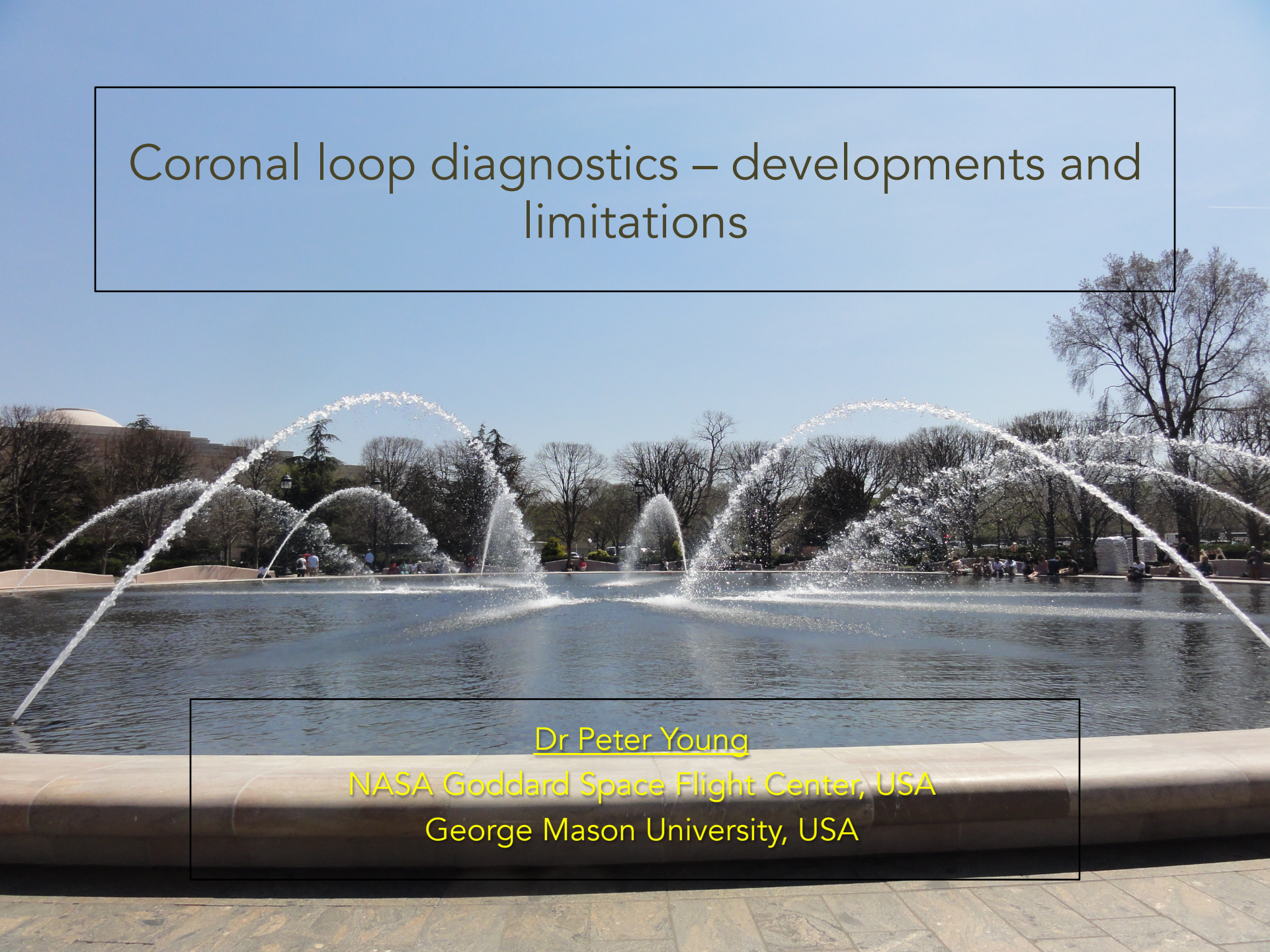
Coronal loop diagnostics – developments and limitations



Dr Peter Young
NASA Goddard Space Flight Center, USA
George Mason University, USA

Overview

- Coronal density diagnostics
  - update of Young et al. (2009) results

- Warm 1 MK loops
  - review of some EIS results
  - new results from IRIS on sunspot loops
  - joint EIS-IRIS sunspot loop data-set

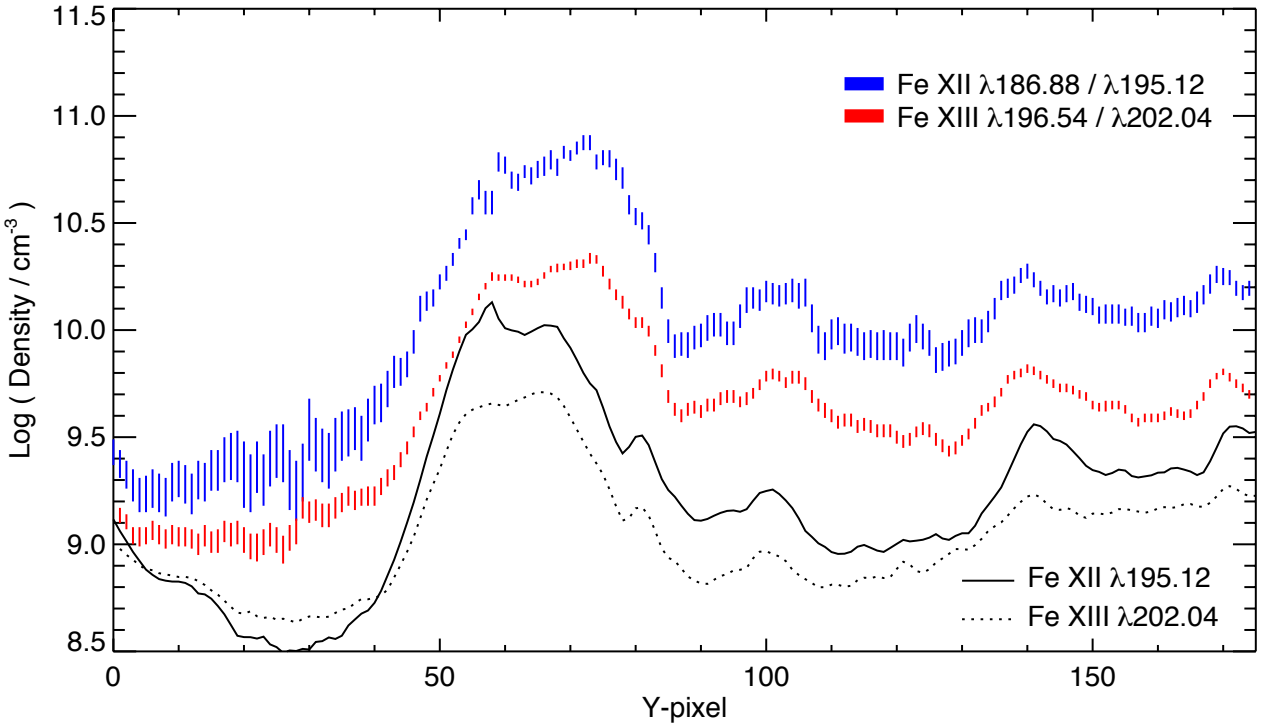
Coronal densities

- The best EIS coronal density diagnostics come from Fe XII and Fe XIII
  - Fe XII: λ 186.88^{b}/ λ 195.12 and λ 196.64/ λ 195.12
  - Fe XIII: λ 203.82^{b}/ λ 202.04 and λ 196.54/ λ 202.04
- Young et al. (2009, A&A) found large differences between densities derived from the two ions

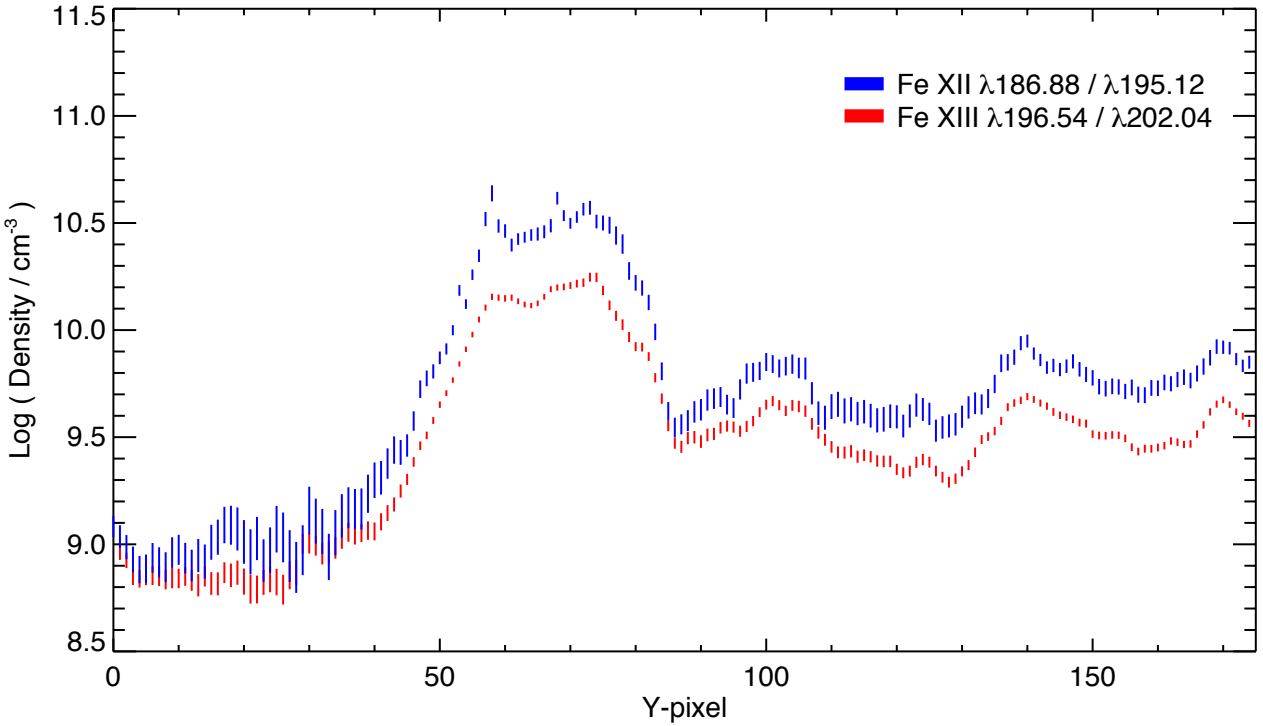
- Since then…
  - CHIANTI has gone from v5.2 to v8.0 (coming soon!)
  - Changes to EIS radiometric calibration have been suggested by Del Zanna (2013) and Warren et al. (2014)

- Are the problems resolved?

