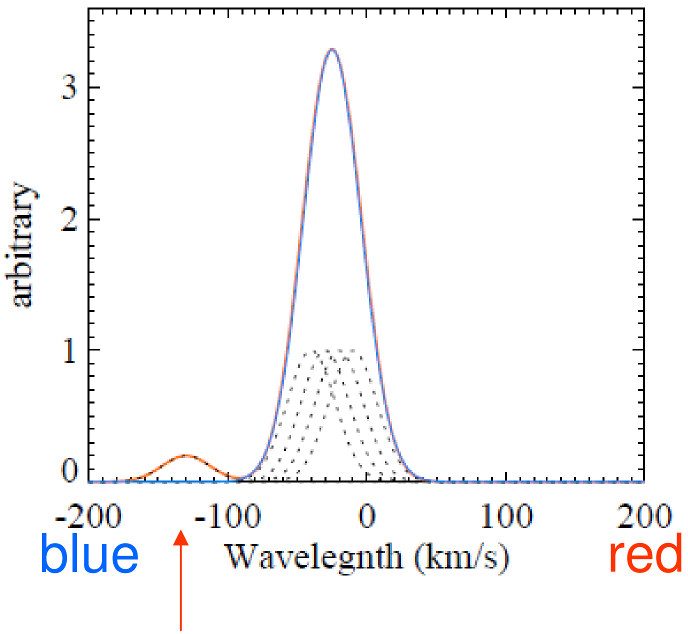
$$V_D = \left(\frac{\lambda - \lambda_c}{\lambda_c} \right) c$$

Clearly showing the presence of unresolved high-velocity upflow components that have weaker emission than primary component.

$V_D / \cos\theta > 200$ km/s ~ V_s

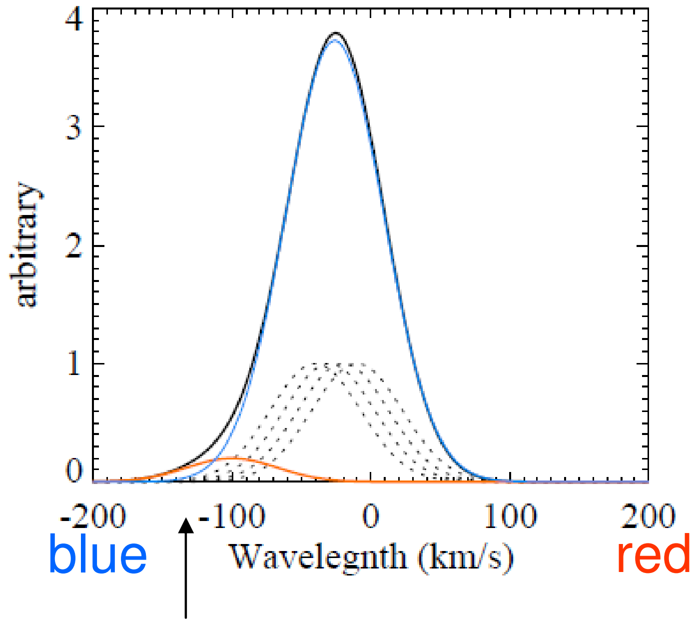
Blue-side Enhanced Line Profile

Line profile
before observations
(solar origin)



High velocity upflow

Line profile
by EIS observations
(instrumentally broadened)



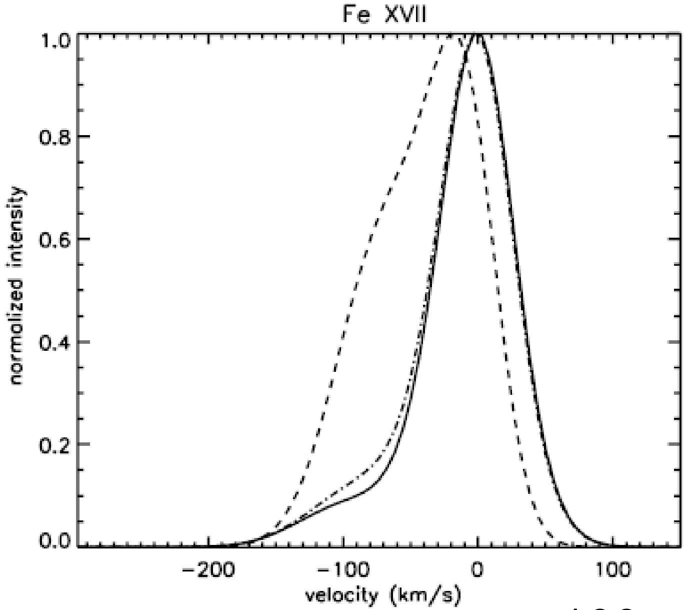
Blue-side enhancement

Blue lines: Gaussian-fitted line

Blue wing enhancement by nanoflares

Simulated line profile

Fe XVII 254 (log *T* = 6.6)



-200 -100 0 100

V_D (km/s)

from Patsourakos & Klimchuk (2006)