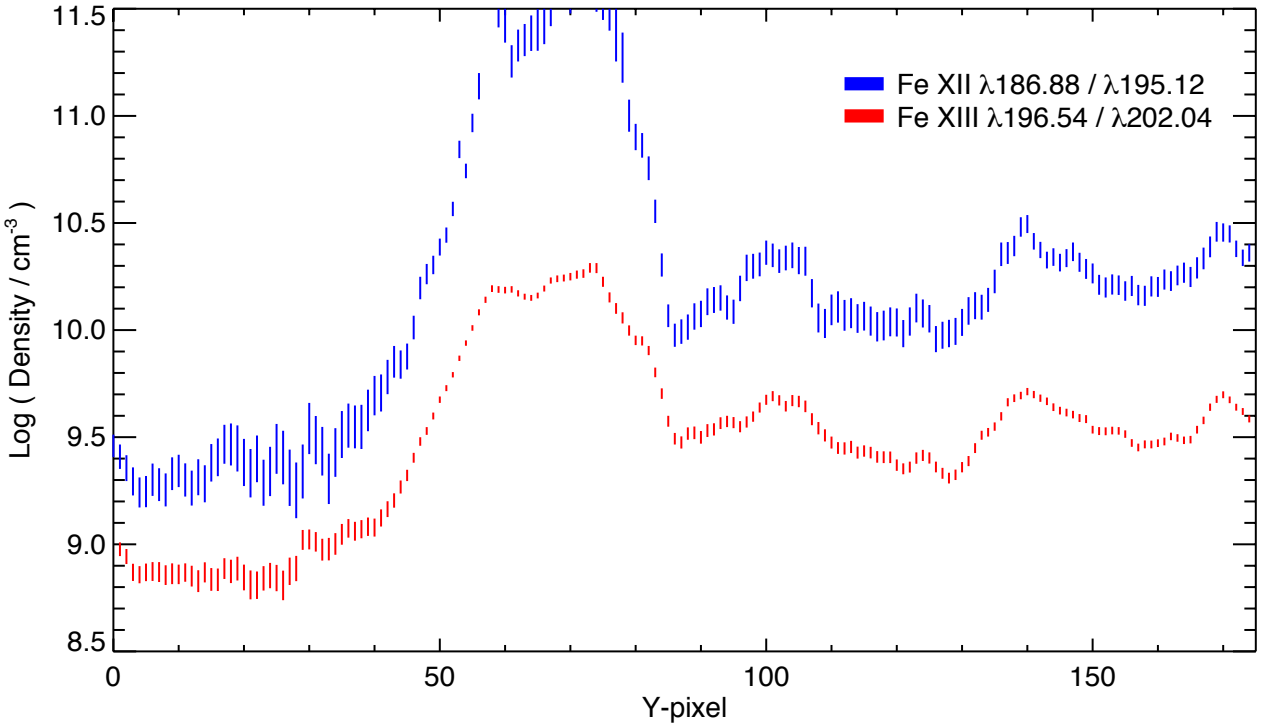
New atomic data: before



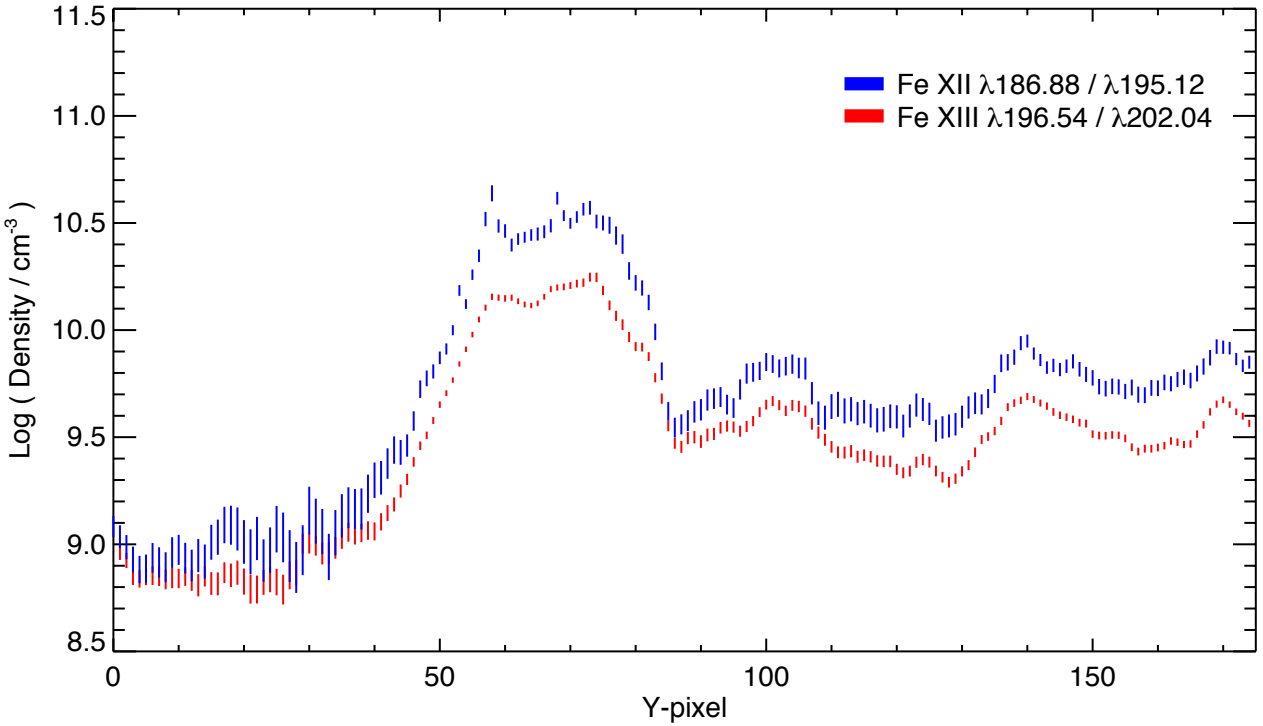
New atomic data: after



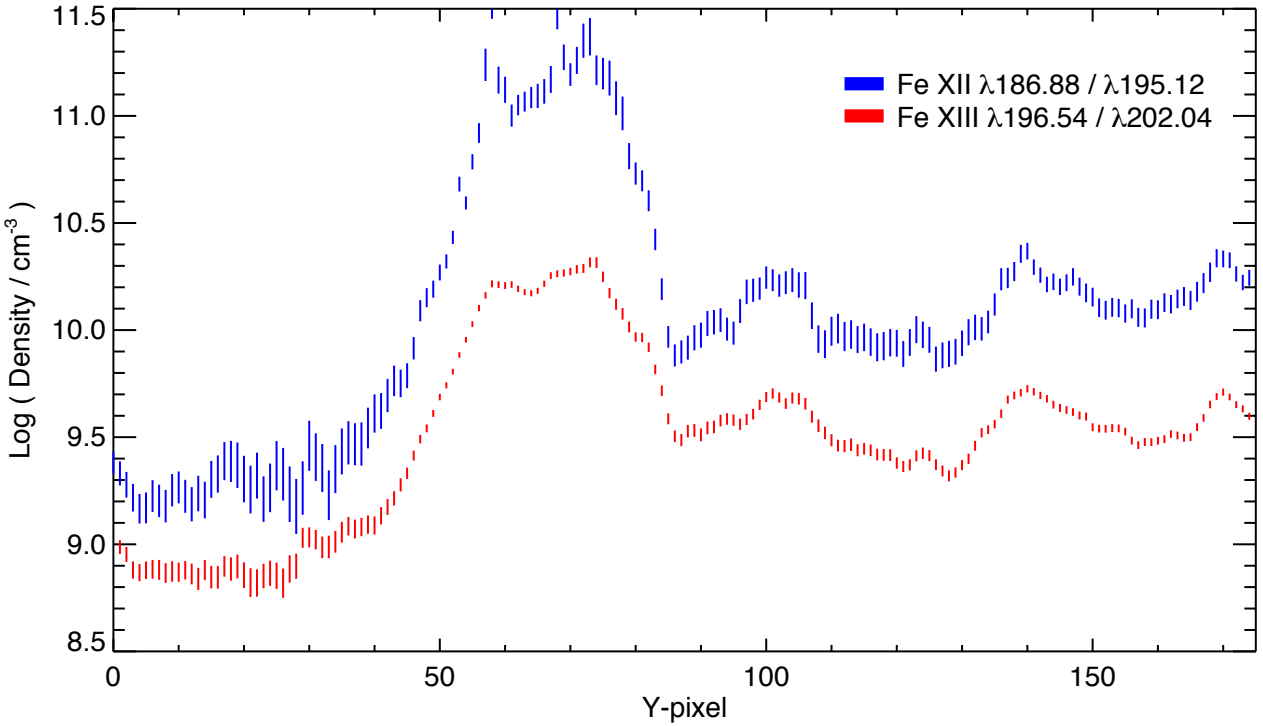
Effect of DZ13 calibration



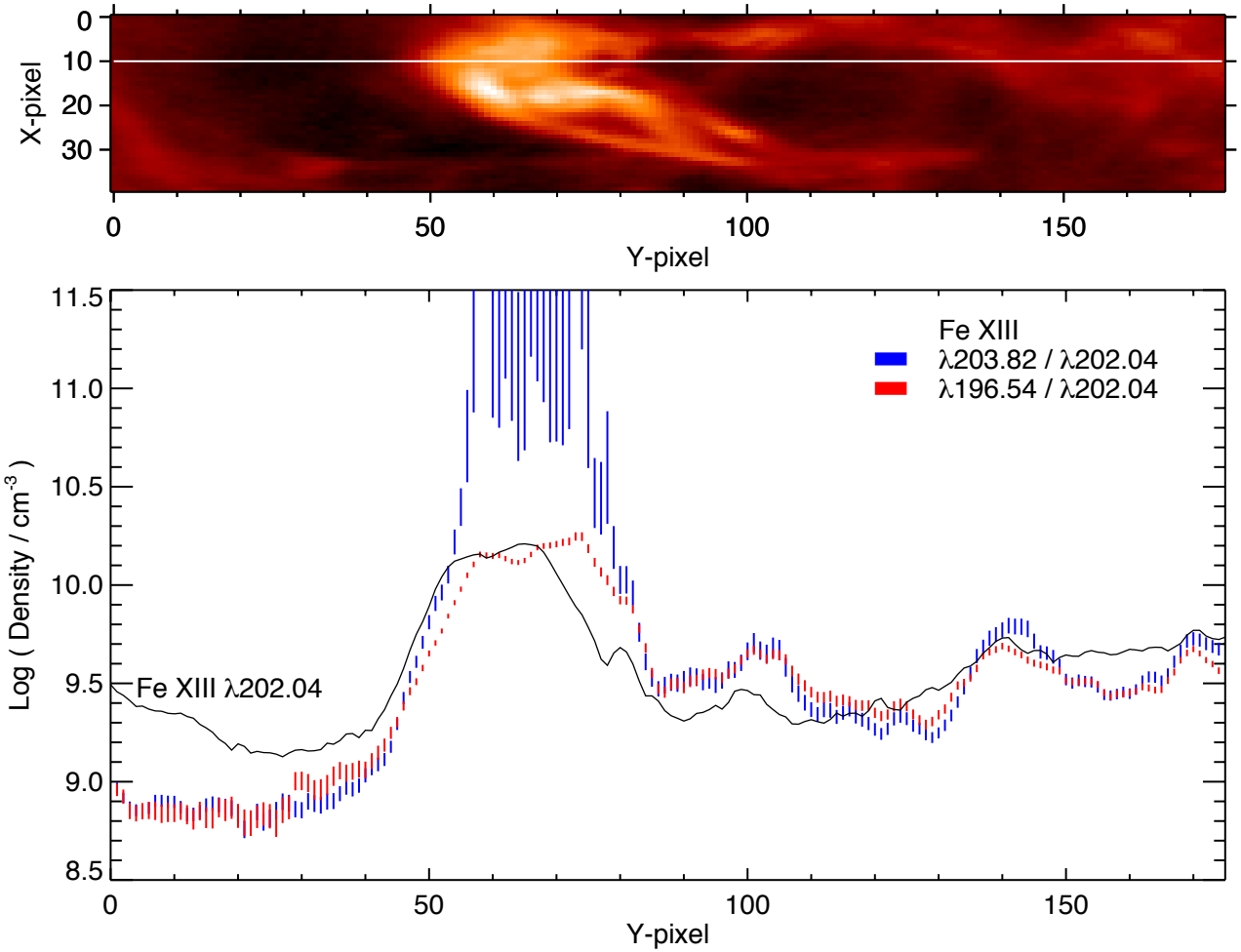
Effect of W14 calibration: before



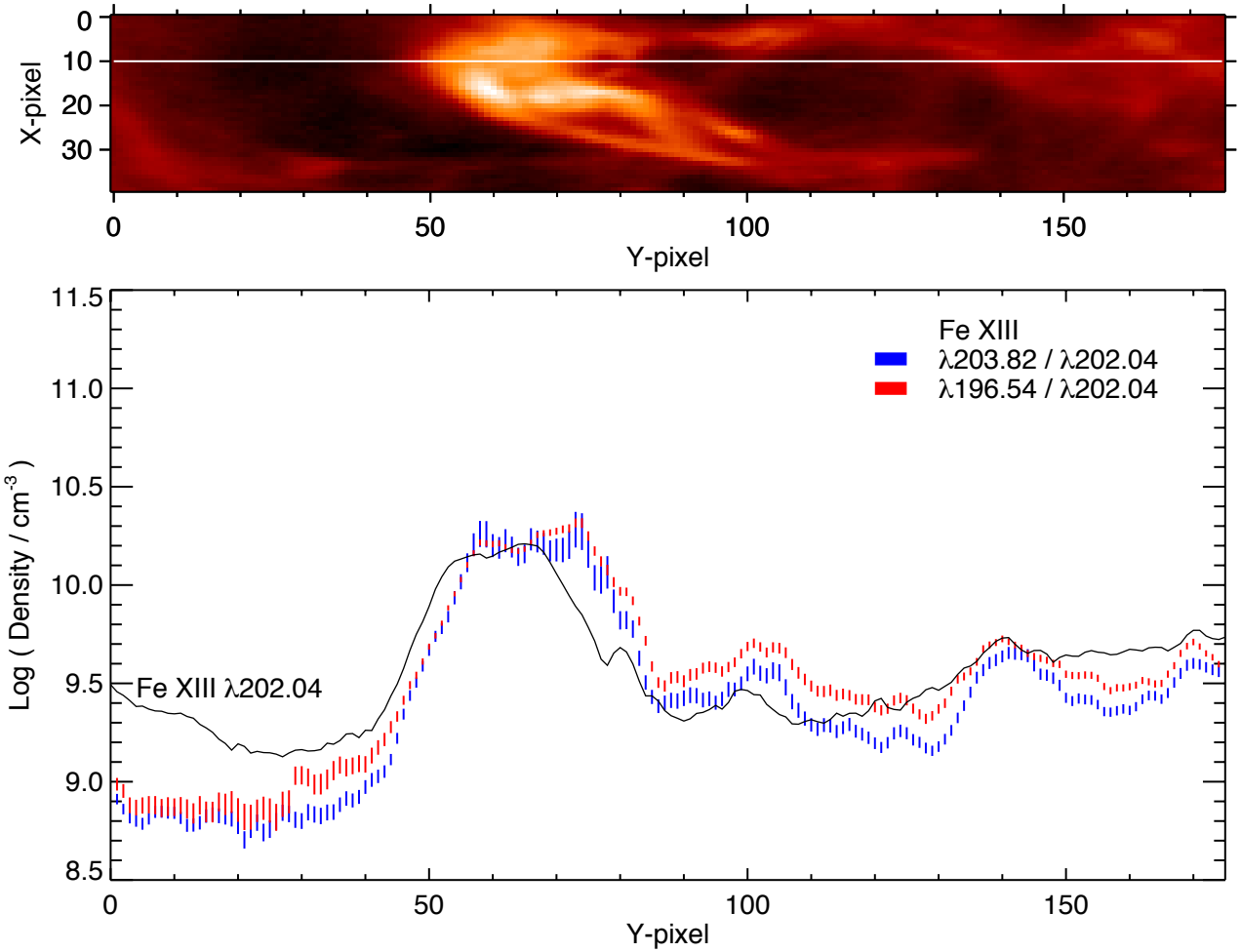
Effect of W14 calibration: after



Improvement for Fe XIII with W14



Improvement for Fe XIII: W14



Fe XII & Fe XIII densities: summary

New atomic data – small improvement

- Fe XIII λ 203.82/ λ 202.04 is worse at high density
- Otherwise, slightly better agreement between Fe XII & XIII, esp. at low densities

Calibration

- Del Zanna (2013) makes things worse (esp. Fe XII λ 186.88/ λ 195.12)
- Warren et al. (2014) gives very good agreement for Fe XIII ratios…
- …but worsens discrepancy between Fe XII & Fe XIII

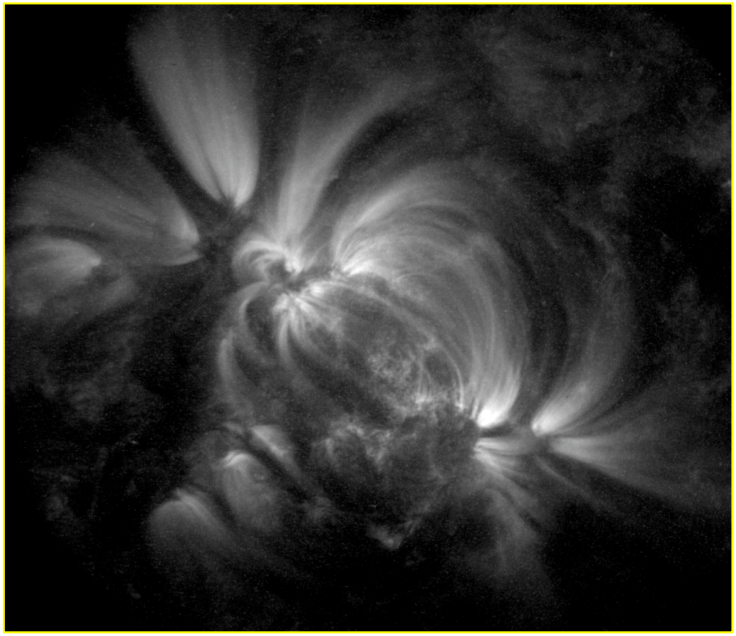
Summary

- Are calibration changes to SW channel justified?
- High density discrepancy for Fe XII a problem (excitation from ^{2}P term?)

1 MK active region loops

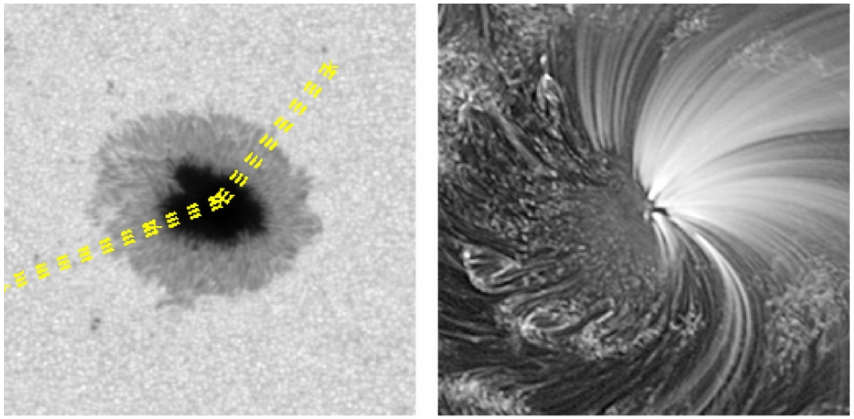
- Consider loops with bright footpoints in 171 channel
- Footpoints can either terminate in
  - sunspots (penumbra or umbra)
  - or AR plage

- LOS velocity measurements
  - EIS & IRIS
- Mg/O abundance
- Density

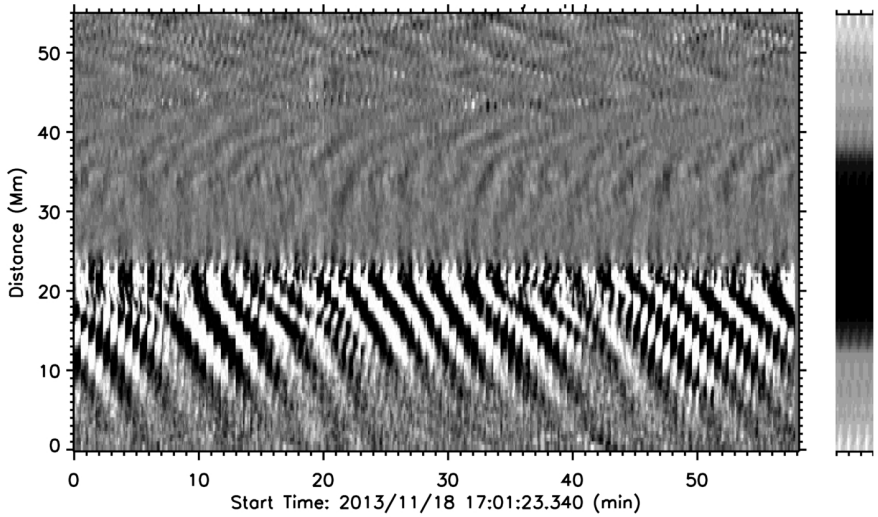


Propagating Coronal Disturbances

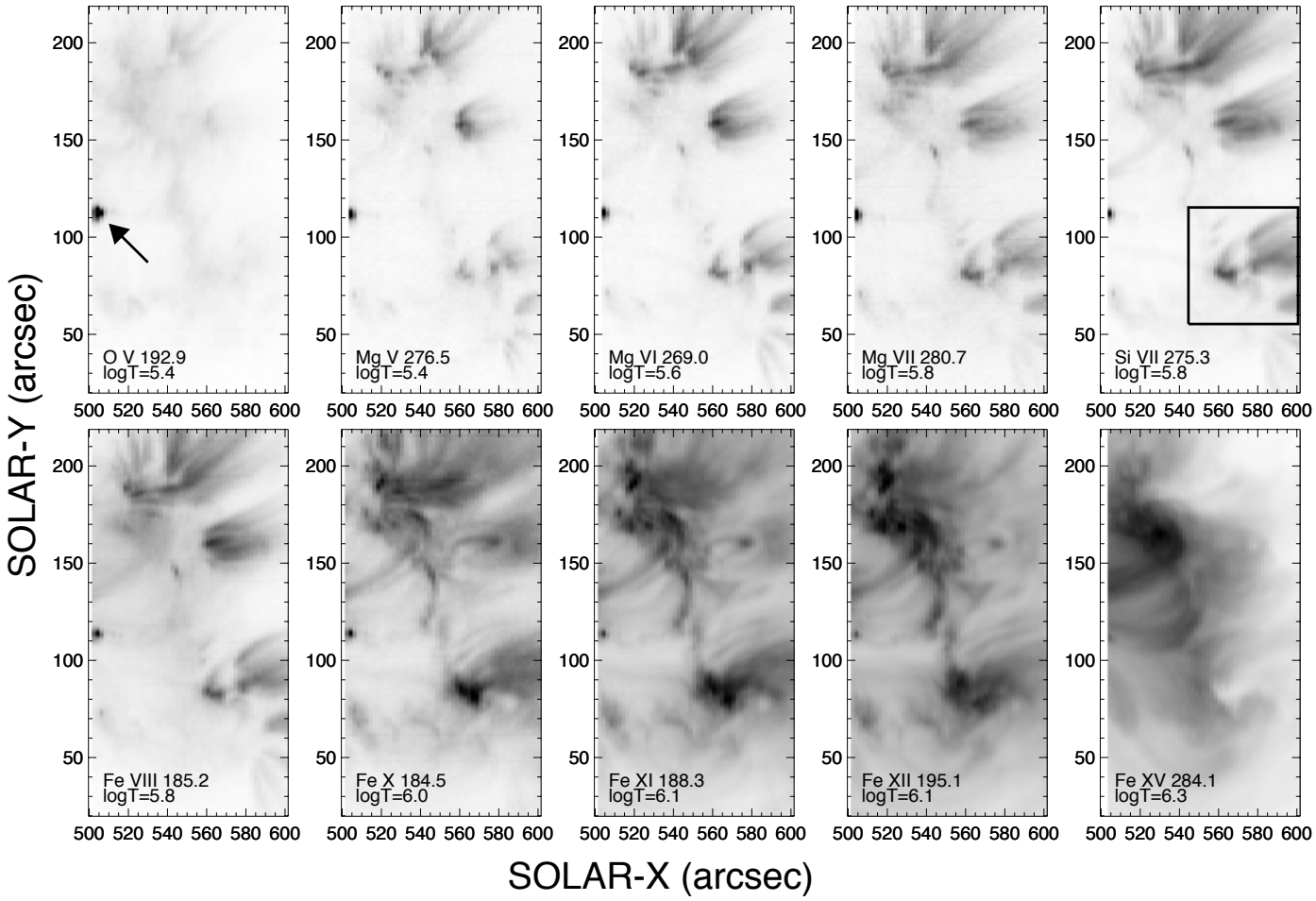
- Warm loops well-known to show propagating intensity fronts at their footpoints
- Periods of 2-10 mins
- Propagation velocity ~ 100 km/s
- Interpretations:
  - slow magnetoacoustic waves
  - quasi-periodic upflows



Sheeley et al. (2014, ApJ)



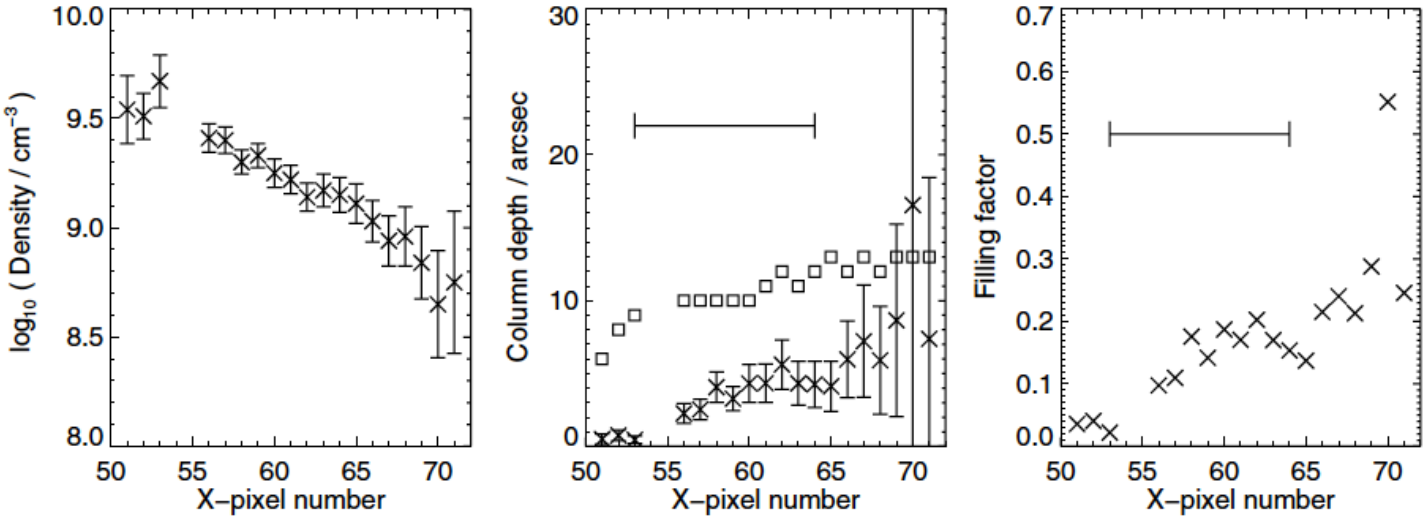
Spectroscopy: temperature structure



Young et al. (2007, PASJ, 59, 727)