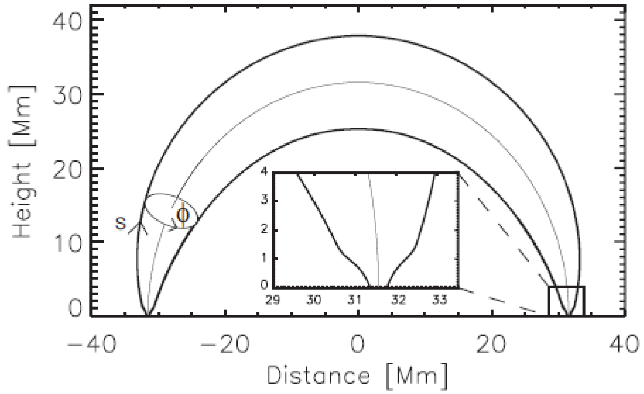
Blue wing enhancement
in Fe XVII 254 line profile
has been expected in
a simple nanoflare simulation by
Patsourakos & Klimchuk (2006).

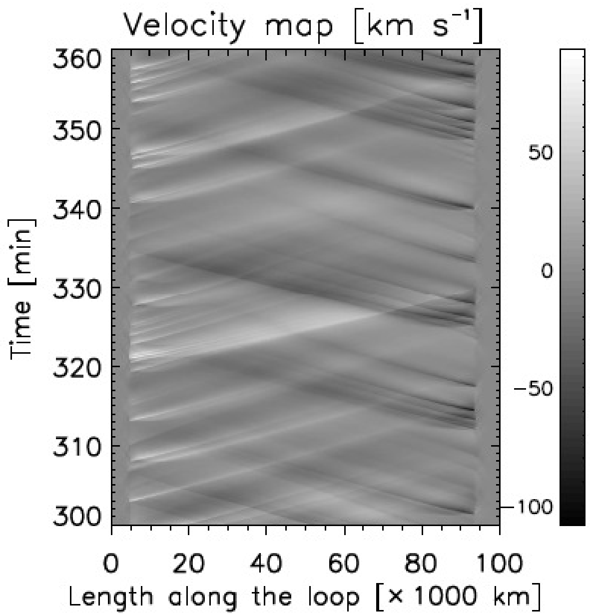
Model: a loop strand impulsively heated in
a uniform manner along the strand

Note: In EIS observations Fe XVII intensity is generally weak.

Line profile from a simulation result

Nanoflare simulation (footpoint heating)
[nanoflare input at 2 -12 Mm height]
Antolin et al. (2008)

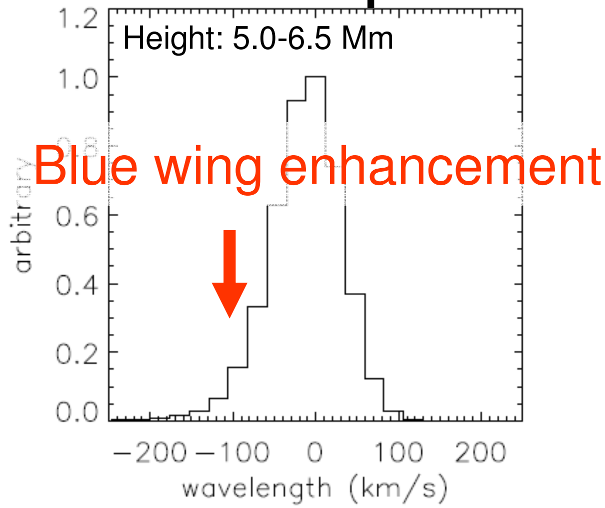




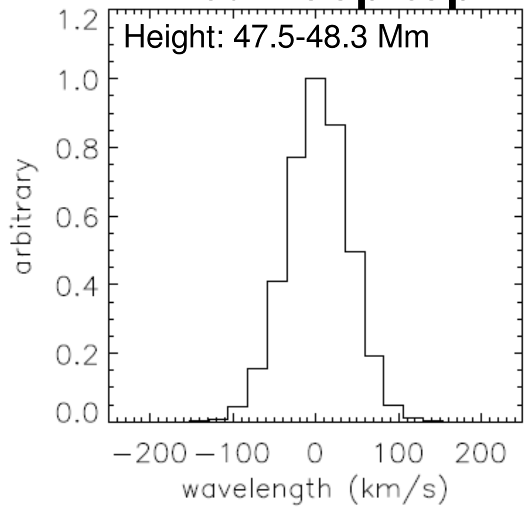
n(z)
T(z)
V(z)

Expected line profile
Fe XV 284

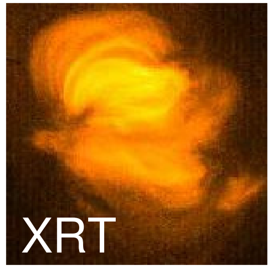
Near footpoint



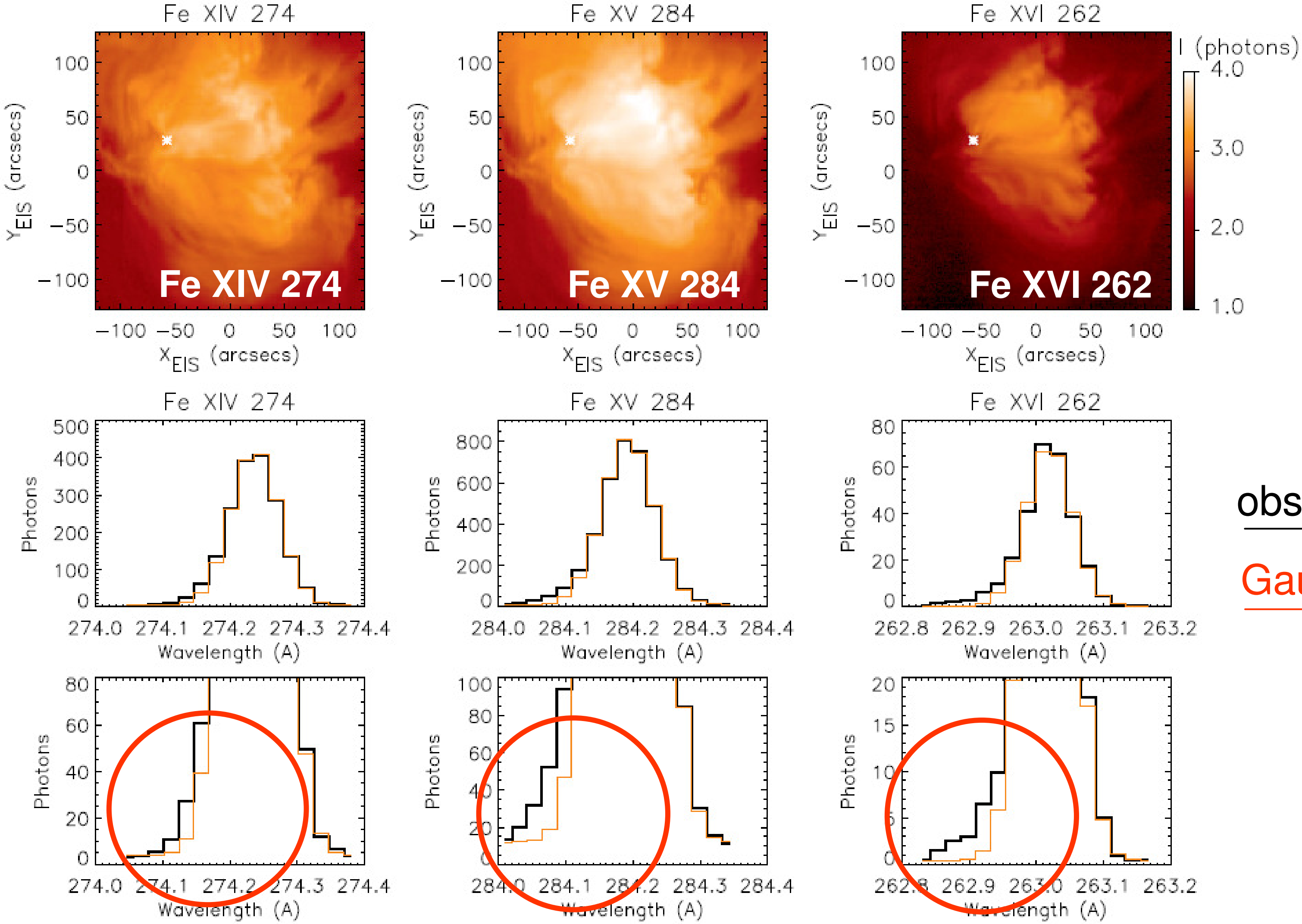
Near loop-top



Blue wing near footpoints



2007 Jan 20 02:33 – 05:31 UT   40 sec exp. at each scanning point

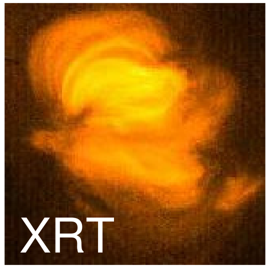


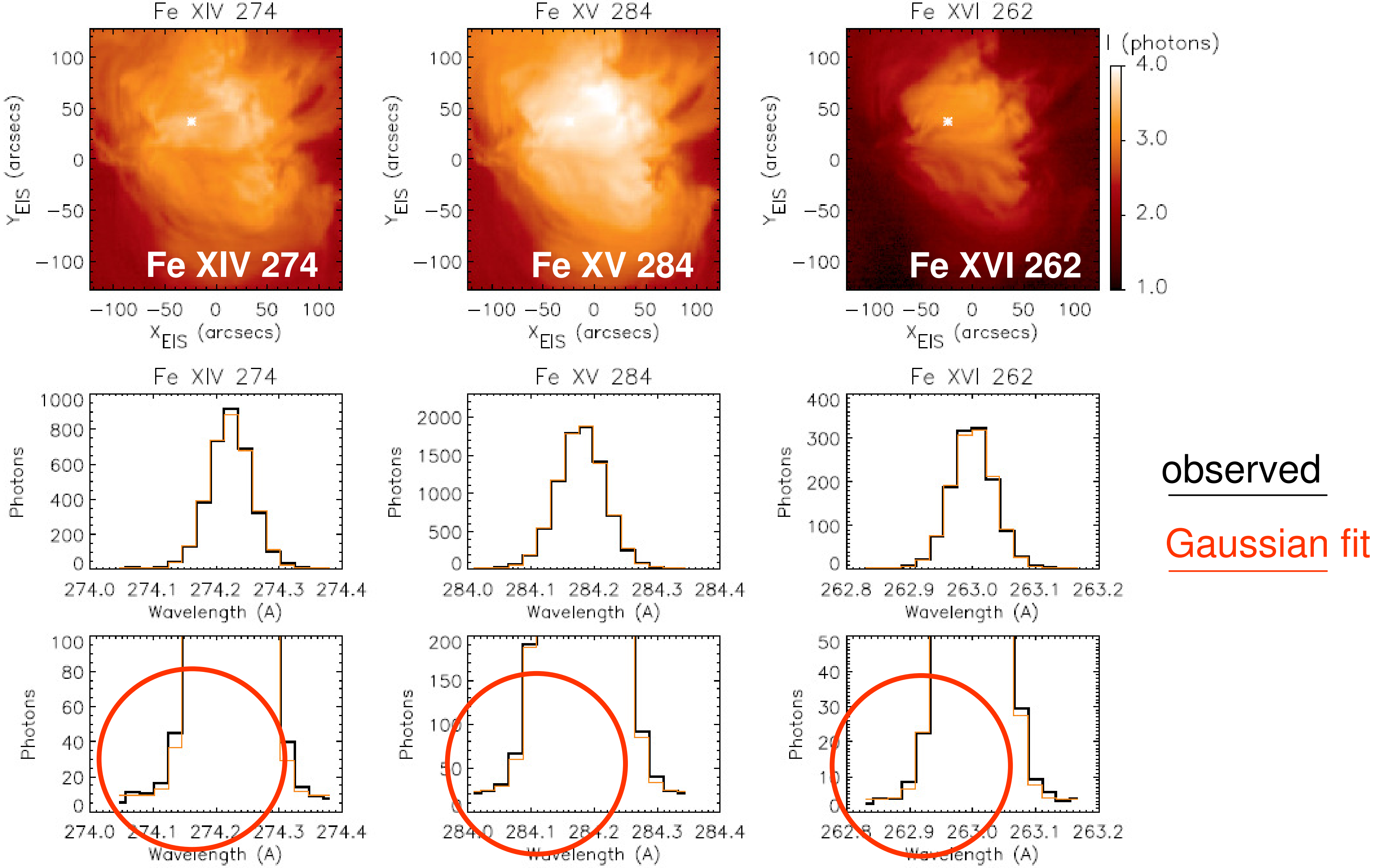
observed

Gaussian fit

Blue wing near loop top

2007 Jan 20 02:33 – 05:31 UT   40 sec exp. at each scanning point