Spectroscopy: loop densities

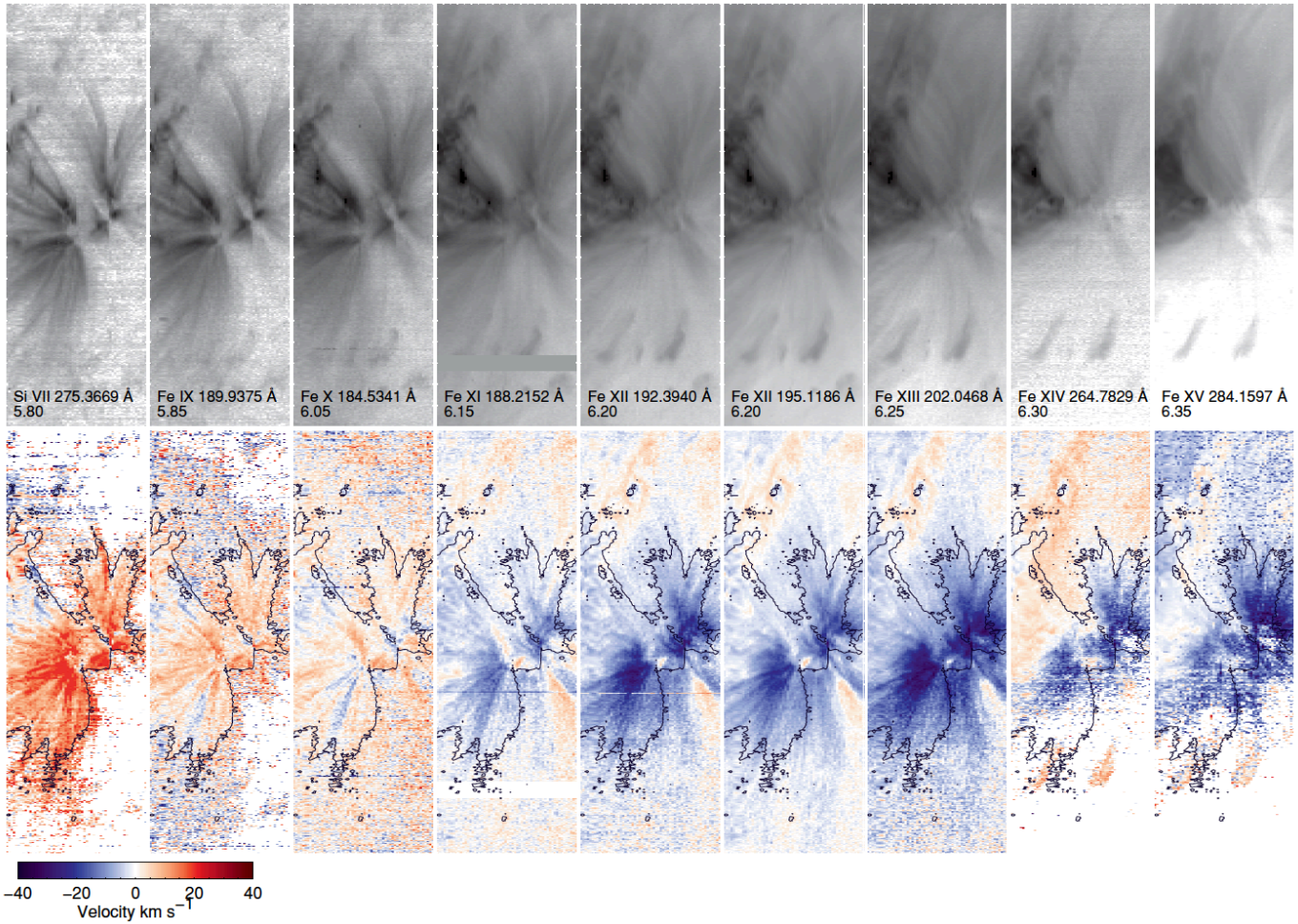
- Mg VII λ 280.75/ λ 278.39 good diagnostic at T=0.7 MK
- Generally gives ≈2-3 x 10^9 cm^{-3} at loop base



Young et al. (2012, ApJ)

See also
Young et al. (2007, PASJ)
Tripathi et al. (2009, ApJ)
Gupta et al. (2015, ApJ)

Spectroscopy: velocity measurements

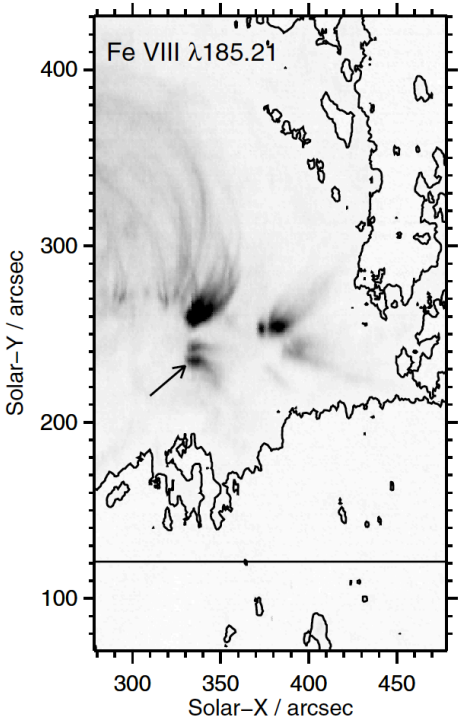


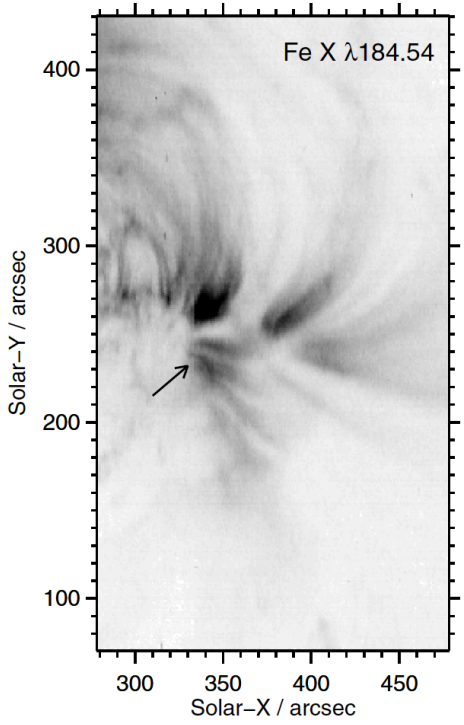
Warren et al. (2011, ApJ)

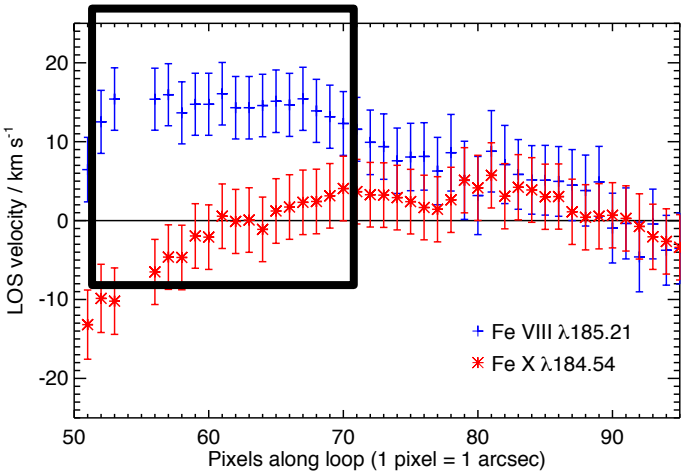
- plage loops have velocities 20 km/s at base, decreasing with temperature
- loops are distinct from the outflow regions

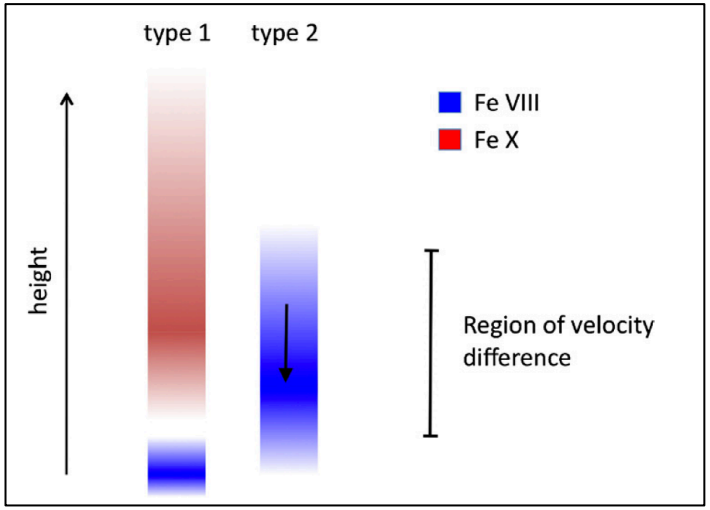
Young et al. (2012) result

- Study of LOS velocities in plage loop in different ions.
- Loop fine structure revealed in velocity.



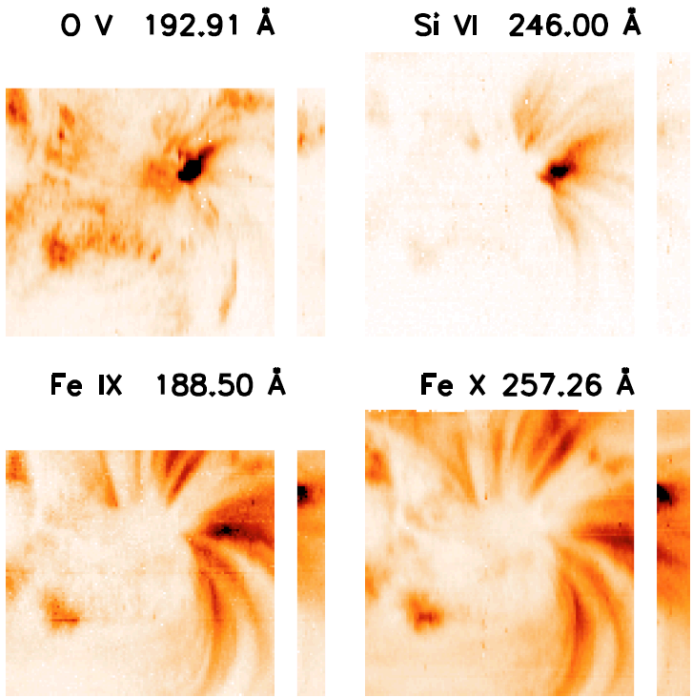






Sunspot loop flows

- Del Zanna (2009, A&A)
- Loops from large sunspot (5-Jan-2007)

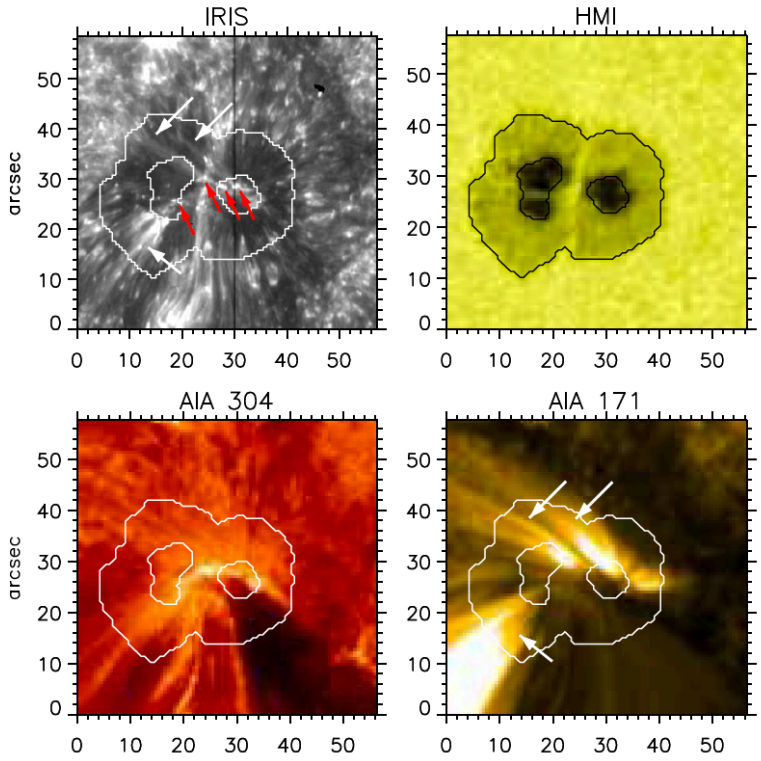


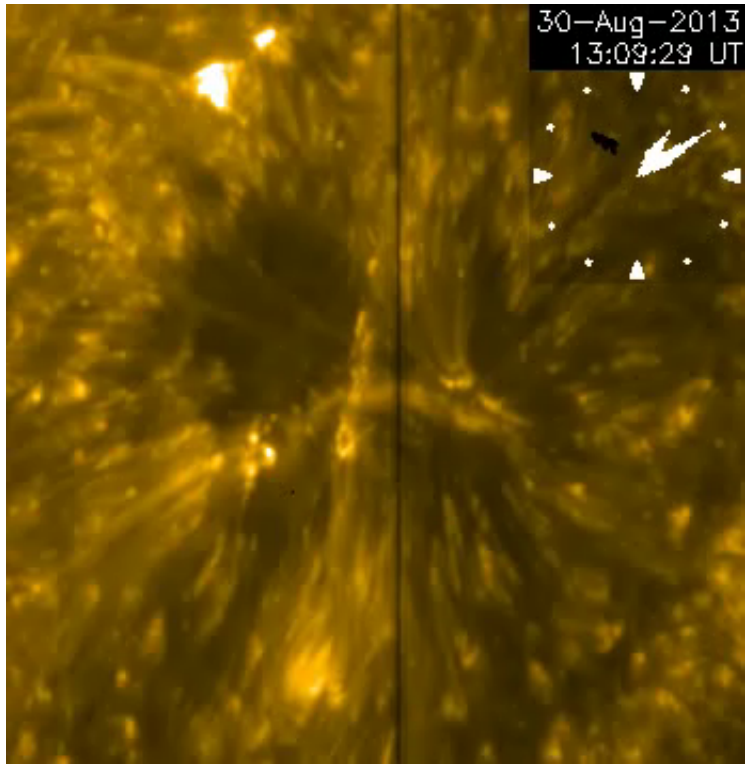
Redshift (km/s)	Ions
+10	Fe IX
+20	Fe VIII, Si VII, Mg VII
+30	Fe VII, Si VI, Mg VI
+35	Cooler ions

Slightly different pattern to plage loop velocities

Sunspot loop flows seen by IRIS

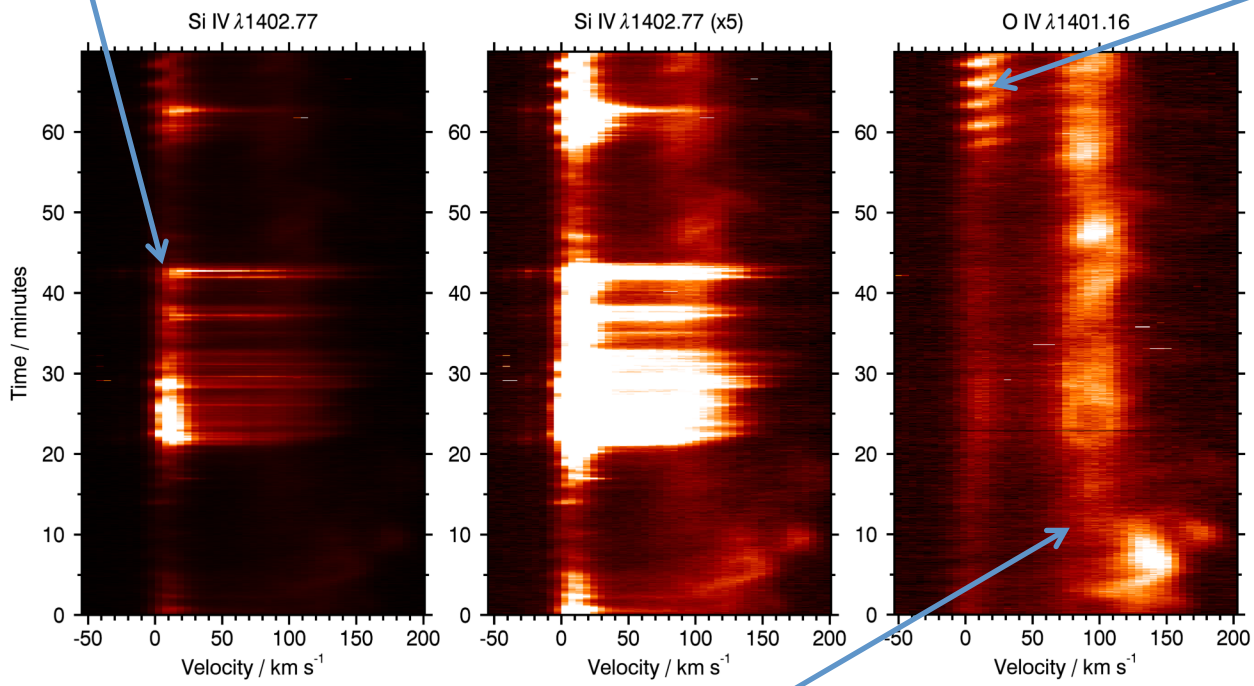
- Kleint et al. (2014, ApJL)
  - bursts at footpoints of AIA 171 loops
  - line profiles extend to +200 km/s (supersonic downflows)
  - identified as coronal rain





Time-sequence in Si IV & O IV

- Short-lived bursts seen at footpoints, with extended red wings
- Identified with coronal rain



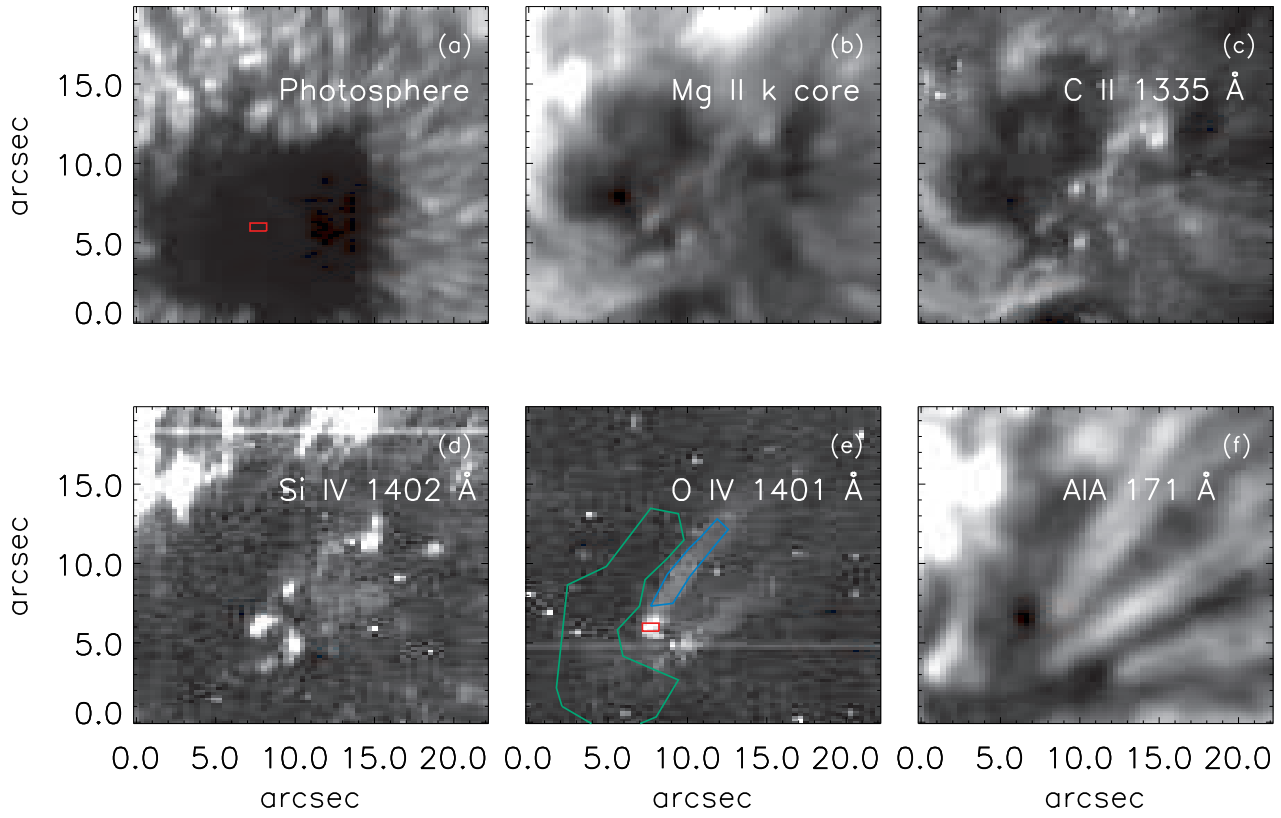
Oscillations studied by Tian et al. (2014, ApJL)

- Also see sustained emission at ≈+100 km/s
  - best seen in O IV line

Si IV: logT=4.90
O IV: logT=5.15

Sunspot loops of 9-Jul-2014

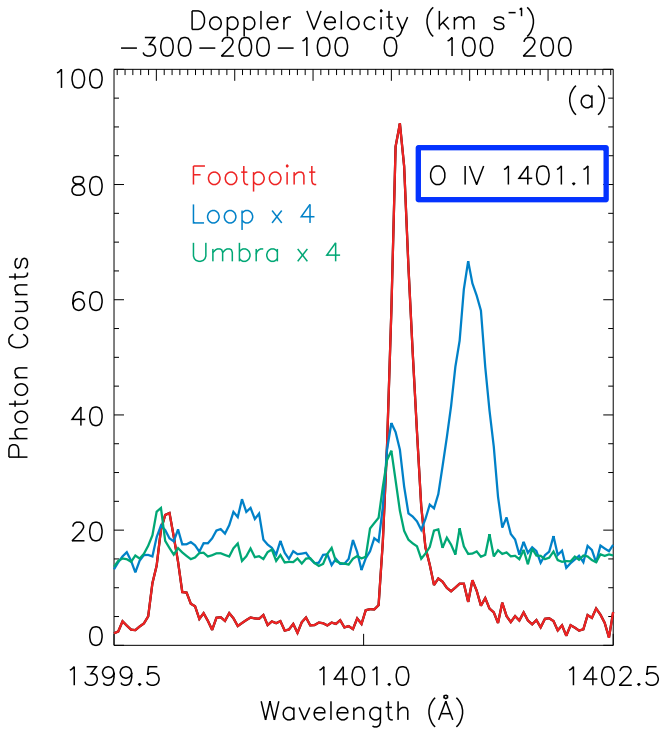
- A raster observation allows spatial extent of loops to be determined
- Note that loops are entering the sunspot umbra

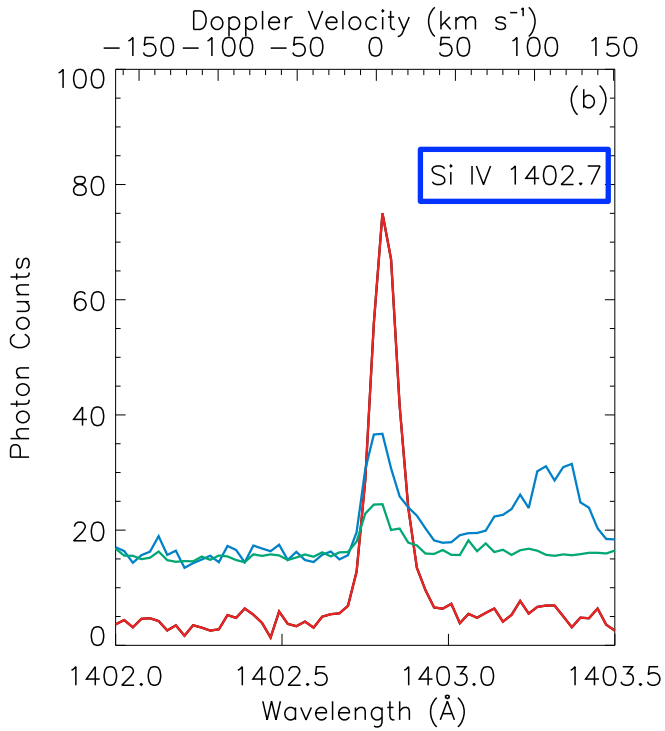


courtesy of Pradeep Chitta (MPS)

Sunspot loops of 9-Jul-2014

- Loop leg shows +100 km/s redshift
- Footpoint shows +10 km/s redshift

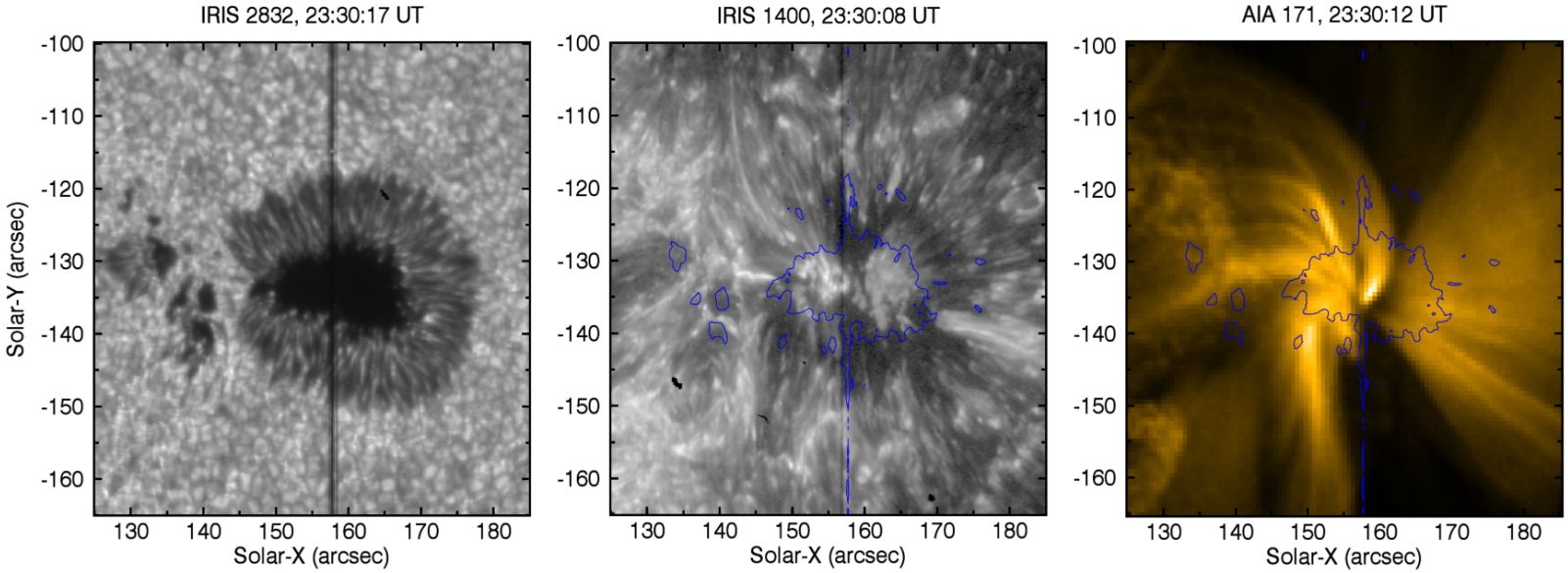




courtesy of Pradeep Chitta (MPS)