Thermal energy of high-velocity component within EIS sampling (1 arcsec) unit

- Emission measure $n^2 l = 2.6\times10^{26}$ cm^{-5}
- Volume $V = (725 \times10^5$ cm $)^3$
  - Width $w = 725 \times10^5$ cm
  - Line of sight length $l = 725 \times10^5$ cm
- $n = 1.9\times10^9$ cm^{-3}
- $T \sim 1.8 \times10^6$ K for Fe XIV 274 observation

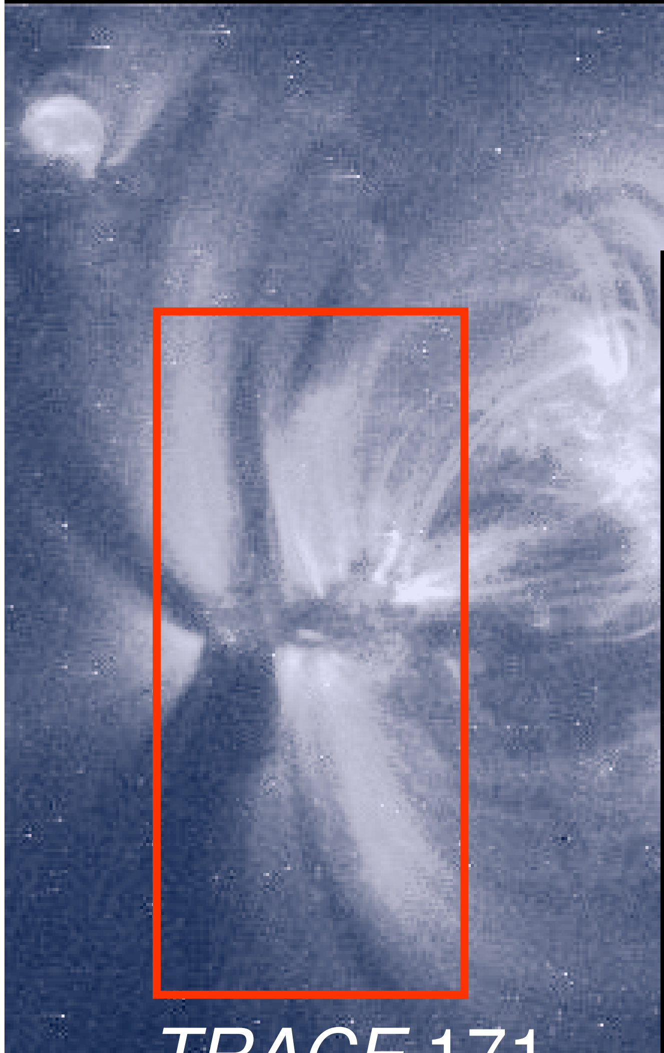
- $3nkTV = 5.4 \times10^{23}$ erg ~ nanoflare energy

Characteristics of Flows in AR 2MK loops

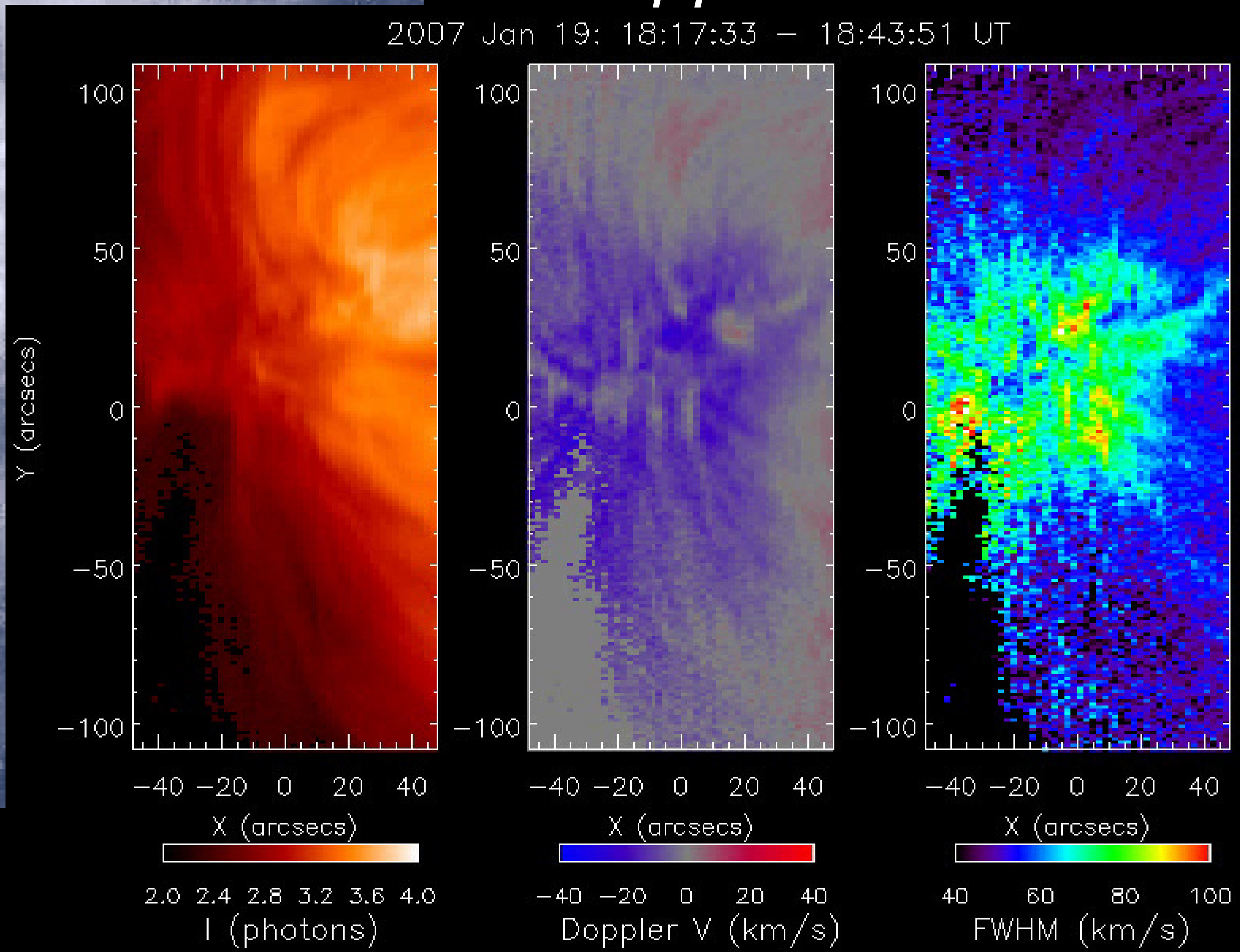
- Disk center observations:
  - Slow upflow (~30 km/s) dominates near loop footpoints
  - Fast flows ($V \sim V_s \sim 200$ km/s) near footpoints found with low emission at blue wing