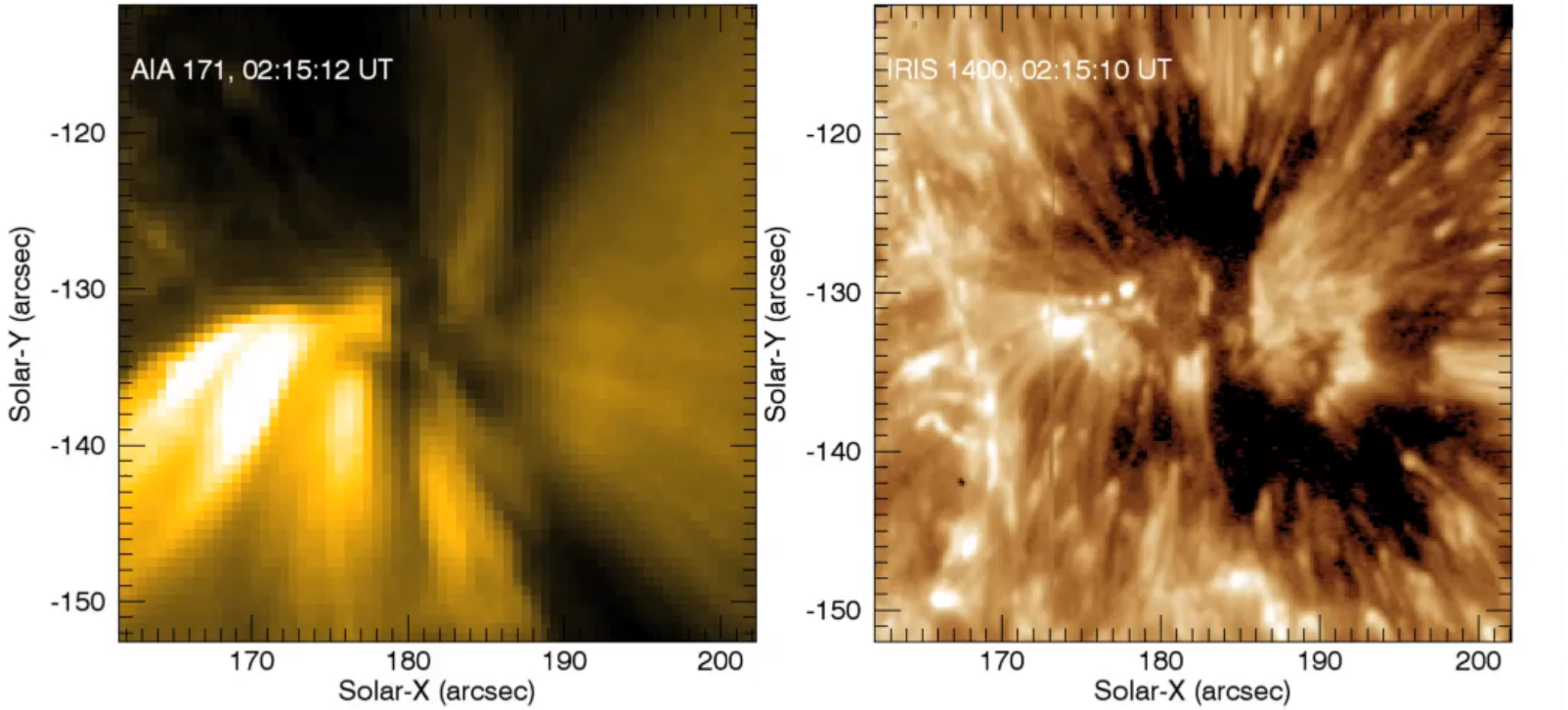
3-Oct-2014 joint EIS-IRIS data-set

- Many loops terminating in sunspot umbra
  - faint fan loops on right side
  - brighter, curved loops on left side
  - footpoints clearly seen in IRIS 1400 channel



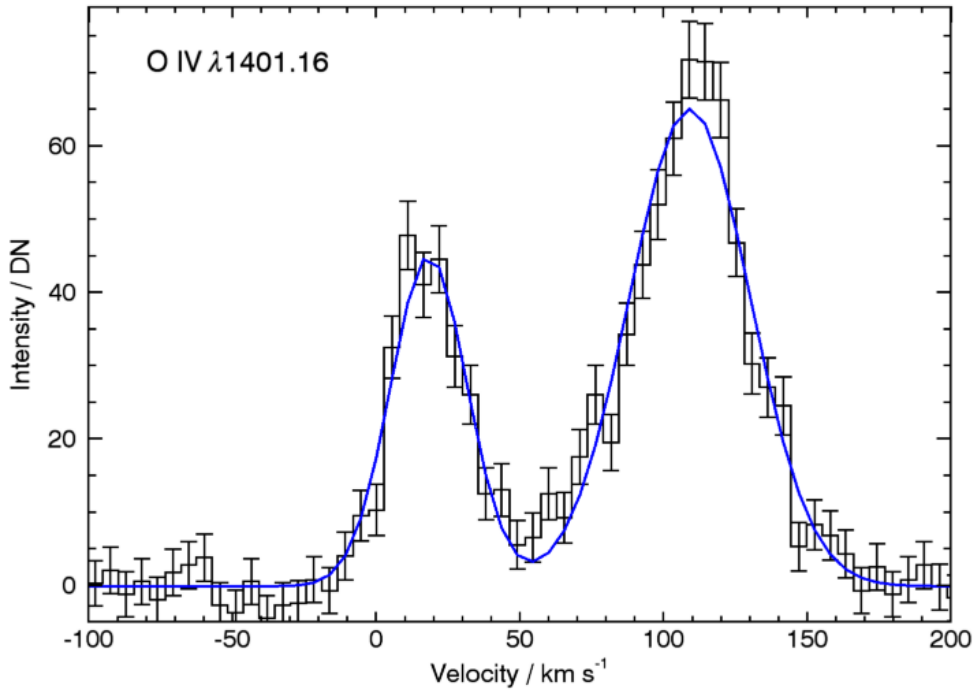
AIA 171 and IRIS SJI 1400 movie

- Sunspot oscillations clearly seen in IRIS movie
  - all bright structures are affected, but best seen in fan loop



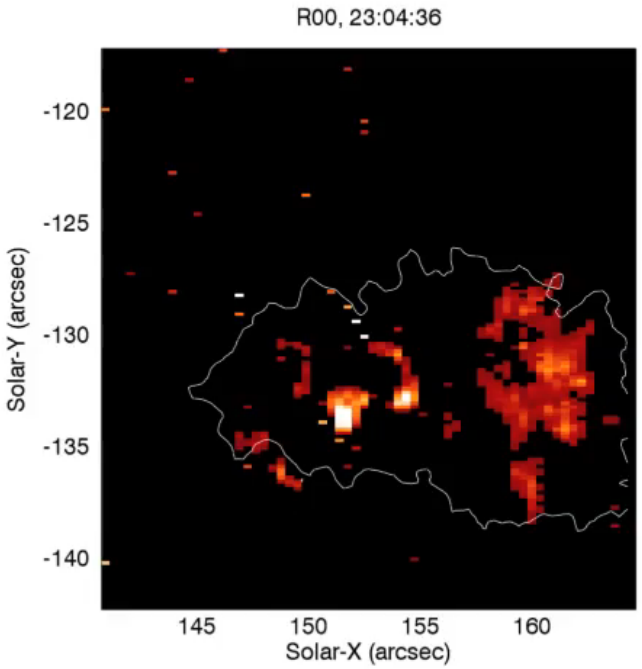
Double-Gauss fit to O IV λ1401.16

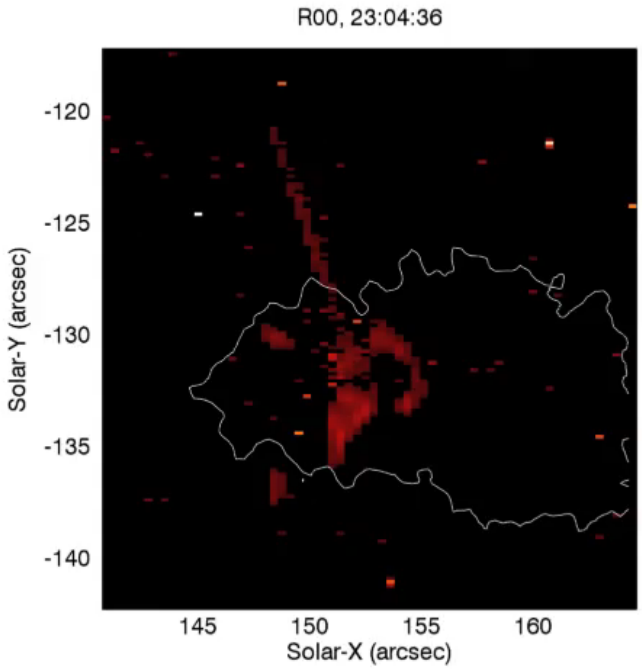
- Force a 2-Gaussian fit to O IV
  - one for "rest" component
  - other for "supersonic" component



The 100 km/s component

- For each raster in sequence (24 frames) make images in the two Gaussian components



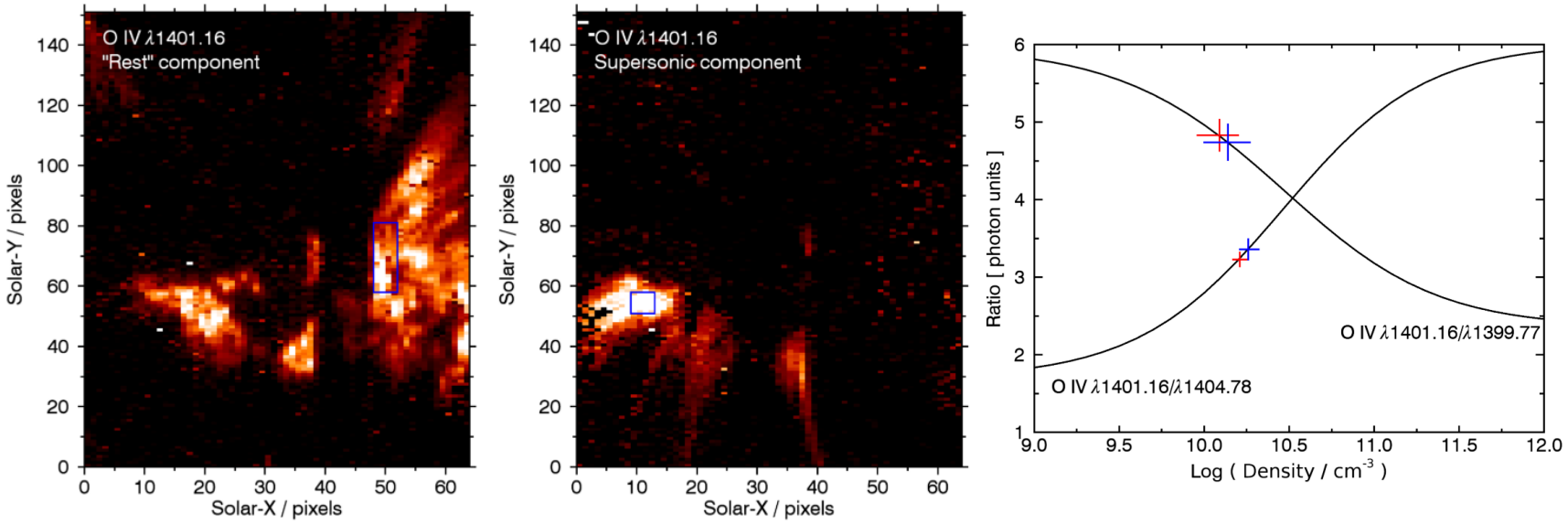


Contour: umbra boundary (from NUV continuum)

- Fan loop (right-side) does not have a high-velocity component
- Fan loop fairly stable
- Dynamic loops migrate to penumbra with time