  →Plasma flows of heated plasmas (evaporation)
- Limb observations:
  - Generally slow flows (<10 km/s)
  - No fast flows found at wings in line profile
  - note: $V_{NT} \sim 20$ km/s

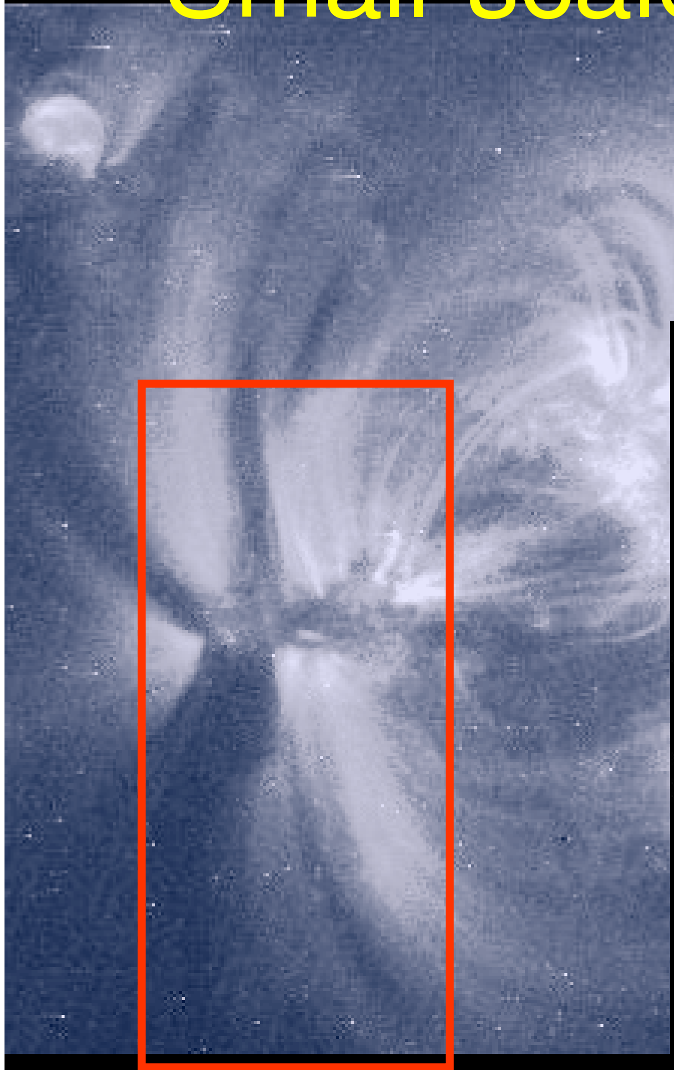
Small-scale Motions at Footpoints

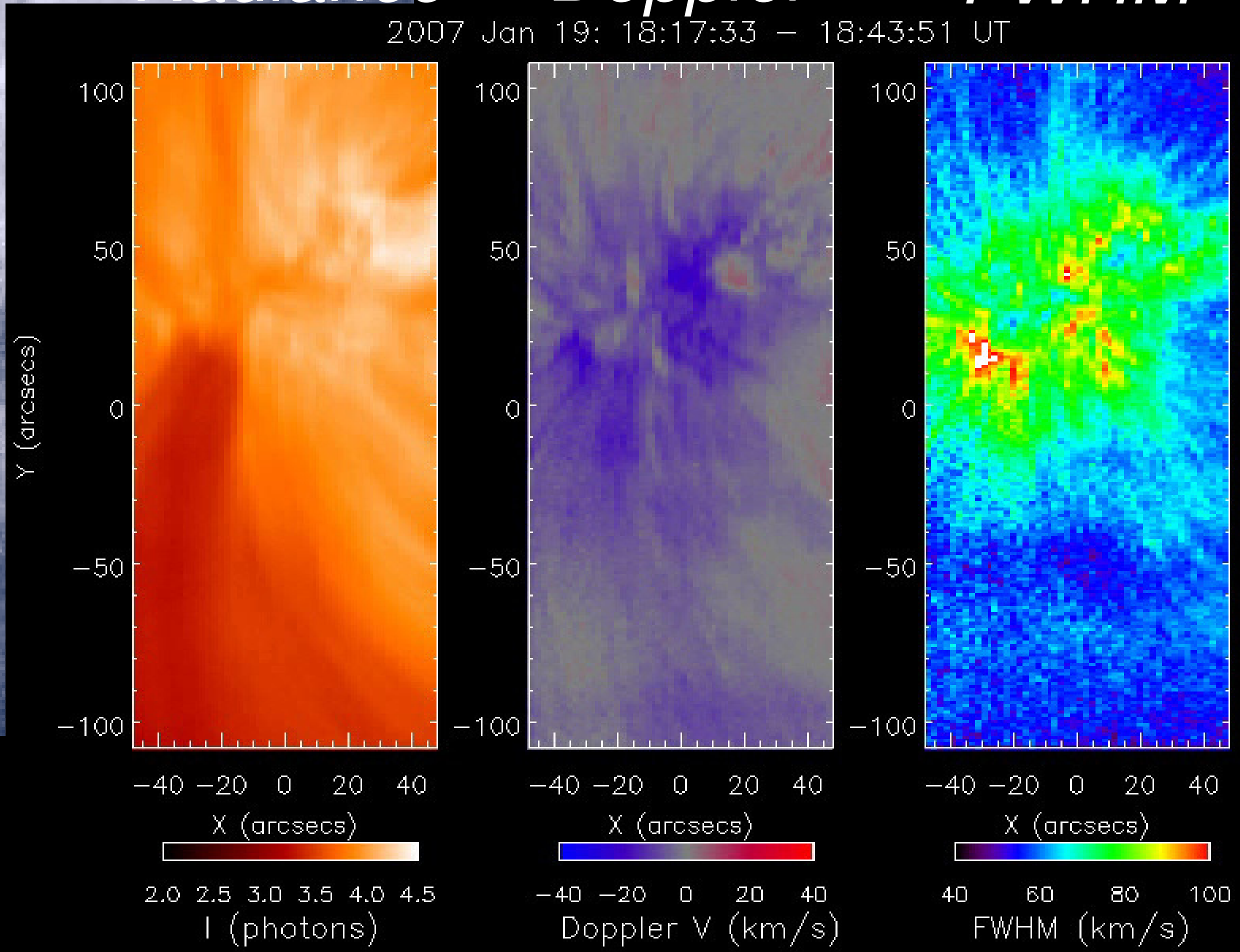


EIS Fe XIV 274 (~1.8MK)

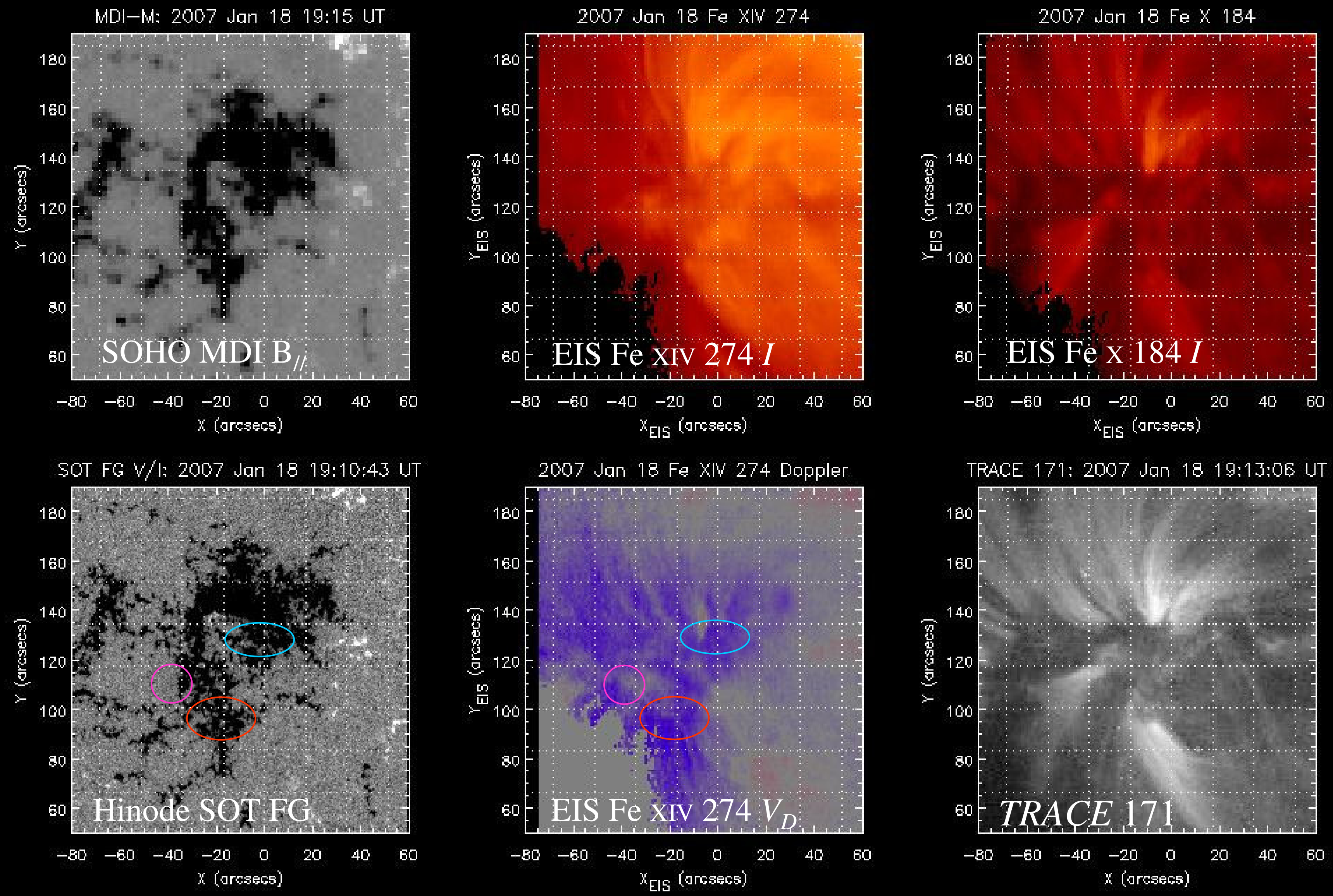


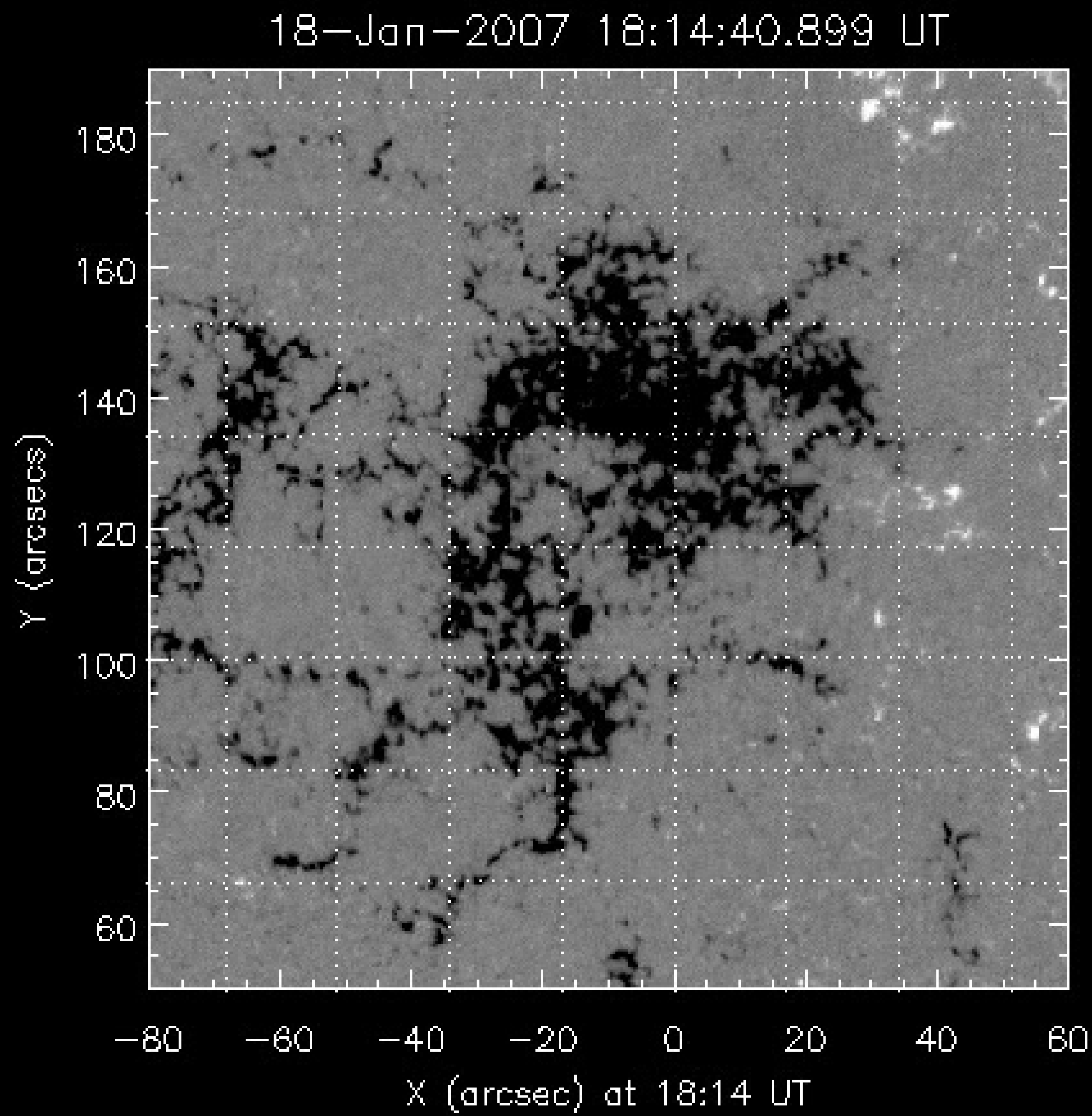
Small-scale Motions at Footpoints





Eastern Loop-Footpoint Area




18-Jan-2007 18:14:40.899 UT
Y (arcsecs)
180
160
140
120
100
80
60
−80
−60
−40
−20
0
20
40
60
X (arcsec) at 18:14 UT

Conclusions

◆ We found from AR observations with Hinode EIS:

- Dynamical motions generally found near footpoints of active region loops
- Broad coronal emission lines found when multiple small-scale Doppler motions along coronal loops, mostly upflows, exist near loop-footpoint regions.
- High-speed ($V\cos\theta = V_D > 100$ km/s, $V \sim V_s$) upflow motions are detected at the footpoints, generally in low emission, as a blue-side enhancement in the emission line profile.

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END