O IV densities

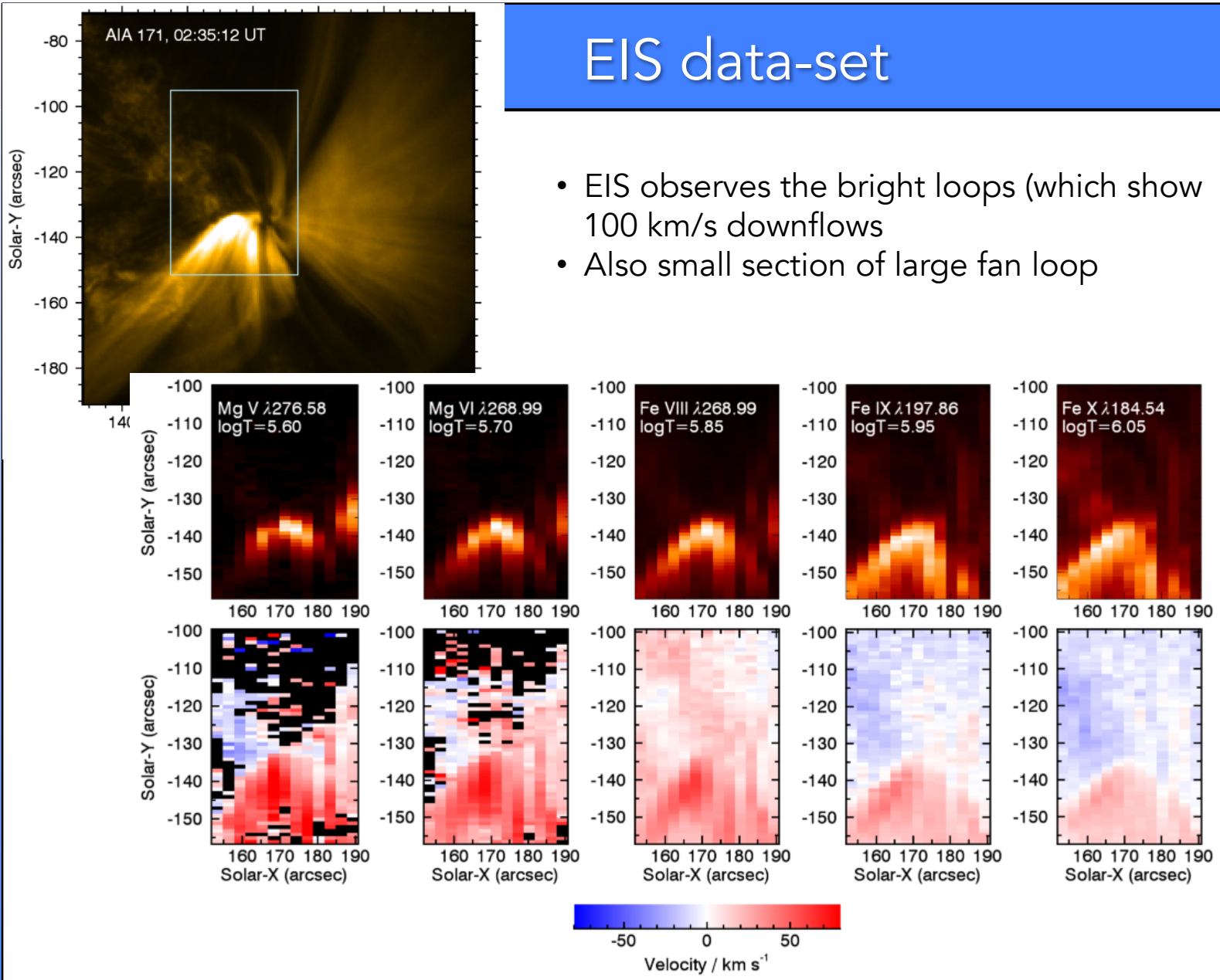
- λ 1399.77/ λ 1401.16 and λ 1404.78/ λ 1401.16 are density diagnostics
- Average over spatial areas in fan loop and "supersonic" loop



- Not much difference: densities around log N_e = 10.1 to 10.4 [log T=5.15]

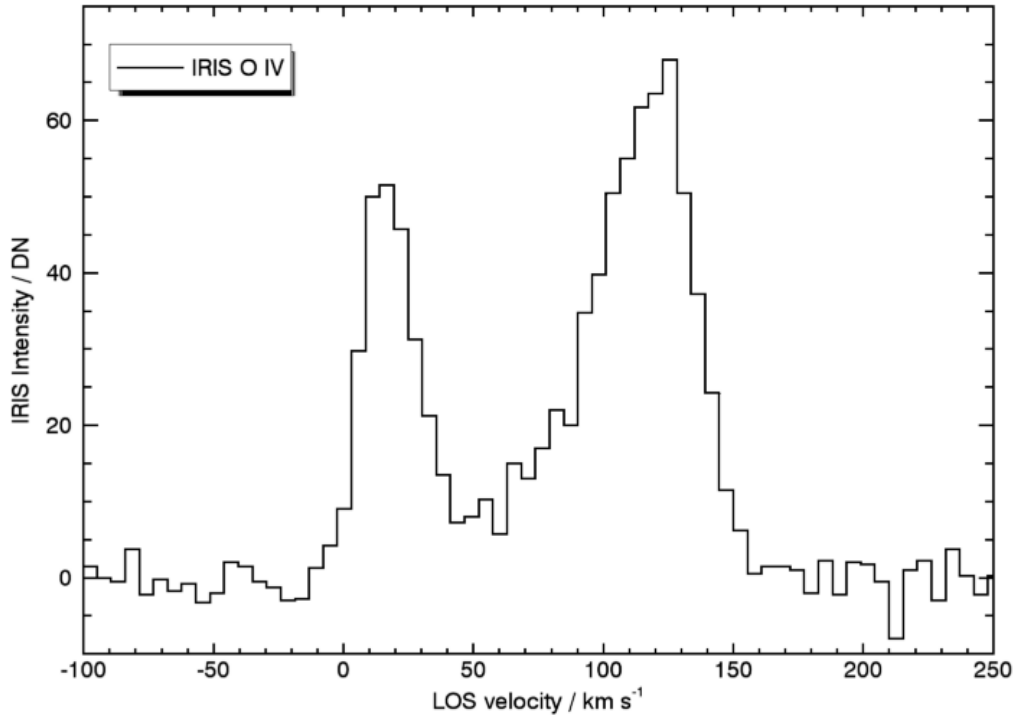
EIS data-set

- EIS observes the bright loops (which show 100 km/s downflows
- Also small section of large fan loop



O IV line profiles

- IRIS λ 1401.16 and EIS λ 279.94 lines



O IV line profiles

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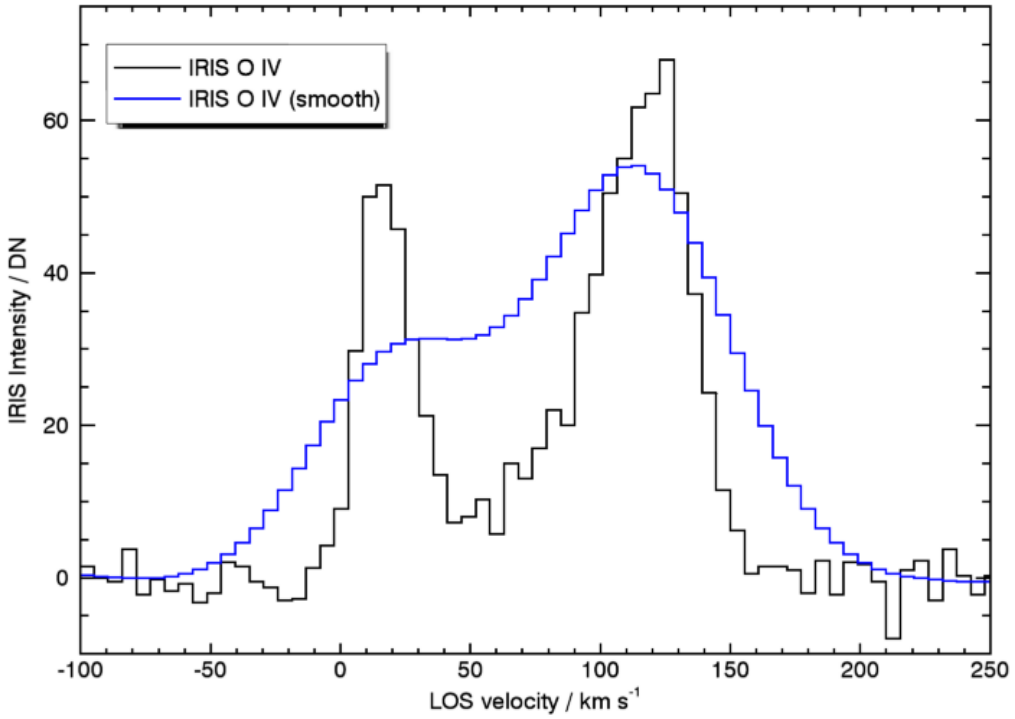

O IV line profiles

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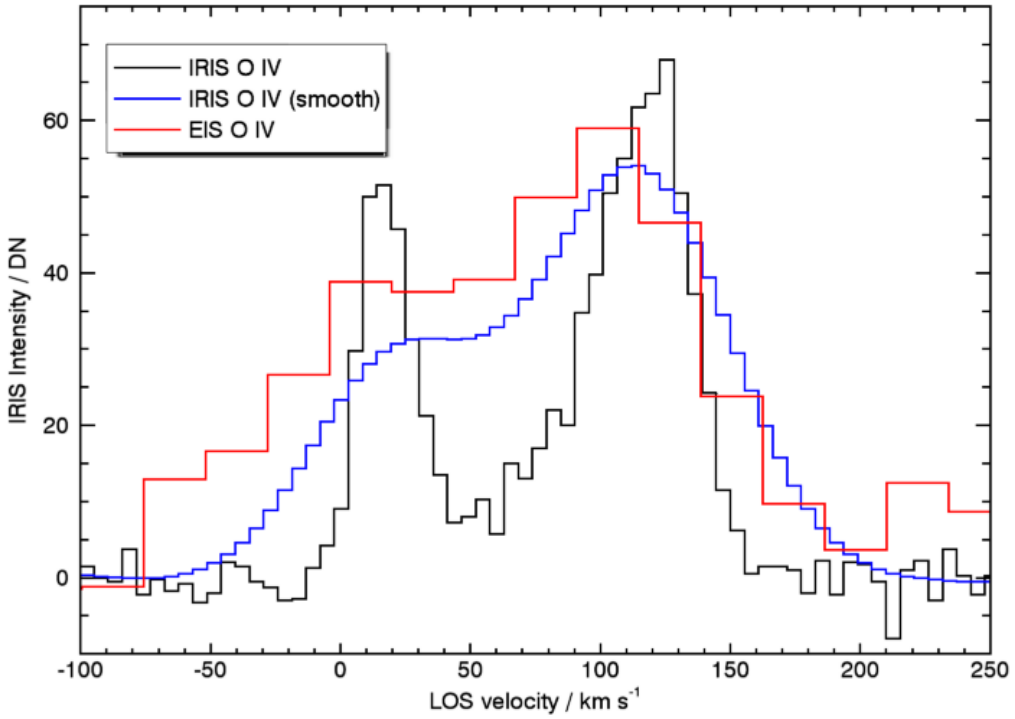
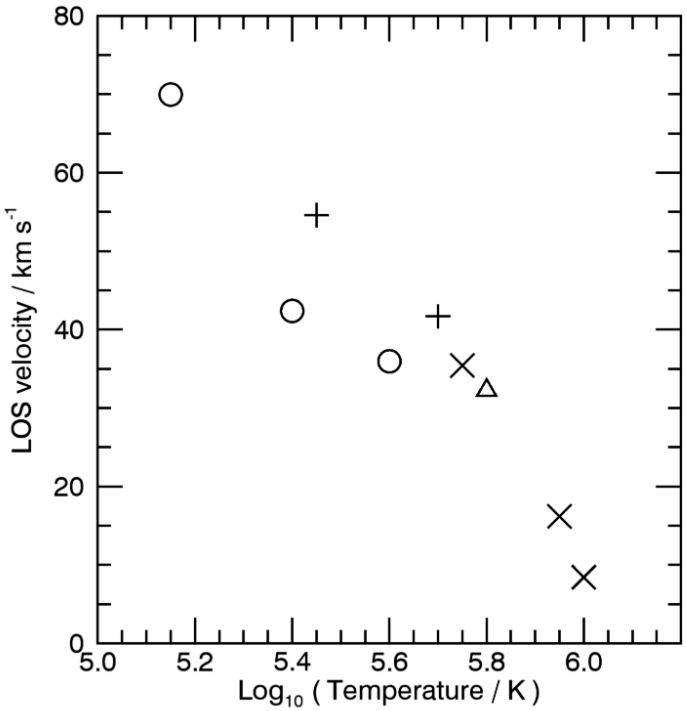
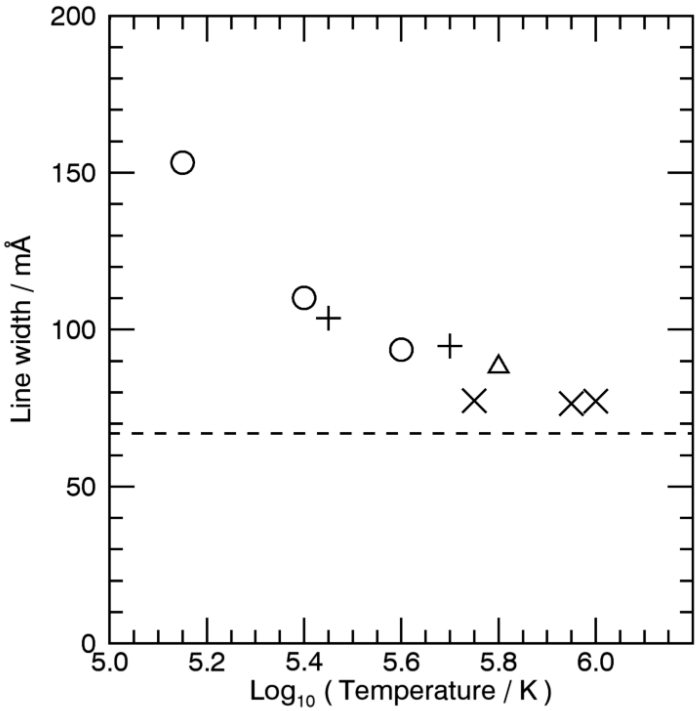


Extension to higher temperatures (EIS)

- Is the 100 km/s component seen at higher temperatures?





Selected a single location on loop

- No – velocities and widths decrease with temperature
- O IV represents a special temperature for downflowing plasma?

EIS densities

- Mg VII λ 280.75/ λ 278.39
- Selecting (approximately) same spatial regions as IRIS O IV regions

	O IV	Mg VII
Fan loop	10.2	9.3
Supersonic loop	10.2	9.6

- $\Delta \log T = 0.6$, so $\approx$ constant pressure

[Note: O V λ 248.46/ λ 192.90 can be measured, but new calibration gives ratios outside sensitivity range.]

Mg/O abundance

- O VI & Mg V-VII can be used to derive FIP bias in loop legs

Feature	Mg/O	FIP bias
Actual photosphere	0.06	1.0
EIS photospheric	0.03	0.5
Fan loop	0.226	3.8
Supersonic loop	0.158	2.6

- The IRIS movie demonstrated the supersonic loops are transient (~ 1 hour)
- EIS data show loops have significant FIP bias
  - disagrees with Widing & Feldman (2001) FIP bias evolution

Summary

Coronal density diagnostics

- Discrepancies still found for Fe XII & Fe XIII
- Revised calibrations have negative effect on ratios

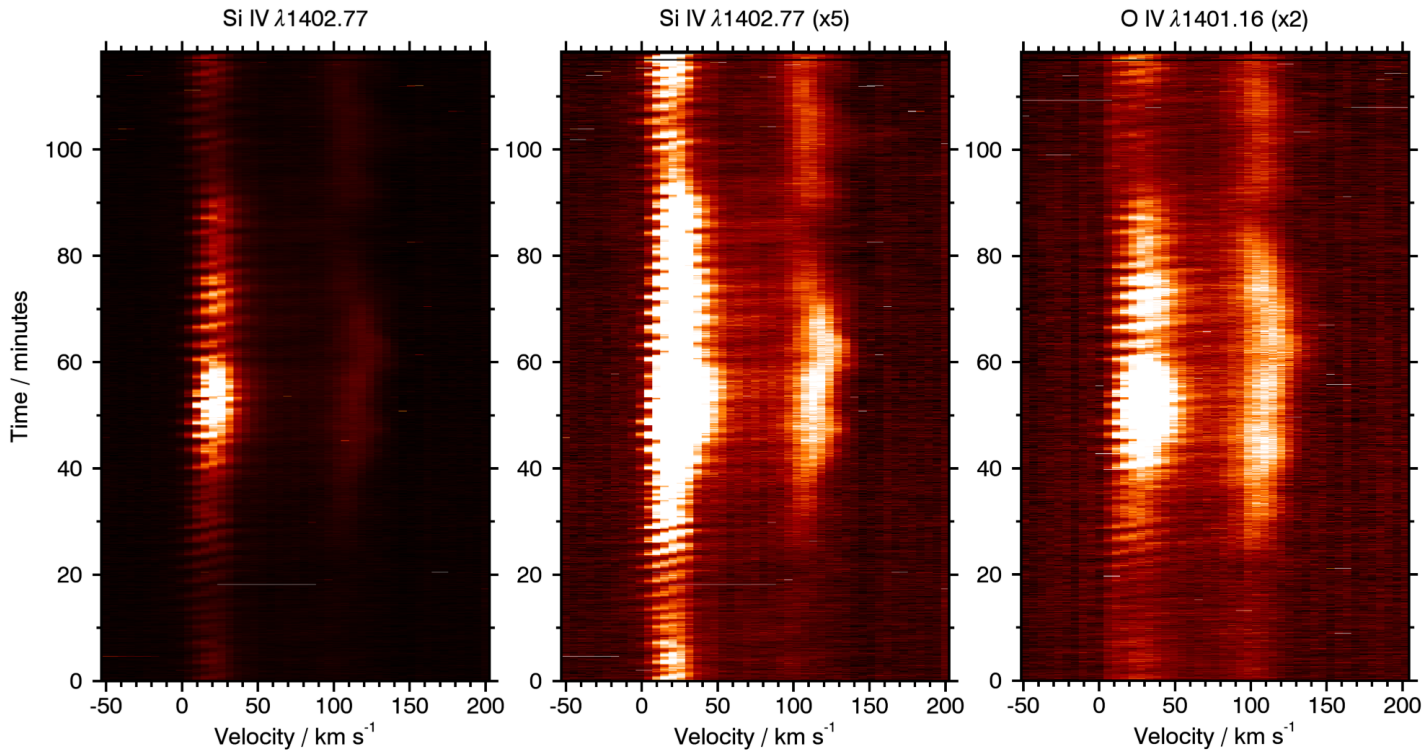
1MK loops

- Excellent "laboratories" for spectroscopic measurements
- Good opportunities for joint EIS-IRIS science [please run IHOP 267!]
- IRIS reveals loop footpoints in great detail
  - complex dynamics and structure
- A spectroscopic survey of plage and sunspot loops would be worthwhile [PhD project?]

- See poster P1.22 (A. Ghosh)
- Speak to V. Andretta

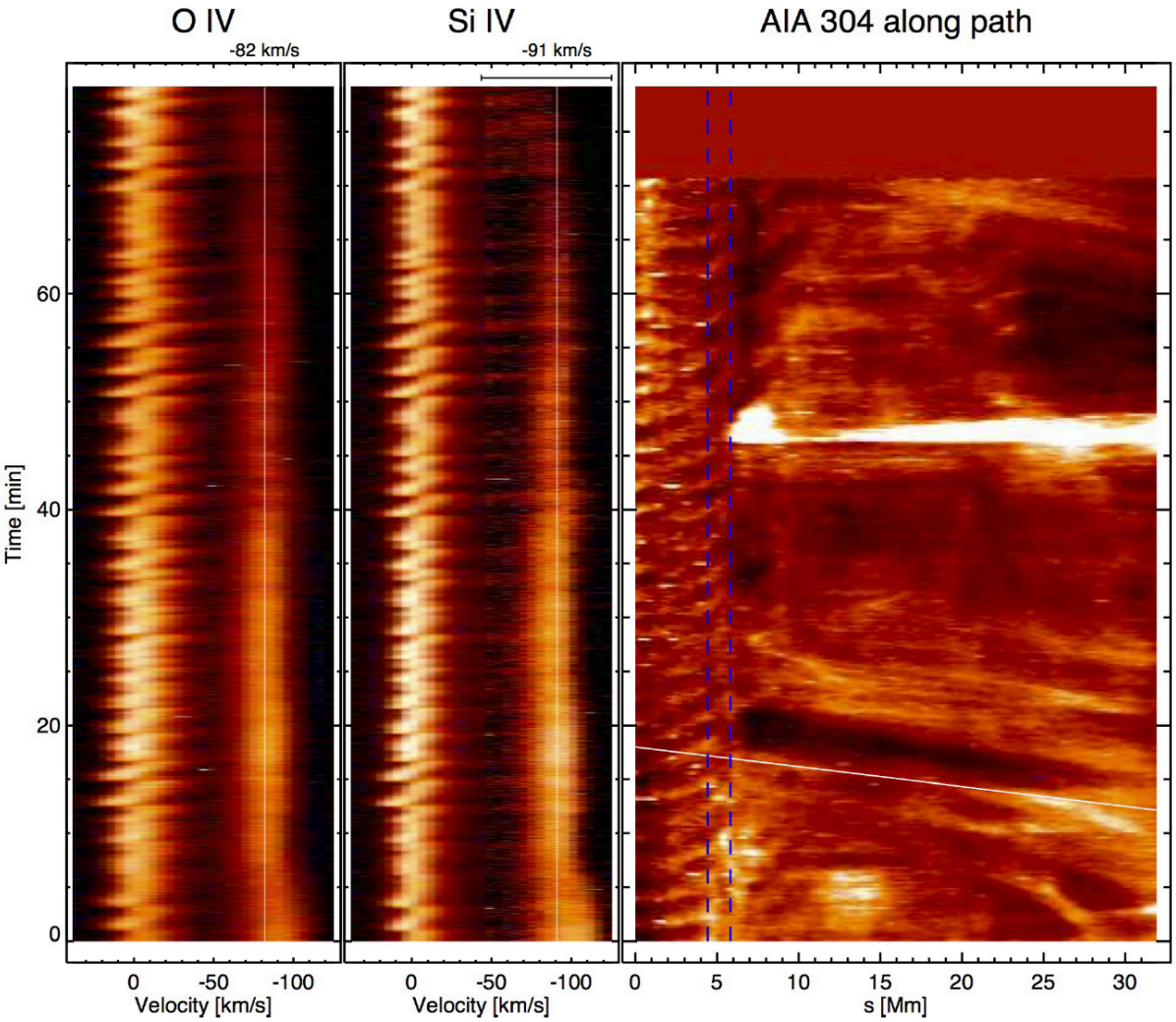
Tian et al. (2014) observation

- Do not see the strong horizontal streaks seen by Kleint et al. (2014)



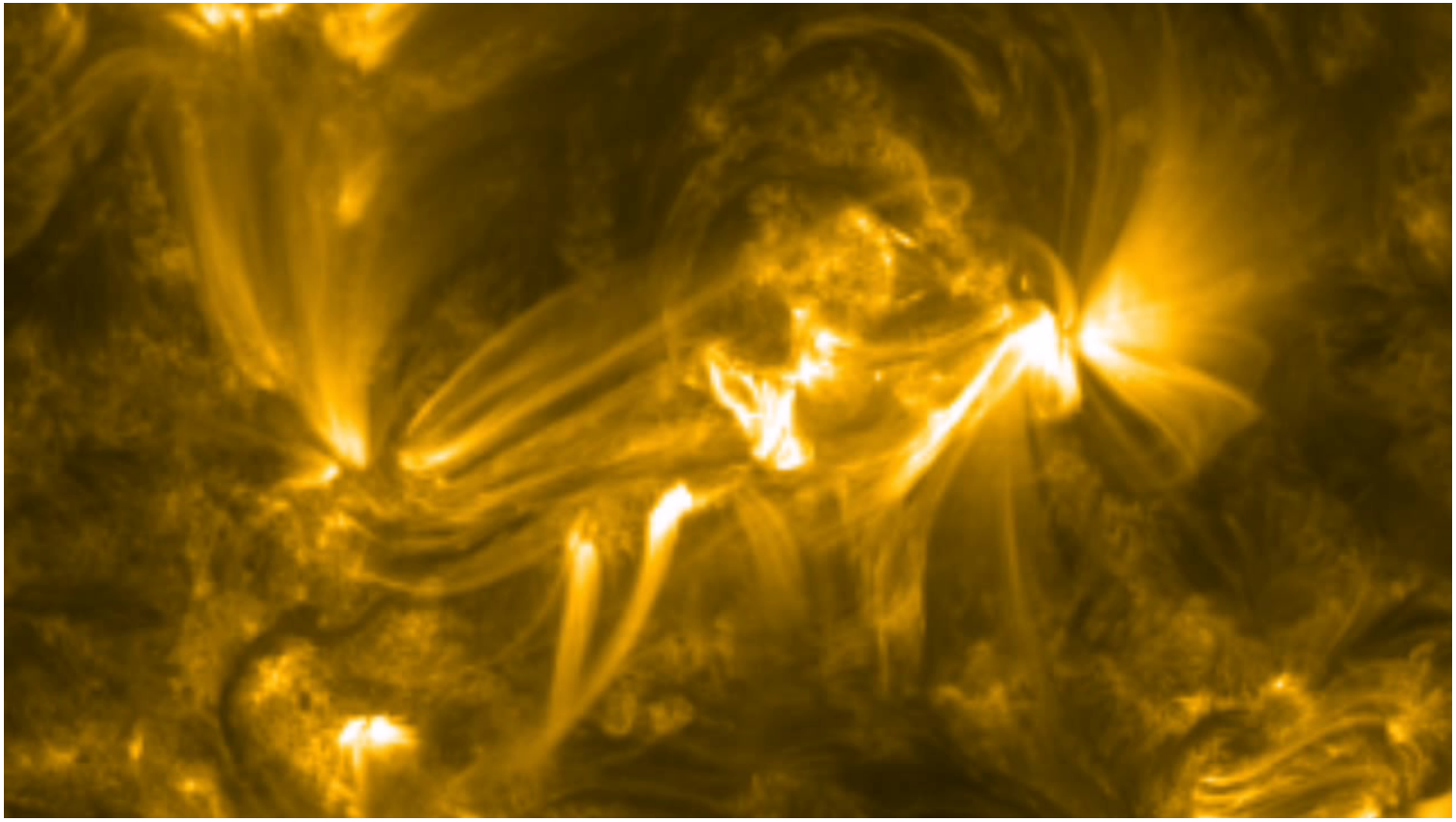
See also Straus et al. (2015, arXiv:1507.04279)

Straus et al. (2015) results



4-Oct-2014 AIA movie

- AIA 171 movie, 00:00-03:00 UT, 2 min cadence



JHelioviewer

O IV velocity components

- Histograms of two O IV velocity components